Section 5: Project Description

1. Project Objectives

The proposed project is designed to restore coastal wetland to reduce GHG and improve important estuarine habitat. This proposal is Phase II of a larger plan to restore at least 110 acres of tidal marshes in Elkhorn Slough and the adjoining 35 acres of existing buffer areas to perennial grassland. Phase I, which is mostly complete, consisted of land acquisition, planning, permitting, and obtaining sediment for the overall restoration work. The funds being requested for Phase II are to begin implementation of restoration and monitoring, and will integrate with other funding sources for the complete restoration project. The overall objective of this phase of the project is to restore 61 acres of tidal salt marsh and 5 acres of a perennial grassland buffer in the southern area of Elkhorn Slough. As funding becomes available the remaining 49 acres of tidal marsh and 30 acres of perennial vegetative buffer will be restored. This proposal requests funds for greenhouse gas research, final engineering, construction and monitoring and is the final step to meeting all the objectives listed below. It is also our opportunity to conduct the first major blue carbon enhancement project in the region, with rigorous post-project monitoring to confirm effectiveness and serve as a model for future such projects

Objective 1: Significantly increase the blue carbon function of the Elkhorn Slough estuary by increasing extent of healthy salt marsh by 9%, representing the largest blue carbon enhancement opportunity in the region

- Sequester 129 Mg atmospheric CO_2 y^{-1} in marsh sediments, additional to pre-restoration conditions, for at least 100 years
- Sequester 156 Mg atmospheric CO_2 in standing biomass of marsh vegetation, additional to pre-restoration conditions, for at least 100 years

Task 1: Greenhouse Gas Assessment

Task 1.a: Pre-restoration assessment – current carbon storage and greenhouse gas flux will be assessed at the site before the end of 2015.

Task 1.b: Post-restoration monitoring of carbon storage and greenhouse gas flux will continue through 2019.

Task 1.c: Analysis and dissemination of monitoring results

Tasks 2 through 7 (construction related) listed below will further achieve this objective.

Objective 2: Restore 66 acres of functioning, resilient salt marsh ecosystem in Elkhorn Slough from channel to uplands through adding sediment to historically diked and drained areas. The following tasks will achieve this objective. See section 5.3.B.1 (Project Description of co-benefits for complete details of the tasks and sub-tasks)

Task 2: Direct Project Administration. This task includes; general project administration, labor compliance, quarterly reporting, and project completion reporting. To be completed at the end of this grant if awarded.

Task 3: Planning/ Design/ Engineering/ Environmental Documentation. This task is already in progress and includes project assessment and evaluation, planning and community engagement, engineering design, environmental documentation, and permit preparation activities to be completed by the end of July 2015.

Task 4: Construction/ Implementation. Restore 66 acres of coastal salt marsh ecosystem from tidal channels to upland in Elkhorn Slough by the end of 2016.

Task 5: Environmental Compliance. Implement CEQA and permitting compliance measures.

Task 6: Monitoring. Monitor the project performance objectives through 2019 to quantify the project implementation and ecological effectiveness.

Task 7: Education and Outreach. Enhance current education and outreach programs at the Reserve through development and incorporation of greenhouse gas reduction and co-benefit concepts into the current curriculum by the end of 2015.

Objective 3: Reduce tidal scour in Elkhorn Slough through adding sediment to historically diked and drained areas. Task 4 above will displace over 140,000 cubic yards of tidal prism and accommodation space in the slough.

Objective 4: Provide resilience to climate change to estuarine ecosystems in Elkhorn Slough through increasing the extent of tidal marsh of sufficient elevation (just over MHHW) to be resilient to moderate sea level rise. Task 3 and 4 above will set the elevation of the new marsh plain higher than the average for the surrounding estuary.

Objective 5: Protect and improve surface water quality in Elkhorn Slough through establishing tidal marsh buffer and providing a filter of vegetative marsh. Task 4 above will accomplish this objective.

Objective 6: Improve Southern sea otter habitat through increasing extent of coastal salt marsh by 9% for resting otters. Task 4 above will accomplish this objective.

Objective 7: 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. Task 6 above will accomplish this objective.

2. Background and Conceptual Models

A. PROJECT LOCATION AND BOUNDARIES

Elkhorn Slough, in the Monterey Bay area, is one of the largest estuaries in California and contains the state's largest salt marshes south of San Francisco Bay. The Slough provides important habitat for an exceptionally broad range of resident and migratory birds, invertebrates, fish, marine mammals and other wildlife, and plays a crucial role in the local estuarine and nearshore food web. This project will occur on the tidal wetlands and uplands of the Elkhorn Slough National Estuarine Research Reserve, which is owned by the California Department of Fish and Wildlife (CDFW) and managed in partnership with the National Oceanic and Atmospheric Administration (NOAA). Project boundaries include 61 acres of coastal tidal wetland and an adjacent 35 acre vegetated buffer between currently fallow farmland and the estuary, established to intercept storm water runoff and provide transitional habitat (Figure 2:Supplemental Material). Five acres of the buffer will be restored to native grassland; 14 acres will be excavated for sediment and graded to a gentle slope that will support 7 acres of new salt marsh and 7 acres of new marsh-to-upland ecotone. The project site, in addition to being designated a National Estuarine Research Reserve, is also a State Ecological Reserve, and its wetlands are part of the Elkhorn Slough State Marine Reserve.

B. GREENHOUSE GASES

1. *Project need – greenhouse gas sequestration*

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. 2005).

Coastal salt marshes are particularly important as carbon sinks because the carbon they capture is buried, and indefinitely sequestered. Salt marshes are depositional environments, with accretion rates in dynamic equilibrium with tidal flooding. Where rates of inundation increase, more sediment accumulation occurs, as marshes are flooded more frequently by sediment-laden waters, providing more opportunity for deposition (Kirwan et al. 2010). Salt marshes thus accumulate sediment, and bury carbon, as a function of their ability to gain in elevation and track sea level rise (Bridgham et al. 2006; Crooks et al. 2011). Furthermore, salt marshes have extremely high soil carbon densities in comparison with other vegetation types, enhancing their carbon storage ability per unit area (Chmura 2013).

Salt marshes are additionally attractive as carbon sinks because they produce negligible emissions of the potent greenhouse gases methane and nitrous oxide, which have significantly higher global warming potentials on a 100 year time horizon than carbon dioxide (Moseman-Valtierra 2012). At soil salinities above 18 ppt, bacteria that mineralize organic carbon in concert with sulfate reduction are thought to outcompete methanogenic bacteria that decompose carbon anaerobically and produce methane (Fenchel and Blackburn 1979; Morris and Whiting 1986). As a result, methane emissions are typically low where soil salinities are high (Chmura et al. 2011; Weston et al. 2014). Nitrous oxide emissions are a minor by-product of nitrogen transformations, and similar to methane, have also been shown to be inhibited at high soil salinities (DeLaune et al. 1990). While measures made in North America of salt marsh nitrous oxide emissions are typically low, some European coastal marshes have been associated with elevated N_2O emission values (Moseman-Valtierra 2012). Based on high carbon sequestration rates and negligible emissions of CH_4 and N_2O, recent analyses conclude that North American salt marshes have a strong net benefit for reducing global warming (Chmura et al. 2011; Crooks et al. 2011). However, researchers do suggest that additional studies should be conducted on greenhouse gas emissions in order to fully investigate potential offsets of carbon sequestration by emissions of other greenhouse gases (Chmura et al. 2011; Moseman-Valtierra 2012).

In central California, the largest blue carbon potential is found at Elkhorn Slough, in central Monterey Bay. This estuary hosts the most extensive salt marsh in California, after San Francisco Bay (Caffrey et al. 2002), and its natural marshes are associated with high rates of carbon sequestration. Blue carbon sites should be designated, protected and enhanced throughout California. 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.

2. Conceptual Model

Elkhorn Slough's salt marshes are already serving as a critical blue carbon resource. Marshes in the estuary are 300-6,000 thousand years old, consist of peat deposits 1-5 meters in thickness, and are composed of sediments ranging from 3-40% organic carbon (Schwartz 1986; Hornberger 1991; Watson et. al 2011). Estimates of current carbon sequestration rates by Elkhorn Sloughs' natural salt marshes have been generated through radiometric dating (^{210}Pb; half life of 22 years) in concert with sediment density and organic content determinations (see "Expected Results", section 5.6.A). The rate of carbon sequestration calculated for Elkhorn Slough's natural tidal wetlands (201 ± 47.0 g C m^{-2} y^{-1}; mean± SD) was found to be higher than that reported for a similar inventory conducted in San Francisco Bay (79 g C m^{-2} y^{-1}; Callaway et al. 2012), due to the higher sediment carbon density and higher sediment accumulation rates found at Elkhorn Slough. (*Note:* calculations in the greenhouse gas section of this proposal are in metric units, because these are typical for scientific evaluations of blue carbon; elsewhere in the proposal we use English units, because they are typical for regulatory agencies.*)*

However, 50% of Elkhorn Slough's salt marshes have been lost in the past century due to human activities, primarily diking and draining of marshes (Van Dyke and Wasson 2005), so the estuary is no longer serving at its full potential as a carbon sink. In regions where marshes have good conservation protection, the best way to enhance blue carbon is through marsh restoration (Chmura 2013). We thus propose to enhance the blue carbon function of Elkhorn Slough by conducting the first salt marsh restoration project in the estuary.

The conversion of mudflats, degraded marsh, and adjacent grasslands to healthy, functioning salt marsh habitat at our restoration site will yield a net benefit of greenhouse gas reduction. Our extensive scientific investigations of Elkhorn Slough salt marshes over the past decade allow us to make rigorous quantitative projections of the increase in carbon sequestration that will result from this project (see detailed calculations in "Expected Results", section 5.6.A).

A numerical approach (Howard et al. 2014) for predicting net carbon sequestration from the proposed coastal wetland restoration was developed to predict carbon sequestration from both vegetation and soil ecosystem components, based on carbon storage for natural Elkhorn Slough salt marshes. An estimate of yearly soil carbon sequestration by the restoration project was calculated as:

$$yearly\ atmospheric\ CO_2\ stored = \left(A * DBD * C_{org} * V\right) * 3.67 \qquad \text{Eqn. A}$$

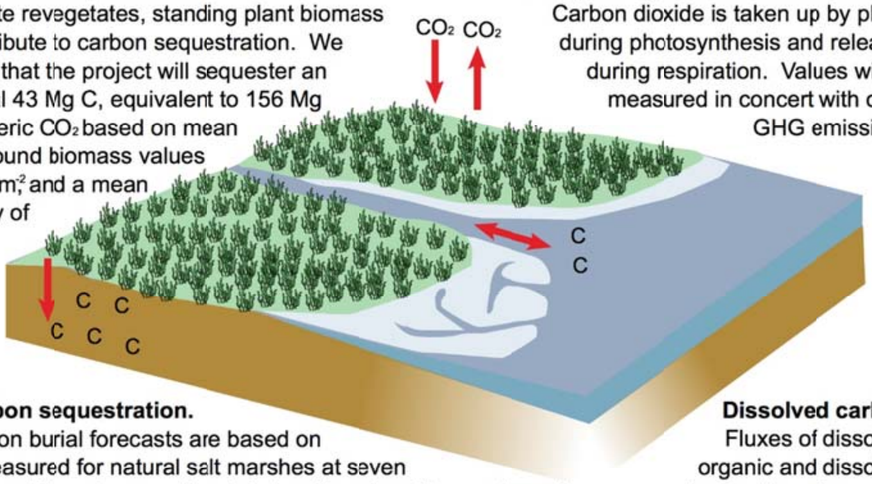
where A is project area (in m^2), DBD is the dry bulk density of the soil, C_{org} is the fraction of the soil that is organic carbon, V is the yearly volume of accumulation, measured through radiometric dating, and 3.67 is a constant used to convert Mg of C to Mg of atmospheric CO_2. Values are site-specific, and taken from natural salt marshes located at Elkhorn Slough.

An estimate of organic carbon storage in vegetation by the restoration project, in Mg of CO_2, was calculated as:

$$atmospheric\ CO_2\ stored = \left(A * AGB * C_{org}\right) * 3.67 \qquad \text{Eqn. B}$$

where A is project area, AGB is the mean aboveground biomass, C_{org} is the fraction of the plant biomass that is organic carbon, and 3.67 is a constant used to convert Mg of C to Mg of atmospheric CO_2.

Using the numerical approach outlined above, we project that an additional 156 Mg of atmospheric carbon dioxide will be sequestered by plant vegetation in aboveground biomass, and that 129 additional Mg of atmospheric carbon dioxide will be sequestered yearly as soil carbon. Monitoring will be conducted to measure progress to these performance targets. While we feel confident that this restored marsh will achieve carbon sequestration targets, we cannot predict the exact length of time necessary for targets to be achieved. Soil carbon inventories measured for restored and natural marshes in San Francisco Bay suggest that soil carbon inventories approach, but do not exceed those found for natural marshes even over a time scale of several decades (Callaway et al. 2012). However, measurement of short-term accumulation rates at a range of restored marshes indicates that restored marshes accumulate sediment at rates similar to those of natural marshes (Orr et al. 2003), suggesting that carbon sequestration targets may be achieved early in the restoration process. To help decrease this uncertainty for future blue carbon enhancement projects, we propose a rigorous monitoring program that focuses on the soil carbon pool.



Plant carbon sequestration.
As the site revegetates, standing plant biomass will contribute to carbon sequestration. We estimate that the project will sequester an additional 43 Mg C, equivalent to 156 Mg atmospheric CO_2 based on mean aboveground biomass values of 950 g m^{-2}, and a mean C density of 28.9%.

Plant photosynthesis and respiration.
Carbon dioxide is taken up by plants during photosynthesis and released during respiration. Values will be measured in concert with other GHG emissions.

Soil carbon sequestration.
Soil carbon burial forecasts are based on those measured for natural salt marshes at seven sites around the estuary, using dated sediment profiles analyzed for bulk density, organic and carbon content. We estimate that the project will bury an additional 35 Mg carbon per year, equivalent to 129 Mg of atmospheric CO_2. Soil carbon burial will also include living and dead belowground biomass.

Dissolved carbon.
Fluxes of dissolved organic and dissolved inorganic carbon occur with tidal flushing and as groundwater underflow, and will not be estimated

Figure 3. Conceptual model of carbon sequestration by the proposed project. Predictions for soil carbon sequestration are based on soil carbon storage in natural marshes of Elkhorn Slough, using empirical sediment density, organic carbon concentration, and accumulation data from radiometric dating. Predictions for sequestration of organic carbon by aboveground vegetation are based on empirical data for mean aboveground biomass and aboveground biomass carbon densities. Details of calculations can be found in the section 5.6.A "Predicted Greenhouse Gas Reductions."

Since we have documented robust vertical accretion rates in other salt marshes in the system, this carbon should be buried and locked up indefinitely in anoxic marsh sediments. The marsh has been designed to last at least 100 years despite accelerating sea levels, so the carbon sequestration benefit will be a lasting one. These storage estimates are generalized below in a conceptual schematic that details major carbon transformations forecast by the restoration project.

This scientific consensus on the net benefits of salt marshes as carbon sinks (Crooks et al. 2011, Howard et al. 2014) has been confirmed recently with empirical data for two salt marsh restoration sites in Huntington Beach, southern California (Keller et al. 2012). At this southern California site, restored salt marshes stored high levels of carbon and fluxes of methane were negligible.

Emissions of greenhouse gases from wetlands are very variable in space and time, so it is difficult to project how emissions of the restored marsh will compare to the mudflat it replaces. However, consensus in the literature is that the carbon sequestration potential of salt marshes outweighs the emissions, in systems with salinities greater 18 ppt (Chmura et al. 2011). The average salinity of the restoration site is 31 ppt (ESNERR water quality data collected from a continuously deployed sonde at the restoration site), well above levels that have been associated with significant nitrous oxide and methane emissions, and restoration will not result in salinity shifts. We will monitor fluxes of CO_2, CH_4 and N_2O before vs. after restoration as a part of this project, but anticipate that they will be negligible compared to the carbon storage benefits.

3. Scientific Basis

The scientific basis of the greenhouse gas reduction component of this project is extremely robust. The broad conceptual model (see section 5.2.B.2) and basis for assumptions about the benefits of salt marshes as blue carbon reserves come from widely respected recent literature on the subject (e.g. Duarte et al. 2005; Chmura 2013; Crooks et al. 2011; McLeod et al. 2011).

The specific projections of carbon sequestration benefits to be achieved by this project are based on extensive salt marsh research conducted at Elkhorn Slough, in particular by the project leaders for this component, Drs. Wasson and Watson. A recent study from San Francisco Bay (Callaway et al. 2012) provided the first 100 year estimate of carbon sequestration rates for a California marsh. Here, we applied identical methods (dated cores analyzed for organic content; see Expected Results section 5.6.A) to comparable sample sizes to obtain equally robust estimates for Elkhorn Slough salt marshes. Since literature values for salt marsh sequestration rates show an order of magnitude of variation, using local data from cores all collected within 5 miles of the project site gives us critical resolution for making robust projections.

The methods that we propose for monitoring carbon storage are comparable to those applied by similar studies (Keller et al. 2012; Lovelock et al. 2014; Howard et al. 2014). In addition, we have the ability to utilize a state of the art field gas analyzer in order to efficiently conduct an investigation of greenhouse gas emissions. Use of this analyzer will allow us to measure emissions at more sites per unit effort, and thus increase our statistical power and confidence in results. Finally, our efforts in the greenhouse gas reduction component of this project, as with the other components, are reviewed and guided by our Salt Marsh Working Group. Active members of this group include J. Callaway, who has conducted the first rigorous studies of marsh sequestration in nearby San Francisco Bay (Callaway et al. 2012), and S. Crooks, who is an international leader in blue carbon initiatives (Crooks et al. 2011). This group will review our technical report synthesizing the greenhouse gas investigation.

4. *Enhanced Scientific Understanding*

This project will pioneer the application of blue carbon enhancement concepts to a salt marsh in California. Our rigorous quantitative projections, robust monitoring, and thorough analyses will be synthesized in a technical report that we will disseminate widely, and eventually in a scientific publication. We will also present our results at local, regional, and international conferences. Our past record of presentations at conferences and of frequent publication in peer-reviewed scientific journals underlines the seriousness of this commitment. **Our study will be among the first to rigorously compare carbon storage and gas fluxes in mudflats, degraded marshes, restored and reference salt marshes, and adjacent uplands, all within one ecosystem.** While numerous studies have quantified carbon storage in salt marshes, none that we know of have compared these rates to adjacent habitat types, nor done so in a time series before vs. after restoration. In addition, we will perform (to our knowledge) the first in situ paired measures of CH_4, N_2O, and CO_2 emissions in a California salt marsh. Very few studies have calculated carbon sequestration rates, and greenhouse gas emission rates (including nitrous oxide) for wetlands of any kind (Neubauer 2014). Our results will thus inform future blue carbon enhancement efforts throughout California and beyond.

C. CO-BENEFITS

1. *Project Need - Co-Benefits*

The project area on ESNERR experienced marsh loss due to diking and draining. According to early written accounts, wetland surveys, and aerials, the site was historically a rich coastal ecosystem, with grassland transitioning to mature salt marshes drained by narrow, meandering tidal creeks (Figure 4a: Supplemental Material). By the 1930s and 40s all of the salt marsh in the project area had been ‘reclaimed’ for agricultural purposes, and the adjacent grassland had been converted to row crops that extended to the edge of the former marsh (Figure 4b).

This draining caused the marsh sediments to subside 12 to 30 inches. Decades later, the dikes began to fail, reintroducing tidal waters to the reclaimed wetlands. Due to the lowered tidal plain, the area converted to an intertidal mudflat, and insufficient sediment supply was available in the tidal waters to rebuild elevation. Row crops and the resulting agricultural runoff reached into the wetlands. CDFW acquired the property in 2009 and has since reduced the farm footprint, installing a 35 acre cover crop between the farm fields and tidal wetland. Nonetheless, today this site bears little resemblance to its past state – the native grasslands are gone and the salt marsh has deteriorated to shallow eutrophic mud pannes (Figure 5: Supplemental Material).

This project is needed to address salt marsh and adjacent coastal grassland losses in Elkhorn Slough, and to increase estuarine stability into the future. Fifty percent of the tidal salt marsh in Elkhorn Slough has been lost in the past 70 years, due largely to “ecological drowning” - loss in the marshes' elevation relative to tidal water levels (Van Dyke and Wasson 2005). This increased flooding, or relative sea level rise, has multiple drivers at Elkhorn Slough. In the late 1800s and early 1900s several local marshes were diked and drained for agriculture. Draining tidal marshes causes marsh sediments to desiccate, compact, decompose, and subside. If tidal waters are restored, the remaining plain is often too low to support marsh vegetation. In addition, the construction of the Moss Landing Harbor in 1946 increased the Slough's tidal prism and raised the height of incoming tides. Today, observations at Elkhorn Slough indicate that many, but not all, of the remaining marsh plain is lower in the tidal frame than healthier marshes elsewhere, and its plants are undergoing dieback in response to inundation stress (PWA et al. 2008, Callaway et al. 2012).

Elkhorn Slough's tidal channels have also been impacted by these changes, deepening and widening through erosion. Marsh loss has contributed to the estuary's tidal prism and accommodation space, which in turn has increased tidal velocity and erosion below the marsh plain (PWA et al. 2008).

In the CDFW-owned tidal wetland, salt marsh will be restored through sediment addition, raising the marsh plain elevation to a height expected to promote both sediment trapping and organic accretion, making it sustainable over the long term. The project will protect and enhance tidal creeks that currently run through the project area, and may help stabilize creeks offsite as well. The upland edge of the tidal wetland will be graded to create a gentle slope, missing in most of Elkhorn Slough, to allow for tidal salt marsh migration as sea level continues to rise. Above this transitional area, 5 acres of lost native grassland will be planted with local native grass and forb species, as part of a perennial vegetated buffer between the upslope agricultural fields and the coastal wetland.

This project will restore and enhance a functioning salt marsh ecosystem, including 61 acres of coastal wetlands and 5 acres of native grassland on California Department of Fish and Wildlife lands. Elkhorn Slough's tidal salt marshes have experienced dramatic declines over the last 70 years, and the project is needed to restore marsh and adjacent habitats that have been lost, and to increase resiliency in an estuarine system susceptible to climate change. Through sediment addition and other restoration actions, the project will enhance fish and wildlife habitat, protect estuarine water quality, and help the Elkhorn Slough estuary adapt to climate change.

2. *Conceptual Model and Scientific Basis*

This project is science based, built upon on accepted models of marsh dynamics. Salt marshes are adapted to intermittent tidal inundation, and the elevation of the marsh plain relative to fluctuating tidal water is a critical factor determining marshes' long-term stability. Salt marsh plants become stressed or die under conditions of excessive tidal flooding, while loss of tidal inundation leads to conversion to upland plants (Friedrichs and Perry 2001). The elevation range suitable for salt marsh in Elkhorn Slough is narrow it occupies just a 2.5 foot vertical range (Figure 6: Supplemental Material).

Because marsh plants are sensitive to tidal inundation times, the long-term stability of a salt marsh is determined by the relative rates of 1) submergence caused by ground subsidence and sea level rise, and 2) sediment accretion on the marsh, which causes it to expand and grow upward in the intertidal zone (Mitch and Gosselink 2000). In many cases these two processes can be self-regulating, allowing marshes to maintain a stable elevation in pace with the natural rate of sea level rise (Friedrichs and Perry 2001). Marshes can accrete soil in two main ways. First, marsh plants' structure can trap sediments and bind soils brought in on flooding tides. Second, plant growth can contribute organic sediment to the marsh plain (Allen 2000). Marsh stability over time may influence more than just the marsh itself. Models indicate that in the face of sea-level rise, vegetated marshes may be critical for maintaining other associated intertidal surfaces, such as tidal creeks and mudflats (Kirwan and Murray 2007). And because marsh plants dampen water velocity across the plain, marsh plains can provide adjacent uplands with protection against coast flooding and wave erosion (Allen 2000).

But salt marshes are not always in equilibrium, and anthropogenic stressors can destabilize estuarine habitats. Loss of sediment sources due to river diversion and rapid relative sea level rise can reduce marshes' ability to keep pace. The resulting too frequent or prolonged inundation can decrease marsh plant root growth, which in turn decreases sediment elevation, further increasing the tidal flooding, which further reduces plant growth (Mitch and Gosselink 2000). This pattern is called marsh drowning, and is characterized by plant loss in the central portions of the marsh (Friedrichs and Perry 2001). Model experiments have found that without marsh plants, sea-level rise also results in the deepening and erosion of tidal channels, which leads to the conversion of intertidal surfaces to completely subtidal surfaces (Kirwan and Murray 2007).

In addition to the above description of the current scientific literature that informed our planning and decisions we also work with established experts in the field, in order to make the best, science based decisions for the marsh restoration. For example, Dave Burdick, co-author of the book Tidal Marsh Restoration; John Callaway, author of a chapter in the Handbook for Restoring Tidal Wetlands; Lisamarie Windham-Myers, a USGS wetland ecologist with an extensive background in advising California marsh restoration. Furthermore, we work closely with a diverse group of science panel members (see supplemental materials for details.) seeking local and national expertise and input to inform our restoration decisions.

3. *Enhanced Scientific Understanding*

This project will be the first major marsh restoration project in the estuary and first beneficial re-use of sediment in the estuary as well. It has a very strong science-based management approach that will inform and build support for future projects locally and regionally. Unique to Elkhorn Slough is the lack of intact dikes and riverine sediment making restoration through wetland fill more challenging than the same type of project in the San Francisco Bay area. Elkhorn Slough's experience with early relative sea level rise, due to harbor construction in the 1940s makes it an ideal test case for restoration strategies that can be applied elsewhere in order to address global sea level rise. The extensive science based collaborative stakeholder engagement provides a platform of lessons learned for similar projects in the future. Lastly the breadth and depth of monitoring planned to support this project will enhance future understanding and prioritization of the most critical factors in marsh restoration through sediment addition.

In addition to extensive agency stakeholder engagement, this project is a collaboration among researchers from various institutions and an opportunity for visiting researchers, graduate students, and graduate and undergraduate interns to work in tidal wetland systems to better understand the effects of restoration on wetland communities. ESNERR scientists work at the interface of academic and applied science, working closely with land managers and decision makers while maintaining a strong track record of publishing our findings in peer-reviewed journals (e.g., Gee et al. 2010, Wasson 2010, Watson et al. 2011, Wasson and Woolfolk 2011, and Hughes et al. 2011, Hughes et al. 2012, Wasson et al. 2012a, Wasson et al. 2012b, Woolfolk and Labadie 2012, Hughes et al. 2013). Thus our findings and lessons learned will be available to other members of the scientific community.

4. *Linkage with other restoration activities*

This project has been developed as part of the Elkhorn Slough Tidal Wetland Project (TWP), a collaborative effort created to develop and implement coordinated strategies to conserve and restore estuarine habitats in Elkhorn Slough. This program was established in 2004 and involves over 100 coastal resource managers, scientific experts, representatives from key regulatory and jurisdictional entities, leaders of conservation organizations, and community members. In 2012 the TWP Strategic Planning Team, informed by input from the TWP Science Panel, recommended a series of actions that should be implemented (Wasson et al. 2012b). Included was a recommendation that ESNERR should restore salt marsh through sediment addition to areas that have subsided due to earlier diking, specifically identifying the proposed project site for action. Salt marsh restoration using sediment addition in previously diked wetland is also recommended in ESNERR's Management Plan (ESNERR 2005) and in the Elkhorn Slough Tidal Wetland Plan (Elkhorn Slough Tidal Wetland Project Team 2007).

This restoration project will complement other recently completed or planned estuarine projects done as part of TWP, as outlined in the Elkhorn Slough Tidal Wetland Plan (Elkhorn Slough Tidal Wetland Project Team 2007). In 2011, ESNERR installed an underwater sill at the mouth of Parson’s Slough, a tributary of Elkhorn Slough 2200 feet northeast of the proposed salt marsh restoration site, using a $4.5 million grant from the 2009 American Recovery and Reinvestment Act. This project reduced unnaturally high velocity tidal currents in Elkhorn Slough, done in order to decrease erosion of tidal channels and to retain more sediment in the estuary. In 2014, ESNERR restored tidal flow to Whistlestop Lagoon, a 13 acre estuarine wetland nested inside of Parsons Slough, 1.2 miles northeast of the planned project site. Also in the planning stages is the restoration of tidal flow and estuarine function to ESNERR's North Marsh.

In 2011-2012 CDFW enhanced salt ponds near the mouth of Elkhorn Slough for the benefit of nesting snowy plovers and water birds, 1.3 miles northwest of the proposed project site.

The Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California (USFWS 2013), recognizes tidal marsh and its adjacent ecotone and uplands as crucial habitat for many sensitive species, and identifies marsh loss due to past diking as a primary threat to those species. The plan states that "Elkhorn Slough's endangered species recovery potential has been greatly impaired by diking and agricultural reclamation, so tidal marsh restoration will be a principal recovery strategy here." In its recovery strategy narrative, the plan calls for restoration actions including "the addition of layers of sediment" in Elkhorn Slough. It also states that "restored marshes must whenever possible be connected to broad undeveloped, gently sloped adjacent terrestrial habitats."

In addition to direct restoration of tidal habitats in Elkhorn Slough, this project complements other regional conservation efforts. CDFW, Wildlife Conservation Board, California State Parks, Elkhorn Slough Foundation and The Nature Conservancy have collaborated over the past 30 years to acquire, conserve and restore key lands in the Elkhorn Slough watershed. Collectively these agencies and organizations along with other collaborators have protected over 18% of the total 45,000 acres in the watershed. Since 2001, over $30 million dollars have been secured to purchase or protect lands in the Elkhorn Slough watershed.

3. Detailed Project Description

A. GREENHOUSE GASES

1. Statement of work for Greenhouse Gases

<u>Carbon sequestration</u>

The emphasis of most blue carbon enhancement projects has been on quantifying carbon storage before and after restoration, and we will follow this approach as well. We project that as the restoration site approaches natural ecosystem structure with respect to plant distribution patterns and soil profiles, the carbon sequestered will match that of natural salt marshes found within the estuary. To test this hypothesis, we will inventory soil carbon, which will include both living and dead belowground biomass, particulate and allochthonous organic carbon. We also will measure carbon sequestration by aboveground portions of vegetation as the site is colonized by marsh plants. Unlike soil carbon sequestration, this figure will not increase over time once the site is fully vegetated. However, these values will represent a significant pool of sequestered carbon over the funding cycle of the grant.

Flux of greenhouse gases

While most of the emphasis of blue carbon projects has been on carbon sequestration, leaders in the field have suggested that more studies are needed to document trace gas emissions (Chmura et al. 2011, Howard et al. 2014). A focus on greenhouse gas emissions is needed to more fully understand controls on methane and nitrous oxide emissions in salt marshes (Chmura et al. 2011; Moseman-Valtierra 2012). Because methane and nitrous oxide have radiative forcings that are 25 and 298 times that of CO_2 on a hundred year time scale, respectively, a better understanding of salt marsh emission rates is necessary to help inform future blue carbon projects. To our knowledge, nitrous oxide emissions from U.S. Pacific coast salt marshes have never been measured (Moseman-Valtierra 2012). We will thus also conduct monitoring of greenhouse gas fluxes (CO_2, N_2O, CH_4) before and after restoration to ensure that carbon sequestration is not offset by emission of other greenhouse gases.

Drs. E. Watson and K. Wasson will complete three major subtasks to address project objectives related to greenhouse gas reduction, with assistance from additional ESNERR staff (Dr. R. Jeppesen, C. Endris, A. Woolfolk) for fieldwork. A student technician at Drexel University will also assist with sediment processing and laboratory analyses. These subtasks all revolve around quantifying the greenhouse gas impacts of the project. We will quantify carbon storage and gas fluxes in three habitat types before restoration (mudflat, degraded salt marsh, adjacent grassland) in areas of the project footprint that are all slated to be high salt marsh following restoration using a BACI monitoring design (Before-After, Control-Impact; Green 1979; Underwood 1994). We will sample at exactly the same sampling sites before and after restoration, and will include sampling at replicated unrestored control locations as well. This will allow us to quantify changes in carbon storage and gas fluxes resulting from the restoration project. All of our methods are consistent with the best available science approaches recommended by a new document providing guidance on blue carbon monitoring (Howard et al. 2014), though in many cases our level of resolution exceeds their basic recommendations

Objective 1: Significantly increase the blue carbon function of the Elkhorn Slough estuary by increasing extent of healthy salt marsh by 9%, representing the largest blue carbon enhancement opportunity in the region.

Task 1: Greenhouse gas investigation

Task 1a: Pre-restoration assessment.

Following the BACI monitoring design, pre-restoration vegetation and soil carbon pool monitoring will be conducted at project site and in replicated control locations, which contain similar habitat types, but will not be restored to tidal marsh.

<u>Carbon storage monitoring</u>. To quantify soil carbon storage, soil cores will be collected from the project area stratified by habitat type. Ten soil cores each will be collected (pre-restoration) per habitat type, for a total of thirty cores collected. Half will be collected from pre-restoration mudflat, marsh, and grassland, and half will be collected from locations which will not be restored, but will remain as reference locations. Cores will be collected using a 10 cm diameter PVC coring tube beveled to a sharpened edge. Core collection depth is anticipated at 30 to 50 cm, which fully includes the active root zone of the dominant plant species that are found at Elkhorn Slough salt marshes (*Sarcocornia pacifica, Jaumea carnosa, Distichlis spicata*), and also grassland taxa. If core collection in the upland zone is not achievable with a standard push corer, an auger will be used. Cores will be sub-sampled at two to three cm intervals, and analyzed for dry bulk density and sediment organic content (Hieri et al. 2001). Dried sediments will be homogenized using a SPEX Shatterbox 8500 puck and ring mill, and subsequently analyzed for total carbon using a Flash EA113 elemental analyzer. Although previous research conducted at Elkhorn Slough has not identified the presence of inorganic carbon in marsh sediments (Quintana Krupinski et al. 2009), a subset of paired samples will be pretreated to verify that this also holds true for mudflat and upland soils. Pre-project soil organic carbon storage, in Mg of CO_2, will be estimated for each zone using the following equation:

$$atmospheric\ CO_2\ stored = \left(A * DBD * C_{org}\right) * 3.67 \qquad \text{Eqn. X}$$

where A is project area, DBD is the dry bulk density of the soil, C_{org} is the fraction of the soil that is organic carbon, and 3.67 is a constant used to convert Mg of organic C to Mg of atmospheric CO_2.

To quantify carbon storage by vegetation, vegetation will be sampled from pre-restoration and control plots. Plant cover will be harvested from randomly placed 0.25 m^2 plots and analyzed for carbon concentration. Algae mats, which are patchy and ephemeral in the estuary, will not be quantified. Vegetation organic carbon storage will be estimated using mean aboveground biomass and the organic carbon density found in aboveground biomass.

Greenhouse gas fluxes. Pre-restoration greenhouse gas fluxes (CO_2, N_2O, CH_4) will be measured in the field using a Picarro G2508 gas analyzer, a field-based analyzer designed to simultaneously measure concentrations and fluxes of water vapor, carbon dioxide, nitrous oxide, methane, and ammonia using near infra-red laser cavity ring-down spectroscopy. We are fortunate to have access to this sophisticated analyzer through our collaboration with Dr. Cathleen Wigand, a wetland project manager with the U.S. Environmental Protection Agency. To calculate fluxes, changes in gas concentration over time will be measured in static chambers by sampling headspace gases. Flux estimates will be corrected for atmospheric pressure and temperature and scaled for area of soil enclosed by the chamber to yield a gas flux rate (shown here for CO_2):

$$CO_2\ flux = \frac{dCO_2}{dt} \times \frac{PV}{ART} \qquad \text{Eqn. Y}$$

where dCO_2/dt is the change in CO_2 concentration over time, P is the atmospheric pressure, V is the volume of the headspace gas within the chamber, A is the area of soil enclosed by the chamber, R is the universal gas constant, and T is the air temperature.

Static chambers will be approximately 15L in volume and measures will be conducted for five minutes. At least six measures will be conducted in each of four habitat types: mudflat, degraded salt marsh, healthy salt marsh, and adjacent grassland, and will be made in pre-restoration and control plots. Measures will be conducted during daylight conditions with clear chambers to quantify net ecosystem exchange, and either at night, or with opaque chambers, to quantify net ecosystem respiration. To help quantify controls on gas emissions, surface soil salinity will also be measured.

Task 1b: Post-restoration monitoring.

Carbon storage monitoring. Carbon storage monitoring will be repeated using identical methods, as described above, twice over the remaining portion of the funding cycle. Monitoring will also occur to identify and correct for the effects of sediment accumulation or consolidation in the measured soil profile carbon inventory (i.e. top 30-50 cm). Consolidation will be monitored using existing benchmarks established around study plots for vertical control; elevation surveys will be performed using an optical level or rotary laser. To account for surface deposition, feldspar marker beds will be used to monitor accumulation. These elevation and deposition measurements will occur as a part our general project monitoring table (see Table 1.) Atmospheric CO_2 stored by the restoration project will be calculated using the area restored, soil bulk density, and soil.

Vegetation establishment will also be monitored as a part of general project monitoring, and sub-samples obtained for biomass and organic carbon measures to estimate carbon storage by vegetation. Vegetation organic carbon storage, in Mg of CO_2, will be estimated using equation B, as above, using the mean aboveground biomass, extent of re-vegetation, and the organic carbon density found in aboveground biomass. Vegetation biomass and carbon concentration will also be measured in non-restored control plots.

As this proposal comprises a partnership between a research reserve dedicated to long-term monitoring and an academic institution that values rigorous publications, we plan to continue monitoring carbon storage intermittently at the restoration site after the project period, to a time horizon of at least a decade, in order to inform future blue carbon projects.

<u>Greenhouse gas fluxes</u>. Greenhouse gas flux measures will be repeated, as above, near the end of the funding cycle, in post-restoration and control plots. If measurable greenhouse gas fluxes are identified, calculations for atmospheric CO2 sequestration will be performed using scaling variables for global warming potential (25 for methane, 298 for nitrous oxide) (Howard et al. 2014).

Task 1c: Analysis and dissemination of results. Analysis of experimental data will be performed in order to estimate carbon sequestration occurring over the time cycle of the grant, and to compare it with data from natural Elkhorn Slough marshes. If significant non-zero fluxes of methane or nitrous oxide are

measured, and attributable to the restoration effort, offsets will be calculated. A summary report focused on carbon sequestration will be produced, and reviewed by the Elkhorn Slough Science Panel and Salt Marsh Working Group. A revised report will be disseminated on the Elkhorn Slough National Estuarine Research Reserve technical report webpage. This report will also be submitted for publication as a journal article. Findings will be presented at local and national scientific conferences.

2. Technical Feasibility

a. Methods and Technologies

This project applies methodologies and technologies that are well understood and proven. Measurement of carbon pools and changes in carbon stocks directly follows methods laid out by the new handbook, "Coastal Blue Carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows" (Howard et al. 2014). In addition, our methodology follows, and expands upon, that employed to measure post-restoration salt marsh carbon sequestration in southern California (Keller et al. 2012). Greenhouse gas fluxes will be measured principally using a state of the art field analyzer, using relatively new field-based technology (wavelength-scanned cavity ring-down spectroscopy) but using methods established for static flux chambers. In addition, the technology is well tested. Piccaro field based analyzers for greenhouse emissions have been used by dozens of agencies and institutions as diverse as NOAA, NASA, and the Lawrence Berkeley National Laboratory, and have been subjected to verification by the U.S. EPA environmental technology verification program.

b. Feasibility

The greenhouse gas reduction monitoring portion of this project proposes feasible methods. ESNERR owns a variety of tools and equipment necessary for the field investigation component of the study. Such equipment includes corers and tools necessary for collection and processing of soil cores and plant biomass, a survey grade GPS and optical leveling equipment for establishment of geospatial control, a laboratory space outfitted with drying ovens, and a furnace for loss on ignition calculations. Reserve support personnel, all of whom have advanced degrees and specialized expertise in wetland monitoring, are available to support the proposed research.

Additional resources are available through collaboration, including access to an elemental analyzer necessary for measuring carbon inventories, efficient puck and ring and mini-mills for necessary for pulverizing and homogenizing field samples, and a field based gas flux analyzer (Picarro G2508). Laboratory equipment is housed at the Patrick Center for Environmental Research at the Academy of Natural Sciences of Drexel University, an organization that has a sixty-year history of multidisciplinary research in support of environmental quality. Drexel University-based personnel are also available to support the proposed research.

B. CO-BENEFITS

1. *Description and significance of co-benefits*

In addition to contributing to greenhouse gas reductions, this project is anticipated to have significant co-benefits, including direct restoration and enhancement of salt marsh and adjacent coastal communities, indirect benefits for offsite wetlands, improvements in water quality, and habitat enhancement for wildlife.

The tasks and personnel working on each task are listed after the objective details. How each task contributes to each objective is detailed in section 5.1 – Project Objectives.

Objective 2*:* Restore functioning, resilient salt marsh ecosystem in Elkhorn Slough from channel to uplands through adding sediment to historically diked and drained areas and planting native perennial grasses in adjacent buffer.

Description of *coastal marsh ecosystem restoration*

Creation of resilient salt marshes in project area

In Elkhorn Slough most existing salt marshes sit relatively low in the tidal frame, close to Mean High Water (MHW) at just 5.0 feet NAVD (Van Dyke 2012). Based on input from TWP's Salt Marsh Working Group, a group of regional and national salt marsh researchers, this project has identified a significantly higher elevation as its marsh plain target: 6.2 ft NAVD. The Working Group identified the range between 5.8 and 6.4 ft NAVD as the zone most likely to yield a long-term stable marsh in Elkhorn Slough, and given variability during construction, the middle elevation was selected. This height is expected to promote healthy marsh plants, capable of trapping sediments and producing organic material for marsh building in the face of future sea level rise.

Tidal creek protection (5 acres)
Five acres of tidal creeks and minor areas of mudflat will be preserved during construction activities. After sediment addition is complete, key tidal creek edges will be planted for stability. Reestablishing connectivity with associated salt marsh will enhance the creeks' role in sediment delivery and habitat value.

Salt marsh-to-upland ecotone creation (7 acres), and restoration of connectivity between wetland and upland natural communities
Currently, the project site includes very little tidal marsh-upland ecotone; in most areas a narrow fringing marsh abuts former farm fields dominated by ruderal grassland habitat (ESA 2013). Seven acres of salt marsh-to-upland ecotone will be created through upland sediment redistribution and grading, and native plant re-vegetation done using experimental components designed to advance regional understanding of best restoration methods. Experiments will include different planting techniques (seeding vs. plug planting vs. artificial wrack placement) and different plant palettes, and will be well-replicated and monitored. Results will be shared in publications and/or regional meetings.

Restoration of native grassland (5 acres)
The project will restore 5 acres of native grassland on uplands adjacent to restored ecotone and salt marsh. Native grass assemblages will be planted using locally sourced plant material collected, cleaned and properly stored by ESNERR staff and volunteers. As with the salt marsh-to-upland ecotone, grassland restoration will take a restoration science approach, using different experimental treatments (methods, species) to determine the best methods to restore this assemblage in the future. The project site includes 35 acres of former farm fields adjacent to wetlands, and using results from this project, ESNERR will continue to convert the vegetated buffer to native grassland species as resources allow.

Increased diversity and cover of native plant species
Currently the project area contains few native plant species. The former salt marshes, now high mudflats are largely devoid of any vegetation, although 7 acres of low pickleweed (*Sarcocornia pacifica*) remains on the wetland plain, and remnant levee berms and high marsh edges also includes small areas of salt grass (*Distichlis spicata*), jaumea (*Jaumea carnosa*), alkali heath

(*Frankenia salina*), and coast gumplant (*Grindelia stricta*). Ecotone vegetation is largely missing at this site, and the uplands are former farm fields dominated by non-native annual grasses, poison hemlock (*Conium maculatum*), and mallow (*Malva* sp.). Native coyote brush (*Baccharis pilularis*) occurs at the north end of the stockpile site and a single small live oak tree (*Quercus agrifolia*) occurs at the south end (ESA 2013).

This project is expected to increase the cover of pickleweed and associated marsh plants by 42 acres, by raising the wetland plain to an elevation that will be colonized by these species. Planting is not anticipated to be needed on the marsh plain, and will be limited to key tidal creek edges identified by project hydrologists and ecologists. The marsh-to-upland ecotone and grassland will be planted with native species, using local, intact native ecotones and grasslands as reference sites.

Significance

This project will directly restore coastal wetlands. Through sediment addition, the project will result in the restoration of 35 acres of marsh lost to previous diking and draining. Sediment addition will also raise the elevation of 7 acres of extant marsh, making it less susceptible to drowning in the future. Sediment is available from two sources. ESNERR has stockpiled 50,000 cubic yards of sediment dredged as part of a recent Pajaro River flood control project, representing beneficial reuse of regional sediments. Sediment is also available from the project site uplands, which were farmed for decades until the recent CDFW acquisition of the property in 2009. Up to 90,000 cubic yards of upland sediments will be excavated adjacent to project wetlands and the remaining sediments will be graded to create a gentle slope.

Through this excavation and grading on former upland farm fields, the project will create 7 new acres of salt marsh. Excavation, grading and native species plantings will also lead to the creation of 7 new acres of marsh-to-upland ecotone. The project will be designed to protect and enhance existing tidal creeks and limited areas of mudflats, improving 5 acres of non-marsh wetland.

The project will also restore 5 acres of native grassland in formerly farmed fields adjacent to the wetlands, and will be accomplished by re-vegetating with native plants. These actions in the ecotone and grasslands will increase the diversity and cover of native plant species, and will restore and enhance connectivity to associated wetland and upland natural communities.

Objective 3: Reduce tidal scour in Elkhorn Slough through adding sediment to historically diked and drained areas

Description

Adding sediment to subsided wetlands at the project site will fill accommodation space, benefiting the larger estuarine system by decreasing downstream tidal prism in Elkhorn Slough, and lessening the potential for scour of subtidal habitats. This project will displace up to 140,000 cubic yards of tidal prism and accommodation space.

Significance

This project aims to support conditions that improve estuarine resilience offsite as well. Adding sediment will displace tidal waters, reducing the tidal prism, which is anticipated to reduce tidal scour in turn, helping to stabilize offsite tidal creeks. Tidal scour erodes habitat, exports valuable sediment and reduces the viability of tidal marshes. The added sediment will also fill accommodation space, deep areas left over from past subsidence, which competes with tidal marsh for sediment suspended in the water column (PWA et al. 2008).

Objective 4: Provide resilience to climate change to estuarine ecosystems in Elkhorn Slough through increasing the extent of tidal marsh of sufficient elevation to be resilient to moderate sea level rise.

Description

Recent modeling revealed that there is limited potential for marsh migration in much of the estuary due to steep hillsides adjacent to the marshes (Wasson et al. 2012a) At the project site, excavation of up to 90,000 cubic yards and grading of the uplands adjacent to the wetlands will create a band of gentle slope (e.g. 1:30) on the hillside, fostering creation of a wider ecotone habitat. This will facilitate future marsh migration potential.

Significance

The project will increase estuarine resilience both onsite and offsite. The project wetlands are likely to be among the most resilient marshes in the entire estuary. This project retains a full tidal range and establishes a marsh plain at a high elevation suitable to reduce excessive inundation time and produce robust stands of tidal marsh vegetation. This is expected to maximize sediment retention and accretion (Friedrichs and Perry 2001), giving these landscapes the greatest potential to endure in the face of sea level rise. The position of the project in the estuary is close to the 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 and marsh vegetation, the project site will be able to thrive despite relative sea level rise.

While the restored acreage is anticipated to be resilient to moderate rates of sea level rise (2-3 mm/y), under higher rates (7 mm/y) (Rahmstorf 2007) the habitat mosaic will shift landward. 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 will be established as part of this project.

Objective 5: Protect and improve surface water quality in Elkhorn Slough through establishing tidal marsh buffer and providing a filter of vegetative marsh.

Description

As a result of restoring coastal salt marsh we expect turbidity to decrease, and we expect the frequency and duration of hypoxia events to decrease. First, restoring tidal marsh will allow suspended sediment from the water column to settle on the substrate near the marsh vegetation. Future marsh vegetation is expected to retain sediment better than current mudflat habitat (Friedrichs and Perry 2001). Both of those factors are expected to contribute to decreased turbidity in the water column. Decreased turbidity can allow for more light which will support phyto- and zoo-plankton communities which in turn support fish populations. Last, decreased turbidity is beneficial for eelgrass beds which is dependent on light for growth. Second, we expect a significant decrease in hypoxia frequency and duration after the marsh restoration. Main contributors to frequent and long periods of hypoxia are eutrophication. Eutrophic conditions support a high abundance of floating algae. Floating algae take up large amounts of oxygen during non-daylight hours which increases frequency and duration of hypoxic events. Vegetated marsh can act as a buffer for eutrophication by nutrient uptake, thereby improving water quality by decreasing hypoxia.

Significance

The project is expected to improve local estuarine water quality. The degraded project area currently has shallow mudflats, with abundant nuisance algal mats. Under these conditions, the habitats experience very low oxygen conditions at nighttime, as respiration by mudflat microbes, animals and algae removes all the oxygen from the shallow layer of water above it. When this area is restored to a salt marsh, only narrow, deep tidal creeks will have standing water. The dissolved oxygen in these creeks should remain much higher, supporting better quality habitat for fish and other sensitive wildlife.

Additionally, the grassland itself is designed to function as a perennial vegetated buffer, reducing agricultural runoff into the restored marsh and improving local water quality.

Objective 6: 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.

Enhance habitat for the benefit of southern sea otters

Description

Benefits to sea otters will be realized through restoration of a functioning salt marsh ecosystem. A regional partnership of research institutions (USGS, UC Santa Cruz, CDFW, Monterey Bay Aquarium, and ESNERR) is currently investigating sea otter use of Elkhorn Slough habitats, because for the time being, Elkhorn Slough is the best example in California of sea otters using estuarine habitats. Recent data demonstrate that sea otters use Elkhorn Slough's marshes as haul-out sites, particularly at low tide, and otters have been observed foraging for lined shore crabs in pickleweed (Scoles et al. 2013). Re-sighting data show that otters, particularly mothers with pups, actively use the salt marsh immediately northeast of the project site, but that they avoid the degraded wetlands in the project footprint itself (USGS unpublished data, Figure 7a: Supplemental Material). It is expected that restoration of the project site marsh and protection of its associated tidal creeks will provide connectivity with the heavily used marsh to the northeast, and provide additional habitat for otters.

Significance

The project is also anticipated to restore important habitat for federally threatened Southern sea otters, contributing to the goals of the Recovery

> Plan for the Southern Sea Otter (USFWS 2003). Elkhorn Slough currently supports more than 100 sea otters (Hughes et al. 2013), and recent research in Elkhorn Slough has established that sea otters, including mother-pup pairs, use ESNERR's protected salt marsh as resting and foraging habitat (Scoles et al. 2013 and Figure 7b: Supplemental Material). One of the most heavily used marsh sites is in healthy, functioning salt marshes adjacent to the project area, but otters are rarely seen using the degraded mudflats of the project area itself (USGS, unpublished data, Figure 8: Supplemental Material showing Yampah vs Minhoto use from recent USGS presentation). Marsh restoration is expected to increase the project site's suitability as otter habitat in the future.

Finally, the project is expected to enhance wildlife habitat for other estuarine species. The tidal marshes in Elkhorn Slough are home to dozens of native plant species, and are used by invertebrates, fish, reptiles, birds and mammals for resting, feeding, breeding and refuge (reviewed in Woolfolk and Labadie 2012). We expect these species will be represented at the new marsh. This project will also preserve the natural tidal creeks on the site, benefiting fish known to utilize Elkhorn's tidal channels, such as northern anchovy, starry flounder, and shiner surfperch, including species known to use Elkhorn Slough as an important regional nursery, such as English sole and leopard sharks. Recent investigations have revealed that fish species richness and fish nursery function are both very sensitive to dissolved oxygen levels in Elkhorn Slough (Hughes et al. 2012), and thus will benefit from the habitat restoration. General wildlife use of restored marshes and enhanced creeks will not be monitored as part of this project, but given the extensive literature on animal use of healthy California marshes, these benefits are anticipated to be substantial.

Task 2: Direct Project Administration (*Partial funding through this proposal*)

This task includes general project administration, labor compliance, quarterly reporting, and project completion reporting.

Task 2.a: Project Administration: The Elkhorn Slough Foundation will conduct all project administration tasks, including managing payroll, invoicing, and communication between ESF staff, project consultants, contractors and project partners throughout the duration of the project period.

Task 2.b: Labor Compliance Program: The Elkhorn Slough Foundation will conduct activities necessary to meet labor compliance requirements, and submit to the lead applicant. Labor compliance will be implemented to meet new Department of Industrial Relations (DIR) Compliance Monitoring Unit (CMU) requirements.

Task 2.c: Reporting: Quarterly reports will be prepared assessing the progress and accomplishments of the project. A final project completion report will also be prepared at the end of the project.

Deliverables: Preparation of invoices as required; submission of Labor Compliance Program requirements; submission of quarterly reports and project completion report.

Personnel: Project personnel for this task include ESF Grants Manager – G. Estill, Tidal Wetland Project Director – M. Fountain, ESF Executive Director – M. Silberstein.

Task 3: Planning/Design/Engineering/Environmental Documentation
This is already in progress and includes project assessment and evaluation, planning and community engagement, engineering design, environmental documentation, and permit preparation activities.

Task 3.a: Assessment and Evaluation (*Funded entirely by DWR and State Coastal Conservancy*): During this task 100 acres of potential project sites will be assessed for project feasibility. Site feasibility will be determined once data has been compiled to characterize each site for restoration design and regulatory compliance purposes. Specific tasks include:

- Compile and process existing site data. This will include biological data, habitat extent, water quality, topography, hydrology, and soil/sediment characteristics
- Collect and process restoration needs for each site, including soil engineering characteristics, staging areas and access routes, and sediment quantities required for restoration
- Conduct wetland delineation and fish and wildlife assessments as necessary for regulatory compliance purposes
- Evaluate alternatives
- Prioritize restoration sites
- Define criteria for acceptable sediment, based on Army Corps of Engineers manuals and other guidance for the beneficial re-use of sediment
- Develop a restoration plan that includes sediment suitability criteria, placement plan and a native grass buffer restoration plan

Task 3.b: Planning and Community Engagement (*Funded by DWR and State Coastal Conservancy*): This task will include 1) meeting with ESF staff, project consultants and the project's technical advisory committee to refine the project goals and objectives; 2) two meetings with regulatory agency staff to develop sediment acceptability criteria and to receive feedback on the project and facilitate agency coordination of key documents and decisions; and 3) evening meeting open to public to discuss project. The purpose of the public meeting is to inform the public of the project and address any concerns. The anticipated outcome is that the public will feel informed about the project. The meeting will be held during the CEQA process.

Task 3.c: 30% Engineering Design (*Funded by DWR and State Coastal Conservancy*): Project engineering designs for the 18-acre sediment addition will be completed by consulting engineers. Designs for the 3-acre native grass buffer will be completed by staff.

Task 3.d: Environmental Documentation (*Funded by DWR and State Coastal Conservancy*): In order to be compliant with the California Environmental Quality Act (CEQA), a project-specific Mitigated Negative Declaration (MND) will be completed for the project.

Task 3.e: Permit Preparation Activities (*Funded entirely by DWR*): The following additional authorization and permits will be obtained prior to implementation of the project. Scope covers effort required to obtain these following permits and permit fees as required:

Federal Agency Authorizations and Permits

- Army Corps of Engineers (individual Section 404 Permit anticipated)
- Monterey Bay National Marine Sanctuary (permit anticipated)
- US Fish and Wildlife Service (Biological Opinion)
- US Fish and Wildlife Service (Incidental Harassment Authorization Endangered Species Act)
- National Marine Fisheries Service (Incidental Harassment Authorization under the Marine Mammal Protection Act)

State Agency Authorizations and Permits

- Regional Water Quality Control Board (401 Water Quality Certification/WDR/ NPDES anticipated)
- California Department of Fish and Wildlife (Right of Entry Permit)
- California Department of Fish and Wildlife (LSA/Section 1602 Agreement)
- Coastal Commission/Monterey County (Coastal Development Permit)

Local Agency Authorizations and Permits

- Monterey County (Design Review)
- Monterey County (Grading Permit)
- Monterey County (Construction Permit)
- Santa Cruz County (Construction Permit)
- Moss Landing Harbor District (Construction Permit)

Task 3.f: 60% and 100% Engineering Design (*Funding requested in this proposal*): Project engineering designs for the 18-acre sediment addition will be updated by consulting engineers incorporating all concerns and/or mitigation measures imposed by the regulatory agencies. Designs for the 3-acre native grass buffer will be updated by staff incorporating all concerns and/or mitigation measures imposed by the regulatory agencies. 100% designs are "construction set" designs and will be prepared for the bid package.

Deliverables: Existing conditions report, sediment criteria technical memorandum, project alternatives technical memorandum, sediment stockpile and placement memorandum, meeting notes, completed Restoration Plan, 30%, 60%, 100% engineering designs, final Initial Study and MND, and permits and approvals required by the agencies.

Personnel: Project personnel for this task providing oversight and input include: GIS Specialist – C. Endris, ESF Grants Manager – G. Estill, Tidal Wetland Project Director – M. Fountain, Estuarine Ecologist – Dr. R. Jeppesen, ESF Executive Director – M. Silberstein, Research Coordinator – Dr. K. Wasson, Stewardship Coordinator – A. Woolfolk. Some planning, engineering, and environmental compliance will be completed by a consulting team lead by ESA – PWA (including H.T. Harvey, Moffatt & Nichol and ENGEO)

Task 4: Construction/Implementation. Construction elements include: Construction contracting, construction of coastal marsh, maintenance of tidal creeks, establishment of ecotone, establishment of a native grass buffer and performance testing and demobilization.

Task 4.a: Construction Contracting (*partially funded by DWR, primarily requested in this proposal*): ESF will advertise this project for competitive bidding between qualified contractors. The process includes the following tasks: advertising, pre-bid meeting, bid opening, bid review, contract awarded, and execution of contract documents. Contracts will be established for construction administration, for the construction of the staging area, and for the establishment of the native grass buffer.

Task 4.b: Construction: Construction is divided into three categories - mobilization and site preparation, project construction, and performance testing and demobilization.

Task 4.b.1: Mobilization and Site Preparation: Construction staking will be performed. Equipment and materials will be ordered and brought to the site.

Task 4.b.2: Project Construction: Contractors operating earth moving equipment will construct sediment berms to restrict tidal flow and move the sediment onto the marsh according to plans and specifications.

Native grass buffer will be graded, seedbed prepared, and planted with native grass seed. Native grassland seed will be procured from the Elkhorn Slough National Estuarine Research Reserve's native grass farm. The grass farm was established in 2010 specifically for seed production for this project. Species include California oat grass, purple needle grass, hair grass, and blue wild rye. Additional species, including creeping wild rye and native perennial forbs, may be grown in ESNERR's greenhouse, based on biological surveys of nearby native grasslands. If ESNERR seed supply is short we will purchase additional native grass seed to plant.

Task 4.b.3: Performance Testing and Demobilization: Construction environmental training and BMP inspection will be performed by an ESF qualified biologist. Inspection and performance testing requiring a licensed engineering will be performed by a contractor to ensure compliance with final designs. Inspections will be conducted weekly for the duration of construction, by licensed engineer to ensure sediment meets construction specifications.

Deliverables: Advertisement for bids, awarded construction contract, photos of project staking, grading, and native grass buffer, as-built designs.

Personnel: Project personnel for this task providing oversight and input include: Stewardship Specialist – B. Candiloro, GIS Specialist – C. Endris, ESF Grant's Manager – G. Estill, Tidal Wetland Project Director – M. Fountain, Estuarine Ecologist – Dr. R. Jeppesen, ESF Executive Director – M Silberstein, Research Coordinator – Dr. K. Wasson, Stewardship Coordinator – A. Woolfolk, TWP Assistant - TBD.

Task 5: Environmental Compliance: Environmental Compliance/ Mitigation/ Enhancement (*Funded by DWR*) - CEQA and permit compliance requirements will be implemented. Requirements will be identified during the CEQA and permit processes and are not yet known. Contractors and staff will develop compliance reports, consisting of items required by environmental compliance and/or permits.

Deliverables: Documentation of Best Management Practices and compliance reports as required as part of environmental compliance and/or permits.

Personnel: Project personnel for this task providing oversight and input include: Tidal Wetland Project Director – M. Fountain, Estuarine Ecologist – Dr. R. Jeppesen, Stewardship Coordinator – A. Woolfolk.

Task 6: **Monitoring**: This task includes project performance monitoring for implementation and ecological effectiveness of the project co-benefits.

Deliverables: Monitoring Plan and Final Report. For a detailed description of what will be included in the plan see section 5.5.C.

Personnel: Project personnel for this task providing oversight and input include: Stewardship Specialist – B. Candiloro, GIS Specialist – C. Endris, Tidal Wetland Project Director – M. Fountain, Estuarine Ecologist – Dr. R. Jeppesen, Research Coordinator – Dr. K. Wasson, Stewardship Coordinator – A. Woolfolk. TWP Assistant - TBD

Task 7: Education/ Outreach: Enhance current education and outreach programs at the Reserve through development and incorporation of greenhouse gas reduction and co-benefit concepts into the current curriculum by the end of 2015.

The Elkhorn Slough Reserve has over thirty years of offering exceptional student, teacher, visitor, and professional education programs.

The Reserve Education Program staff hosts more than 20 educational institutions and nearly 5,000 students, parents and chaperones each year in their teaching lab and on self-guided field walks. The Education Program staff have created dynamic, hands-on activities for school children and their teachers. The Reserve Education staff works with the Watsonville Area Teens Conserving Habitats (WATCH) program, a collaboration between ESNERR, Monterey Bay Aquarium, and the Pajaro Valley Unified School District (Watsonville and Pajaro Valley are underserved communities).

The Elkhorn Slough Visitor Program staff welcomes over 40,000 visitors annually through guided tours, award winning exhibits in the Visitor Center, and exciting public events.

Deliverables: Three curriculum segments designed for K-12, adults and teachers.

Personnel: Project personnel for this task providing oversight and input include: Tidal Wetland Project Director – M. Fountain, ESNERR Education Specialist – V. Guhin, Estuarine Ecologist – Dr. R. Jeppesen.

2. *Monitoring and Assessment for Co-Benefits*

A unique strength of this project is the breadth and high caliber of the scientific monitoring, analysis, and outreach that will be conducted to track restoration outcomes. The Elkhorn Slough National Estuarine Research Reserve conducts long term monitoring programs as part of its core mission. These cover of a wide array of environmental indicators, including water quality, land cover, shorebird abundance and diversity, and benthic invertebrate abundance and diversity. ESNERR staff also has a demonstrated track record of regularly publishing results of Elkhorn Slough science in peer-reviewed scientific journals and sharing findings with regional managers and policy-makers.

ESNERR staff will intensively monitor the success of the restoration for five years following completion of construction. Staff monitoring will be conducted by ESNERR's Research Coordinator (Dr. Kerstin Wasson), GIS Specialist (Charlie Endris), Stewardship Coordinator (Andrea Woolfolk), and trained volunteers. Monitoring has been designed specifically to evaluate the success of co-benefit objectives, as shown in Table 1, below. Best available science has been incorporated into field and analysis methods, and sampling design has been conducted in a rigorous, hypothesis-testing statistical framework. Statistical analyses will focus on temporal comparisons for some indicators, e.g. analyzing marsh acreage or dissolved oxygen before vs. after restoration. Analyses will focus on spatial comparisons for other indicators, e.g. analyzing marsh biomass and accretion rates in the best reference marshes vs. the restoration site following marsh colonization.

Table 1. ESNERR Monitoring Plan to Evaluate Project Effectiveness for Co-Benefits

Project Co-benefit	Question	Monitoring Method
Restore 49 acres of coastal salt marsh (35 acres of lost marsh restored; 7 acres of extant marsh raised; 7 acre of new marsh created)	How much has marsh cover increased in the project area following sediment?	Remote sensing: aerial photographic analysis (annual CDFW photos digitized and analyzed in GIS)
	What is the elevation of the project area following sediment addition?	Remote sensing: analysis of LiDAR data for rough characterization of entire area
		Field transects: real time kinematic measurements at 10 m intervals along transects in restored area
Protect 5 acres of existing tidal creeks and mudflat on site	How have creek numbers and sizes in the project area changed following sediment addition?	Remote sensing: as a part of the marsh aerial photographic analysis, examine maintenance or development of creeks
Create 7 acres of salt marsh-to-upland ecotone, and restore	How much ecotone habitat has been created?	Fieldwork: Mark and GPS perimeter of ecotone

connectivity between wetland and upland natural communities		assemblage.
Restore 5 acres of native grassland	How much native grassland habitat has been restored?	Fieldwork: Mark and GPS perimeter of native grass assemblage.
Increase diversity and cover of native plant species	How do marsh plant community attributes differ in the project area vs. in other Elkhorn marshes?	Field transects: percent cover and canopy height of marsh plants measured in quadrats along permanent transects, in project area and Elkhorn Slough reference sites
	How does marsh-upland ecotone community composition compare in the project area vs. other Elkhorn marshes? How is this affected by different restoration techniques used in project?	Field transects: percent cover and canopy height of ecotone plants measured in quadrats along permanent transects, in project area and Elkhorn Slough reference sites
	How is community composition of the native grassland changing? What are the effects of different planting and weeding treatments?	Field transects: percent cover and canopy height of grassland plants measured in quadrats along permanent transects.
Create resilient salt marshes in project area, by establishing plain high in its tidal range capable of maintaining height relative to sea level rise	What is the inundation time of the marsh in the project area, and how does this compare to other Elkhorn marshes?	Modeling and calculations: calculate from elevation data correlated to water level data from long-term data sonde
	How much of the sediment was retained on marsh plain over first year following addition?	Field transects: set and monitor long rebar rods along transect where distance from sediment surface to top of rebar can be measured manually
	How is elevation of the project area changing over time?	*Field transects: real time kinematic* measurements at 10 m intervals along transects in restored area
	How is marsh elevation and sediment accretion changing in the project area vs. in other Elkhorn marshes, and how is this affected by elevation?	Fieldwork: surface elevation tables (SETs) coupled with feldspar horizon markers to determine both sediment accumulation and subsidence contributions to elevation change, across elevation gradient (locate along vegetation/elevation transects

		described above)
	How sustainable is salt marsh in the project area vs. in other Elkhorn marshes?	Remote sensing: aerial photographic analysis (annual CDFW photos digitized and analyzed in GIS)
Provide a migration area for salt marsh if sea level rise rates are high	What is the location and elevation of the marsh/ecotone boundary?	Field transects: as part of Slough wide ecotone monitoring mark and GPS the location of the upper edge of salt marsh where it is adjacent to uplands graded during project.
Reduce tidal prism to benefit onsite and offsite tidal habitats, including tidal creeks	How much tidal prism was displaced by the sediment addition?	Modeling and calculations: GIS analysis of elevation changes
	How much are creek dimensions changing in the project area vs. in other Elkhorn marshes?	Remote sensing: as a part of the marsh aerial photographic analysis, track development of creeks over time, and determine whether they are widening in project area and in rest of Slough
Improve water quality in local wetlands	Has dissolved oxygen improved in channels in the project area following restoration, and how do levels compare to other channels in the estuary?	Deploy YSI sonde to channel within project area, to collect data every 15 minutes from July-September every year
Enhance habitat for the benefit of southern sea otters	How have sea otter numbers changed in the project area following restoration, and how does this compare to other Elkhorn Slough marshes and channels?	Field work: field surveys to count otters in target marsh/creek complexes

3. *Technical Feasibility*

Construction elements

Project objectives will be accomplished through the addition of sediment to subsided historic marshes. The construction approach is as follows: sediment will be sourced as described above and placed on the land surface using low pressure earth moving equipment, long reach excavators or other heavy machinery. Sediment will be placed dry. Containment dikes, where required by regulatory agencies, will be constructed of the same sediment as the marsh and designed to be smoothed down to the correct elevation at the end of construction. The buffer zone above the wetland will be vegetated with native grasses planted with a transplanter and by contractors.

Methodologies

The approach of restoring subsided wetlands in Elkhorn Slough through the beneficial reuse of sediment was developed in detail by ESNERR and Moffatt & Nichol (2010). The hydrodynamics and geomorphology of Elkhorn Slough has been investigated in detail, as reported in Philip Williams and Associates (2008). A major recommendation of that report was to restore the historic landscapes in Elkhorn Slough by importing sediment and adding it to subsided areas. The specific strategy is to add sediment to an elevation close to the upper range of the marsh plain. Tidal marsh established at that higher elevation is expected to grow vigorously, contributing organic material to the soil and gaining elevation at a faster rate than other tidal marsh, making it more resilient to sea level rise (Callaway personal communication).

Project conceptual designs for restoring subsided wetlands through the beneficial reuse of sediment generated from harbor dredging, flood control projects and other sources were developed in ESNERR and Moffatt & Nichol (2010). The plan discusses construction approaches, provides conceptual designs and itemizes cost estimates for restoration on a per-acre basis. These concepts were refined during meetings of the Parsons Slough Team, a technical advisory committee of agency and university scientists and land managers. Additional review was provided by the Science Panel and Strategic Planning Team of the Elkhorn Slough Tidal Wetland Project (SP, SPT listed in the Supplemental Material). Key regulatory agency staff participated in those meetings and the production of that document.

Extensive technical tools are supporting project development. Professionally developed hydrodynamic modeling files and base data are owned by the project proponent. Key data of the project sites have been acquired, including LiDAR elevation data, water quality stations with records going back 15 years with continuous data and 20 years with monthly data. The bibliography of scientific papers on Elkhorn Slough includes over 900 entries.

Samples of the Pajaro River bench sediment and the upland soil at the project site have been tested for grain size, nutrient status, heavy metals and organic pollutants such as pesticides. All of the tests meet standards for ocean disposal identified by the San Francisco Bay Regional Water Quality Control Board: Beneficial reuse of dredged materials: Sediment screening and test guidelines. Staff Report (SF Bay Regional Water Quality Control Board 2000).

4. Timeline

This project includes a realistic implementation plan based on careful determination of the timeline for permitting, contracting, and construction. The implementation plan including tasks and deliverables is provided in the Supplemental Material. Details of key parts are below.

GENERAL TIME FRAME AND READINESS TO CONSTRUCTION

Task 1: Greenhouse gas investigation

Task 1a: Pre-restoration assessment. In summer 2015 we will conduct initial monitoring of soil and plant carbon storage and gas emissions in project and control areas to determine baseline.

Task 1b: Post-restoration monitoring. Twice over the funding period of the grant, in summer 2017 and 2019, soil and biomass carbon stocks will again be monitored in the restoration area and in control plots, including measures of soil accumulation and consolidation. Greenhouse gas emissions will be monitored again post-restoration at restoration and control plots. We are also committed to continuing this monitoring for another five years beyond the grant funding period.

Task 1c: Analysis and dissemination of results. From fall 2019 to spring 2020 we will complete the final analysis and report, and disseminate findings to local managers, regional audiences, and international conferences.

5. Deliverables

A. GREENHOUSE GASES

We will produce a 10-20 page technical report that describes the projected greenhouse gas reduction benefits, the monitoring conducted to test these projections, and the analyses conducted to confirm them. This report will serve as a model to inform future regional blue carbon enhancement projects. This report, including raw data on carbon stocks and greenhouse gas fluxes, will be publically available and archived on the ESNERR website. A version of the report will also be published in a peer-reviewed journal, but since the review process is always of uncertain duration, we will not commit to completing this deliverable within the time-frame of these grant funds. Positions of sampling stations will be submitted as an ArcGIS shapefile with accompanying meta data on a CD.

B. CO-BENEFITS

There are a number of deliverables for the co-benefits and they are described in detail within the description of each task in 5.3.B.1.

C. DATA MANAGEMENT AND ACCESS

This project, will generate a wealth of environmental data (see Table 1). The monitored parameters and the methods for assessing them are closely based on nationally accepted marsh restoration monitoring guidelines (Neckles et al. 2002, Burdick and Roman 2012), especially those developed by NOAA (Thayer et al. 2003; Thayer et al. 2005). The standards to be used for data/metadata format and content vary for each of the monitoring parameters listed in the summary table. In every case the monitoring methods, including the database structure, will adhere to models of demonstrated successful monitoring and data management dissemination, based on the currency of peer-reviewed publications by our own scientists or by other experts in the field.

ESNERR is committed to robust data archiving, sharing, and dissemination. Our environmental databases are maintained using Excel, Access, or ArcView software as appropriate to the data type. We ensure that two different permanent staff members have copies of and are familiar with all the methodological databases, metadata, and databases for our monitoring programs. Data are entered and QA/QC'd within a month of data collection. We make all our raw data available to any requestors. We also prepare timely analyses, with graphs and summaries, and make these available through our webpages and present them at regular meetings of the Tidal Wetland Project. As an example of our web-based dissemination of data and reports, see http://www.elkhornslough.org/research/conserv_marsh.htm.

ESNERR scientists work at the interface of academic and applied science, working closely with land managers and decisionmakers while regularly publishing in peer-reviewed journals (e.g., Gee et al. 2010, Wasson 2010, Watson et al. 2011, Wasson and Woolfolk 2011, and Hughes et al. 2011, Hughes et al. 2012, Wasson et al. 2012a, Wasson et al. 2012b, Woolfolk and Labadie 2012, Hughes et al. 2013). We will publish the results of the restoration monitoring for this project in an international journal, to share lessons learned and data with the broader estuarine science community.

6. Expected Quantitative Results (Project Summary)

A. PREDICTED GREENHOUSE GAS REDUCTIONS

Carbon sequestration

Carbon sequestration rates in salt marshes are generally high, but vary greatly. For instance, a review by McLeod and others (2011) reported an average sequestration rate of 218 g C m^{-2} yr^{-1}, measured across 96 sites, but with a range of 18-1713 g C m^{-2} yr^{-1}. We are fortunate to be able to provide very robust carbon sequestration rates for Elkhorn Slough marshes, and these are close to the average reported by McLeod: 201 ± 47 g C m^{-2} yr^{-1}.

We calculated these carbon sequestration rates from sediment cores collected from seven natural areas of tidal wetlands at Elkhorn Slough (Figure 9), all within five miles of the proposed project. Marsh vegetation was dominated by the perennial succulent *Sarcocornia pacifica*. Cores were collected using a Russian peat borer, a side filling coring device that collects sediment core profiles free of compaction and core shortening (Aquatic Research Instruments). Sediment cores were sub-sampled at one to three-cm intervals for bulk density and organic content determinations (Hieri et al. 2001). One cc subsamples were dried to constant weight, and combusted for 4 hours at 550°C. Soil organic matter content was converted to soil C content using an empirical conversion function developed using 60 sediment samples collected at Elkhorn Slough and analyzed for organic content using loss on ignition (Heiri et al. 2001) and for carbon content using a Flash EA113 CHN elemental analyzer (Figure 10).

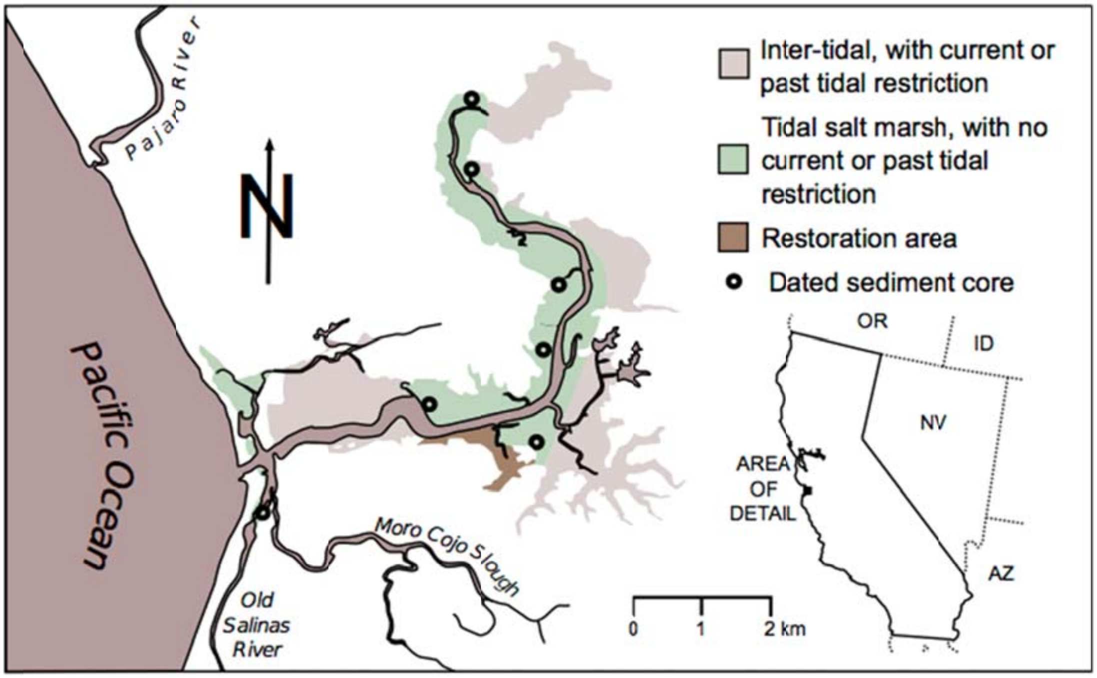


Figure 9. Map of Elkhorn Slough showing location of cores analyzed for carbon accumulation.

To calculate recent accumulation rates, sediments were analyzed for ^{210}Pb and ^{214}Pb activity using low-energy germanium gamma ray detectors. A linear regression of the natural log (ln) of the excess ^{210}Pb activity vs. depth was used to estimate core sedimentation rates (Table 2; Figure 11; Callaway et al. 2012). The carbon sequestration rate was calculated as the product of sediment bulk density, fraction C, and accumulation rate, multiplied by 10,000 (cm^2 m^{-2}) to scale from square cm to square m.

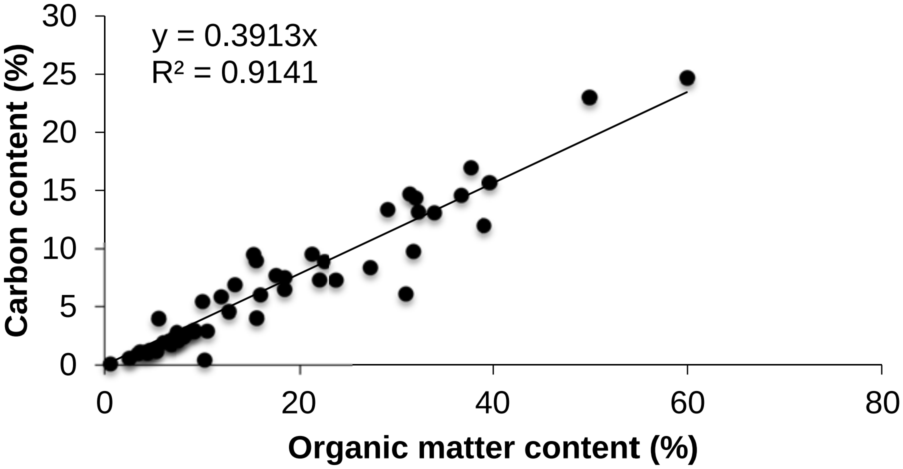


Figure 10. Relationship between sediment organic content and carbon content based on data from 60 sediment samples collected from tidal marshes and tidal flats at Elkhorn Slough. Based on this very strong relationship, sediment organic content was converted to carbon content for dated cores.

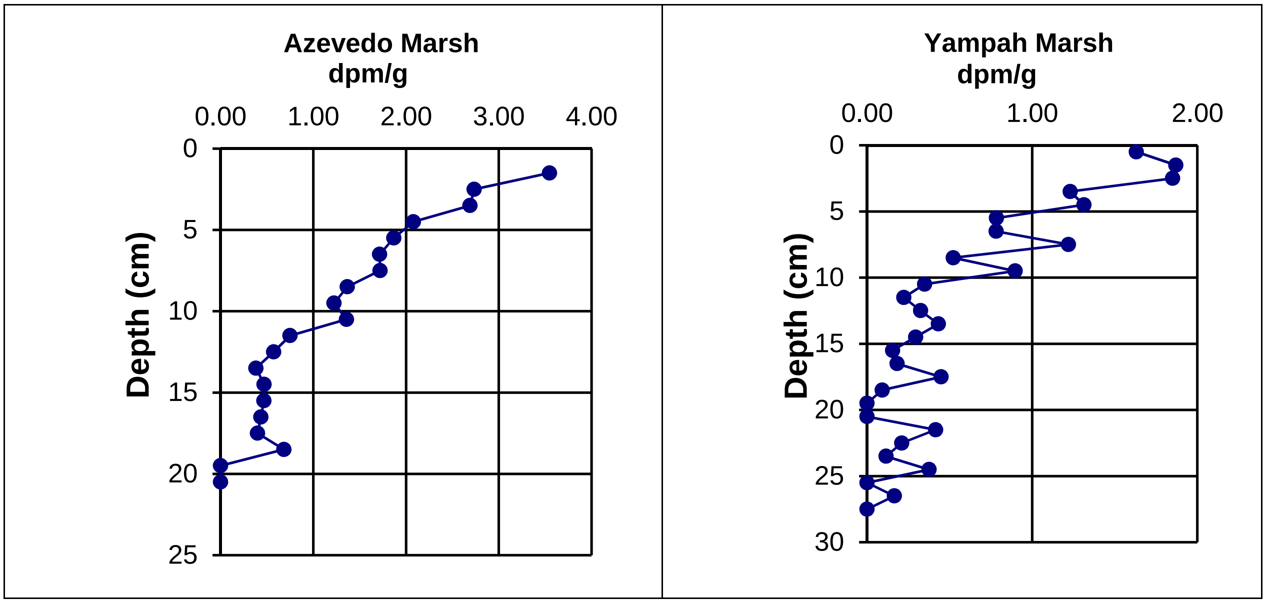


Figure 11. Sample downcore excess 210Pb activity plots from Elkhorn Slough sediment cores. Units measured are decays per minute per gram as a function of depth.

Table 2. Estimates of Elkhorn Slough salt marsh soil carbon sequestration rate from

Core	Accumulation rate	Bulk density	Fraction C	C sequestration rate
	[cm y^{-1}]	[g cc^{-1}]	[%]	[g C m^{-2} y^{-1}]
Hudson’s	0.3	0.39	11.6	126
Rubis	0.8	0.65	4.5	233
Big Creek	0.71	0.66	4.9	230
Harbor	0.34	0.66	7	157
Round Hill	0.8	0.31	10.1	255
Yampah	0.54	0.36	11.9	223
Azevedo	0.32	0.43	13.1	181
Mean±stdev				**201±47**

dated sediment profiles analyzed for bulk density, organic matter and carbon content.

Elkhorn Slough's carbon sequestration values are higher than reported for San Francisco Bay using lead-210 dating (79 g C m^{-2} yr $^{-1}$, Callaway et al. 2012), likely because of higher accretion rates and higher percent organic material at Elkhorn Slough, but are very similar to the average reported for salt marshes by McLeod et al. 2011. We are very confident in this estimated carbon sequestration rate for Elkhorn Slough marshes, and the same rates should apply to the nearby restored marsh. Thus, in the calculation of expected carbon sequestration (Table 3) in the newly restored salt marsh, the average rate of 201 g C m^{-2} yr $^{-1}$ by soil sequestration is very robust. The exact timing at which the newly restored marsh will be fully vegetated and thus achieving these carbon sequestration rates is not certain, but colonization by pickleweed (the marsh dominant), is known to be rapid in areas of appropriate elevation, so we anticipate the time frame being within 2 years of the completion of construction.

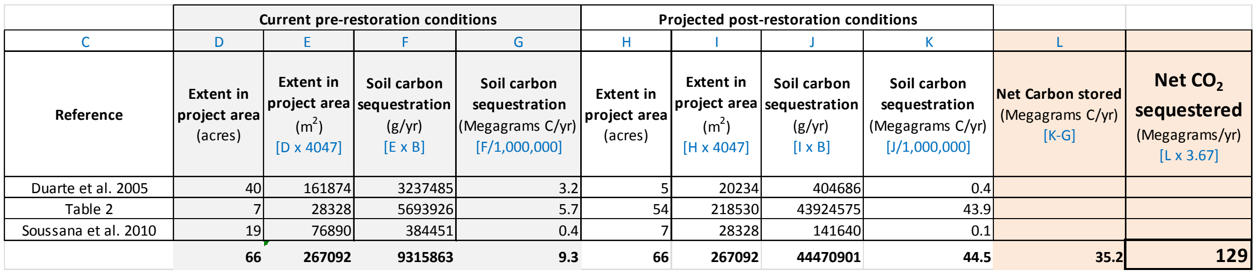
Calculation of the change in soil carbon sequestration before vs. after the project requires estimation of carbon sequestration rates in the mudflat and adjacent grassland areas that will be converted to salt marsh. These estimates involve much more uncertainty than our estimates for salt marsh carbon sequestration, because we do not have empirical data of our own from Elkhorn Slough to rely on, but must use literature values for similar habitats. It is clear from the literature that salt marshes generally have much higher sequestration rates than other habitat types, but the exact magnitude of this difference is hard to quantify.

For mudflats, Duarte et al. 2005 report a rate of 45 g C m^{-2} yr^{-1}. However, carbon sequestration depends on sediment accretion. At Elkhorn Slough, while the marshes have robust accretion rates (Van Dyke 2012), most un-vegetated areas lower in the tidal frame and subject to tidal scour appear to be eroding (Malzone 1999). If the mudflats in the project area are eroding, they have negative carbon sequestration rates (loss of carbon), while if they are stable (not eroding or accreting), they should have a rate of zero. Given this range of possibilities, we used a number of 20 g C m^{-2} yr^{-1} in our calculation. We are confident that this is a high estimate, producing a conservative result. If the number actually turns out to be 0 (revealed by our project monitoring), then the net carbon sequestration benefit of the project will considerably higher than we projected.

For grasslands, there are also a range of values in the literature, and we used an average value of 5 C m^{-2} yr^{-1} from a review of global grasslands (Soussana et al. 2010). Once again, this is likely an overestimate, because most values from California grassland show net <u>loss</u> of soil carbon (e.g. Hungate et al. 1997, Chou et al. 2008). We will determine actual rates in our monitoring, and if grasslands are really losing rather than gaining carbon in our project area, then the net carbon sequestration benefit of the project will be higher than projected.

Table 3 summarizes our calculations of project benefits through soil carbon sequestration, incorporating our robust numbers for salt marsh soil sequestration and our conservative estimates for grassland and mudflats. The net benefit of the project is calculated to be **129 megagrams of carbon dioxide sequestered per year for at least 100 years**.

Table 3. Estimates of soil carbon sequestration resulting from project.



	Current pre-restoration conditions				Projected post-restoration conditions					
C	D	E	F	G	H	I	J	K	L	
Reference	**Extent in project area** (acres)	**Extent in project area** (m^2) [D x 4047]	**Soil carbon sequestration** (g/yr) [E x B]	**Soil carbon sequestration** (Megagrams C/yr) [F/1,000,000]	**Extent in project area** (acres)	**Extent in project area** (m^2) [H x 4047]	**Soil carbon sequestration** (g/yr) [I x B]	**Soil carbon sequestration** (Megagrams C/yr) [J/1,000,000]	**Net Carbon stored** (Megagrams C/yr) [K-G]	**Net CO_2 sequestered** (Megagrams/yr) [L x 3.67]
Duarte et al. 2005	40	161874	3237485	3.2	5	20234	404686	0.4		
Table 2	7	28328	5693926	5.7	54	218530	43924575	43.9		
Soussana et al. 2010	19	76890	384451	0.4	7	28328	141640	0.1		
	66	**267092**	**9315863**	**9.3**	**66**	**267092**	**44470901**	**44.5**	**35.2**	**129**

In addition to the carbon sequestered annually in the sediments, the standing crop of salt marsh will sequester a significant amount of carbon. Nelson (2012) measured above ground biomass of salt marsh at Elkhorn Slough more than a dozen sites around the estuary, all within five miles of the project site. The mean was 950 g m^{-2}. We have recently also analyzed the mean carbon density of marsh plants from multiple samples from Elkhorn Slough, and found it to be 28.9%. Thus 275 g m^{-2} (950 x 0.289) of carbon are stored in salt marsh plants in the estuary, and will likewise be stored in the restored marsh within a few years, when it becomes fully vegetated. This is a very robust number, based on empirical values from more than a dozen marshes near the restoration site.

To estimate project benefits to carbon captured in plant material, we again made comparisons with the habitat types currently dominating the project area. For mudflats, we used a local measurement of carbon captured in algae on mudflats at Elkhorn Slough (Hughes 2009). This represents a high value, because measurements were taken during peak biomass (not year-round averages). For grasslands, there is a range of values in the literature. We used a relatively high value for intact California grasslands (Hungate et al. 1997). This is also likely to be an overestimate for the project area, which was farmed for many years and does not have healthy grasslands currently.

Table 4 shows calculated increases in carbon storage in plant material. **We predict that an additional 156 megagrams of carbon dioxide will be sequestered as a result of this project**. As explained above, this is very likely to be an underestimate of the true benefit of the project, since we have dealt with uncertainty in values for mudflats and grasslands with conservative estimates.

Table 4. Estimates of plant carbon sequestration resulting from the project.

			Current pre-restoration conditions				Projected post-restoration conditions					
A	B	C	D	E	F	G	H	I	J	K	L	
Habitat type	**Aboveground biomass carbon sequestration** (g/m2)	**Reference**	**Extent in project area** (acres)	**Extent in project area** (m^2) [D x 4047]	**Aboveground carbon sequestration** (g) [E x B]	**Aboveground carbon sequestration** (Megagrams C) [F/1,000,000]	**Extent in project area** (acres)	**Extent in project area** (m^2) [H x 4047]	**Aboveground carbon sequestration** (g) [I x B]	**Aboveground carbon sequestration** (Megagrams C) [J/1,000,000]	**Net Carbon stored** (Megagrams C) [K-G]	**Net CO_2 sequestered** (Megagrams) [L x 3.67]
Mudflat & channel	16.8	Hughes 2009	40	161874	2719487	2.7	5	20234	339936	0.3		
Salt marsh	274.55	Nelson 2012	7	28328	7777450	7.8	54	218530	59997473	60.0		
Grassland	150	Hungate et al. 1997	19	76890	11533540	11.5	7	28328	4249199	4.2		
TOTAL			**66**	**267092**	**22030477**	**22.0**	**66**	**267092**	**64586608**	**64.6**	**42.6**	**156**

An increase of 47 acres of salt marsh represents a 11.5% increase in salt marsh at Elkhorn Slough, which has about 511 acres of high quality marsh currently (Van Dyke and Wasson 2005). Thus, the additional carbon sequestered by this project will significantly increase the blue carbon function of the estuary, which in turn is the most significant blue carbon resource in the region.

Greenhouse gas fluxes

Marshes can emit greenhouse gases. Overall, the fluxes of CO_2, CH_4, and N_20 are considered to be negligible relative to the carbon storage potential of salt marshes (Crooks et al. 2011, Howard et al. 2014). However, these fluxes have rarely been monitored in the context of salt marsh restoration projects and blue carbon enhancements, which we will do in order to ascertain that fluxes are indeed negligible. Data rigorously demonstrating net benefits of carbon storage relative to minor levels of emissions of potent greenhouse gases such as CH_4 and N_20 will be important to build support from policymakers and stakeholders in the future.
The high salinity of the project area (average salinity 31 ppt) should result in very low methane emissions, due to the effects of sulfate (Duarte et al. 2005, Chmura et al. 2011, Keller et al. 2012). Given the extremely high range of variation in fluxes of greenhouse gases from mudflats and marshes in estuaries, we cannot make quantitative estimates. However we are confident, based on the blue carbon science literature, that emissions will be outweighed by the benefits of carbon storage.

While there will be some contribution of greenhouse gas emissions associated with construction, these will be very finite, lasting under a year, while the carbon sequestration benefits will be indefinite, lasting at least 100 years. It is estimated that it will take only 4.43 years (assuming 1 year for vegetation establishment) for the project to self-mitigate for these construction emissions.

B. ADDITIONALITY

The proposed restoration will sequester additional atmospheric carbon dioxide in addition to that being sequestered naturally by the current salt marsh acreage at the Elkhorn Slough Estuary. We do not anticipate that carbon dioxide sequestration rates would be dependent on a specific emissions scenario, although on a centennial time scale, some aspects of climate change may result in enhancements of or reductions to the carbon sink created by this restoration and enhancement project. For example, more rapid rates of sea level rise might result in more rapid carbon burial.

C. PERMANENCE

Permanence is a key criterion for prioritizing blue carbon projects (Chmura 2013). Our earlier paleo-ecological work revealed that many of our salt marshes are thousands of years old, a very solid record of permanence (Watson et al. 2011). One of the greatest threats to permanence is accelerated sea level rise, which may drown salt marshes. To prove resilient to sea level rise, marshes must accrete ample sediment so their elevation can increase at the same rate as even accelerated sea level rise. We have monitored accretion rates at eight sites in Elkhorn Slough for 10 years using feldspar marker horizons adjacent to surface elevation tables; accretion rates in the lower estuary near the project site average 4.5 mm yr^{-1} (Van Dyke 2012). Likewise, analysis of our dated cores reveal robust accretion rates for the past 50 years (Watson et al. 2011). Thus, restored Elkhorn Slough marshes should have resilience to sea level rise through accretion.

More importantly, the restored marsh will have high resistance to sea level rise. The restored marsh will have a mean elevation considerably higher than most other marshes at Elkhorn Slough, 6.2 ft (1.9 m) above Mean Lower Low Water (MLLW). Marsh persists down to an elevation of about 4.2 ft (1.3 m) above MLLW at Elkhorn Slough. Thus, even with zero accretion, the restored marsh can withstand two feet of sea level rise. Given that we also expect ample accretion, it should easily withstand three feet of sea level rise, which is the high end projection for the next 100 years, estimated by the Intergovernmental Panel on Climate Change.

This prediction of strong resistance and resilience of high elevation marshes created by this restoration project to climate change is also supported by forecast modeling performed for Elkhorn Slough salt marshes conducted using the Sea Level Affecting Marshes Model (SLAMM) (Wasson et al. 2012a). This modeling effort revealed that while low elevation marshes at Elkhorn Slough were likely to undergo drowning with three feet of sea level rise, the highest marshes in the system, of elevation similar but lower to the marsh restoration site, will persist. The SLAMM modeling also revealed that there was limited potential for marsh migration in much of the estuary due to steep hillsides adjacent to the marshes. At the project site, the slope is more gradual, and the scraping of the area adjacent to the marsh will further decrease the slope. This will facilitate future marsh migration potential.

Thus, in terms of resilience, resistance, and migration potential, the restored marsh has a very high likelihood of permanence for at least 100 years, and probably much more assuming accretion rates continue at current levels.

D. EXPECTED RESULTS – CO-BENEFITS

Coastal marsh restoration (47 acres total)

- The project is designed to add sediment to a degraded coastal wetland and restore 35 acres of salt marsh previously lost to diking and draining.
- The project will also add sediment to extant, low elevation marshes in the project area, raising them higher in the tidal frame.
- The project will create 7 acres of new salt marsh through upland sediment redistribution and grading

Salt marsh vegetation is expected to colonize the raised plain naturally, without additional plantings (Mayer 1987).

7. Protocols

Our protocols for restoration activities, monitoring, and the greenhouse gas reduction study are all described in detail in section 5.3

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