ELKHORN SLOUGH
TECHNICAL REPORT SERIES 2020: 2

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Salt marsh conservation, restoration and enhancement opportunities in and around Elkhorn Slough in the face of sea level rise

Monique Fountain, Charlie Endris, Andrea Woolfolk, Kerstin Wasson

June 2020

HOW TO CITE THIS DOCUMENT

The appropriate citation for this document is:

Fountain, M.; Endris, C.; Woolfolk, A.; Wasson, K. 2020. Salt marsh conservation, restoration and enhancement opportunities in and around Elkhorn Slough in the face of sea level rise 2020:2. Available at http://www.elkhornslough.org/research-program/technical-report-series/

AUTHOR AFFLIATION

Monique, Andrea and Kerstin are staff at the Elkhorn Slough National Estuarine Research Reserve. Monique is the director of the Tidal Wetland Program (TWP) a collaborative, interdisciplinary science based approach to wetland conservation and restoration in the Elkhorn Slough region. Andrea Woolfolk is the Stewardship Coordinator overseeing a diverse portfolio of state lands. She also has expertise in historical ecology of the region. Kerstin Wasson is the Research Coordinator overseeing a broad range of critical coastal ecosystem research projects. Charlie is with the San Jose State University Research Foundation specializing in UAV and GIS integration.

The content of this report was discussed at length at the January 2020 TWP meeting, and feedback from TWP participants on criteria and locations for sea level adaptation projects was incorporated. A draft version of the report was circulated to the entire 90 plus person membership for review.

DISCLAIMER

ABOUT THE ELKHORN SLOUGH TECHNICAL REPORT SERIES

The mission of the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve is conservation of estuarine ecosystems and watersheds, with particular emphasis on Elkhorn Slough, a small estuary in central California. Both organizations practice science-based management, and strongly support applied conservation research as a tool for improving coastal decision-making and management. The Elkhorn Slough Technical Report Series is a means for archiving and disseminating data sets, curricula, research findings or other information that would be useful to coastal managers, educators, and researchers, yet are unlikely to be published in the primary literature.

Overview
The purpose of this document is to highlight opportunities for marsh conservation, restoration, and enhancement in the Elkhorn Slough region in the face of accelerated sea level rise. This is a brief overview of selected approaches and priorities and does not include every possible adaptation strategy, nor does it describe any in depth. We identify potential priority locations for future marshes, which can be incorporated into other regional planning and sea level rise adaptation efforts.

Background
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. Fifty percent of the tidal salt marsh in Elkhorn Slough has been lost in the past 85 years, due largely to "ecological drowning" - loss in the marshes' elevation relative to tidal water levels (Van Dyke and Wasson 2005). From 2010-2012, the Elkhorn Slough National Estuarine Research Reserve (ESNERR) developed, refined, and implemented tools to help coastal managers understand and manage for salt marsh sustainability in the face of threats from anthropogenic changes to sediment inputs and water quality resulting from land-use changes, and sea level rise associated with global climate change. The project was developed in response to needs from end users engaged in the Tidal Wetland Project (TWP), a collaborative ecosystem-based management initiative launched and directed by ESNERR. Here, we build on the findings from this project (summarized in Wasson et al. 2012, and Wasson et al. 2015), providing geospatial decision support tools to identify potential priority areas for future marsh restoration projects.

Our focus is on elevation which is the single most important predictor of tidal marsh distribution. Salt marsh occurs in a narrow elevational range between about Mean High Water and the King Tide line (the level of the highest tides of the year). At Elkhorn Slough's fully tidal marshes, this range spans from about 1.3-2.3 m NAVD88 – just one meter of vertical elevation. Below that, marsh cannot survive due to excessive inundation; above that, marsh is outcompeted by upland plants (and also challenged by lack of moisture).

Current Sea level rise projections
Sea level rise prediction models vary greatly and depend largely on predicting global ice melt and ocean expansion from increased ocean temperatures. Both of these are tied to global warming and are thus inherently unpredictable. NOAA data from 1973 through 2018 indicate a sea level rise trend of 1.57 mm per year in the Monterey region (Fig 1, NOAA 2019). NOAA sea level rise projections for the next 80 years in the Monterey region range from 35 cm to 3 m (Fig 2, NOAA 2019). The California Ocean Protection Council Science Advisory Team Working Group developed a sea level rise guidance report that includes a probability matrix for a number of regional areas. The table for the Monterey predictions is included below (Table 1, Griggs 2017). Combining probability with impact is particularly helpful in understanding risk.

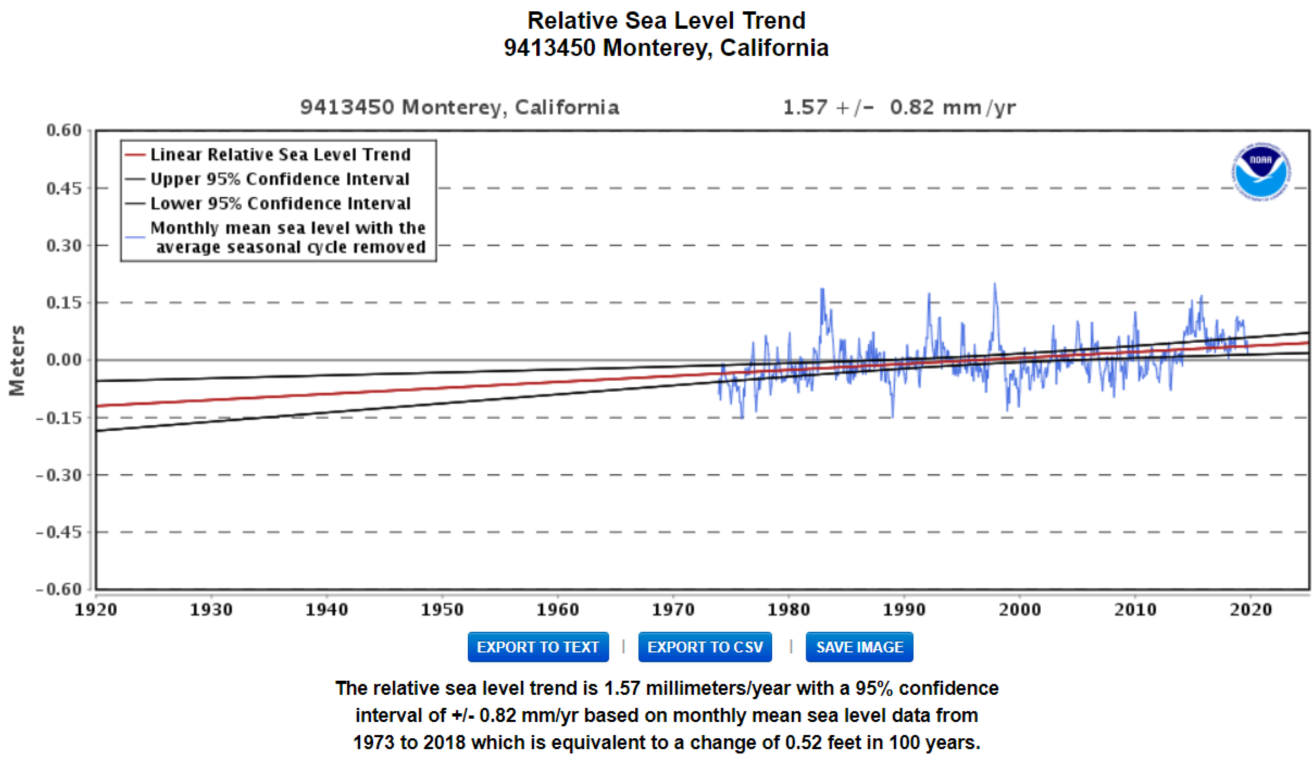

Figure 1. Observed sea level trend for the Monterey region. Past sea level data varies greatly with a trend of 1.57mm per year over the last 50 years.

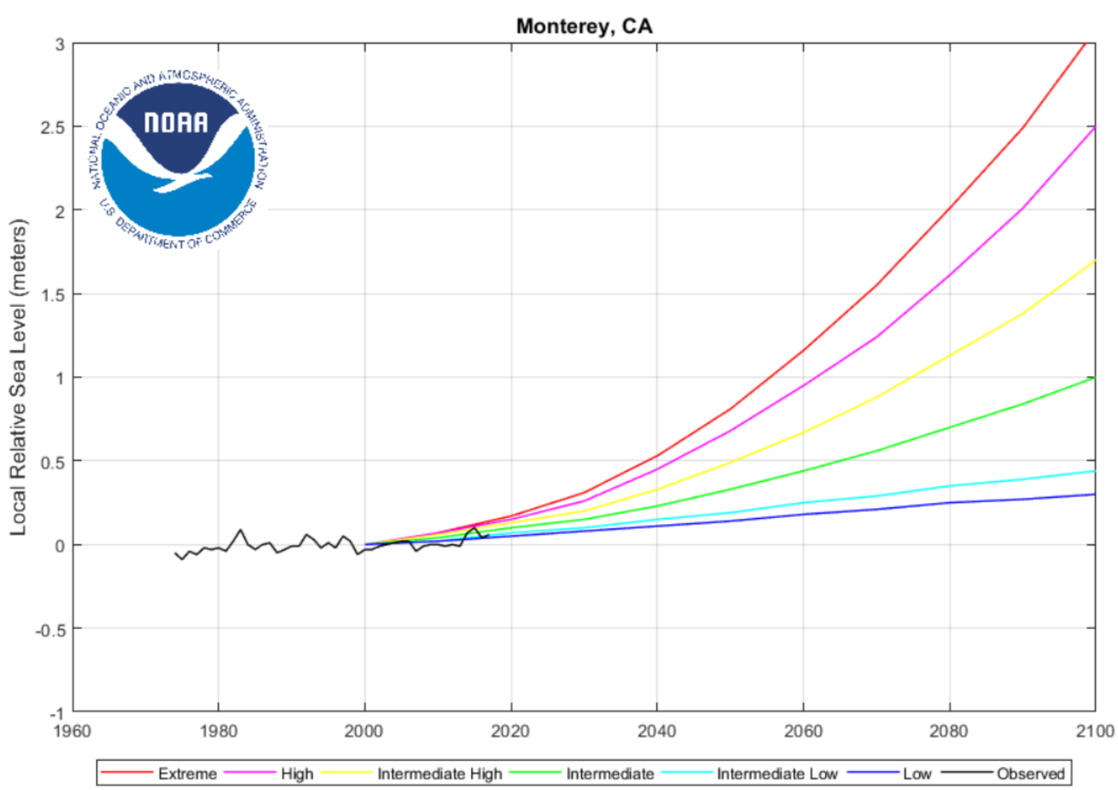

Figure 2. NOAA sea level rise for the Monterey region (observed and future projections). Projections range from 30cm to 3 meters under various sea level rise scenarios.

Table 1. Sea level rise probabilities. Copied from Ocean Protection Council report for Monterey, Table 17 (OPC 2018) Based on Griggs et al. 2017.

TABLE 1: Probability that Sea-Level Rise will meet or exceed a particular height (in feet) in Monterey

Estimated probabilities that sea-level rise will meet or exceed a particular height are based on Kopp et al. 2014. All heights are with respect to a 1991 – 2009 baseline; values refer to a 19-year average centered on the specified year. Areas shaded in grey have less than a 0.1% probability of occurrence. Values below are based on probabilistic projections; for low emissions (RCP 2.6) the starting year is 2060 as we are currently on a high emissions (RCP 8.5) trajectory through 2050; ***the H++ scenario is not included in this table.***

MONTEREY - High emissions (RCP 8.5)

	Probability that sea-level rise will meet or exceed… (excludes H++)									
	1 FT.	2 FT.	3 FT.	4 FT.	5 FT.	6 FT.	7 FT.	8 FT.	9 FT.	10 FT.
2030	0.1%									
2040	2.5%									
2050	24%	0.3%								
2060	55%	2%	0.2%	0.1%						
2070	77%	11%	1.1%	0.2%	0.1%					
2080	88%	29%	4%	0.8%	0.3%	0.1%	0.1%			
2090	93%	48%	12%	3%	0.8%	0.3%	0.2%	0.1%	0.1%	
2100	94%	63%	25%	7%	2%	1%	0.4%	0.2%	0.1%	0.1%
2150	100%	93%	73%	46%	25%	14%	7%	4%	2%	2%

50 cm 100 cm 200 cm

Habitat changes

Landscapes change over time. Salt marsh has naturally gone through multiple cycles of gain and loss at Elkhorn Slough over the past thousands of years, and paleoecological evidence suggests that historically, for varying periods of time, there has been less salt marsh than is present today (Wasson et al. 2012). However, in the last 200 years, California has lost over 90% of its coastal wetlands due in large part to human land use practices. In the future, as sea level rises, coastal salt marsh will be most at risk and this means that each acre of wetland now becomes that much more important to conserve or restore. Over the past century, diking and draining of marshes has caused the landscape to sink too low to sustain marsh under a natural tidal regime (Van Dyke & Wasson 2005). Even undiked marshes have been sinking, perhaps due to groundwater overdraft and fertilizer-fueled decomposition (Wasson et al. 2012). Because of these decreased elevations across the landscape, marshes in the Elkhorn Slough area have already undergone substantial losses. In the absence of any adaptation actions, modeling suggests about 90% of Elkhorn Slough's current marshes will be lost with one meter of sea level rise (SLR) (Wasson et al. 2012). However, the past losses are reversible: addition of sediment can raise the elevation of the landscape within the historic marsh footprint, allowing marsh vegetation to return. If the new landscape is built near the top of the elevational range of marsh, near the King Tide line, then the marsh can withstand one meter of SLR. Such an approach has been pioneered with the recent construction of Hester Marsh within Elkhorn Slough.

In addition to marsh that can be sustained within the historic footprint (Fig. 3), marsh can occupy new, somewhat higher areas in the face of SLR. Today's marsh is mostly flanked by steep slopes that do not offer extensive opportunities for marsh migration, but new areas along the Old Salinas River Channel, Tembladero Slough, and the Pajaro River may host future marshes. There are also some limited but important opportunities for marsh migration close to existing marshes, due to the presence of gentle slopes extending from current marshes' edges. These enhancement opportunities have yet to be explored.

When SLR drowns salt marsh, it can convert to intertidal mudflat, which is valuable to migratory shorebirds. Even greater SLR converts formerly intertidal areas to subtidal ones. Subtidal habitats are home to the clams, fat innkeeper worms, and crabs that form the primary food of sea otters and leopard sharks, and support eelgrass beds that serve as fish nurseries. Estuaries dominated by subtidal habitats, such as Tomales Bay, provide rich ecological functions and ecosystem services. Thus, Elkhorn Slough will continue to provide valuable ecosystem services even with a changed distribution of habitat types as is expected with SLR (Fig. 4-7).

To support the unique functions salt marsh provides, from carbon sequestration to food web support to recreational enjoyment (Woolfolk & Labadie 2012), coastal managers want to ensure that some marsh habitat is represented in different parts of the estuary for the indefinite future. **The objective of this document is to highlight opportunities for different pathways to ensure that the Elkhorn Slough area will perpetually host healthy salt marshes. By identifying potential priority locations for conservation, restoration, and enhancement, these future marshes can be included in regional planning efforts.**

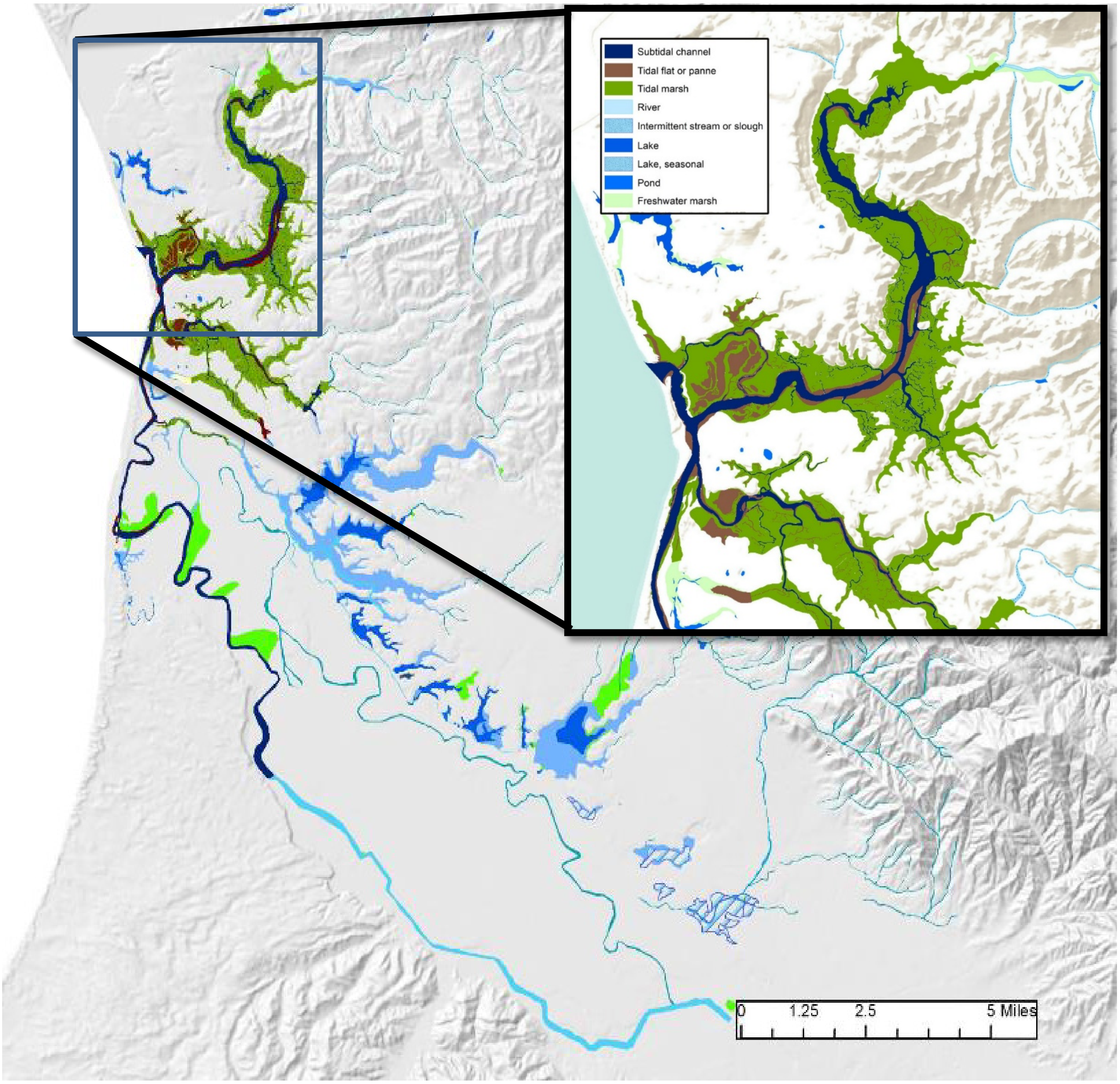

Figure 3. Historical extent of wetlands. Many of the tidal and marshes and freshwater habitats that were present in the region historically have been lost, but understanding of their past distribution helps guide future planning. Areas with historic wetlands provide potential opportunities to support wetland restoration or migration. (Historical reconstruction by Andrea Woolfolk.)

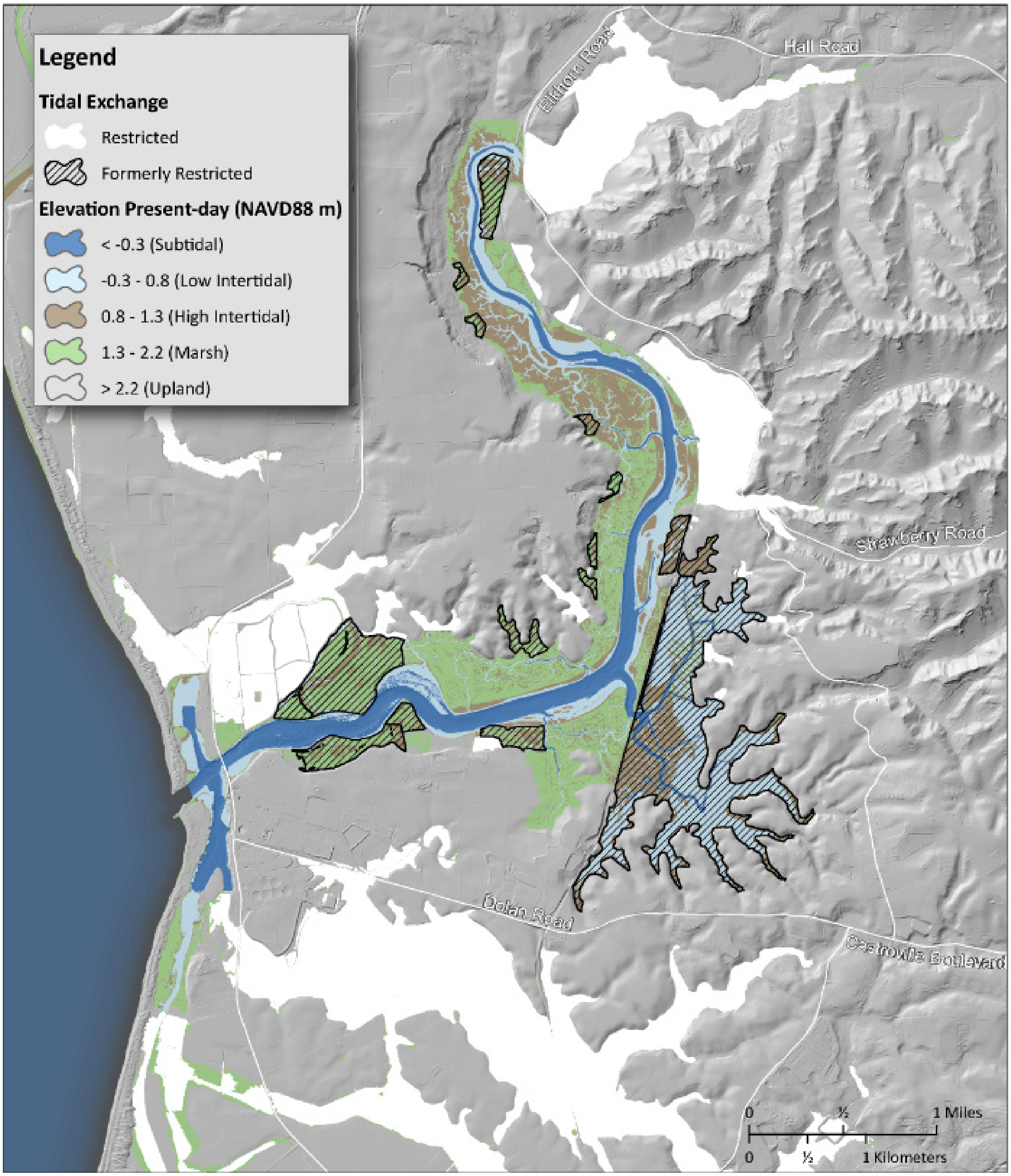

Figure 4. Current distribution of tidal wetlands in Elkhorn Slough. Current distribution of tidal wetlands in Elkhorn Slough including formerly diked and tidally restricted areas.

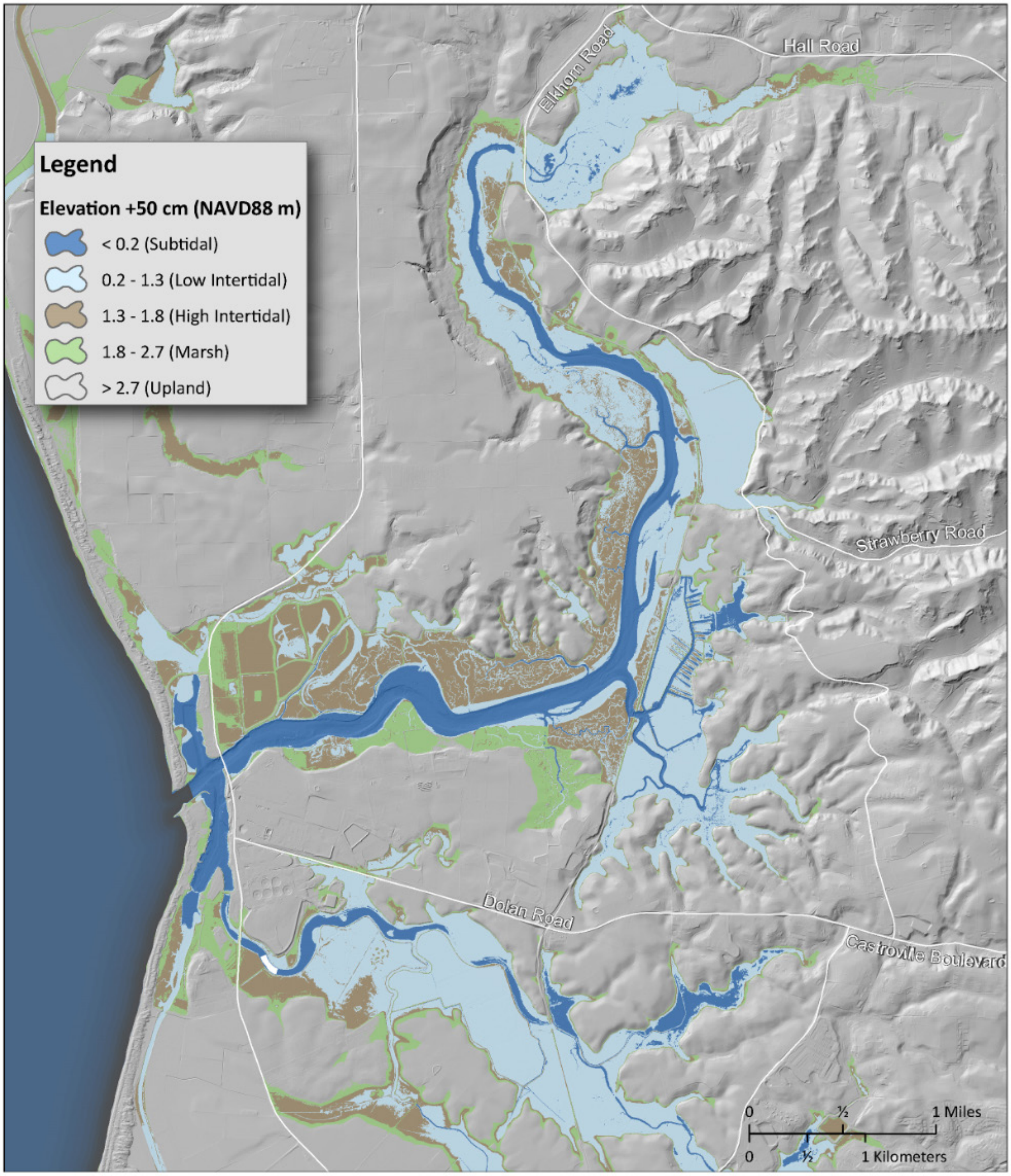

Figure 5. Extent of wetlands after 50 cm of sea level rise. Extent of tidal wetlands in the Elkhorn Slough region assuming no additional action is taken. 50 cm sea level rise overtops all muted areas.

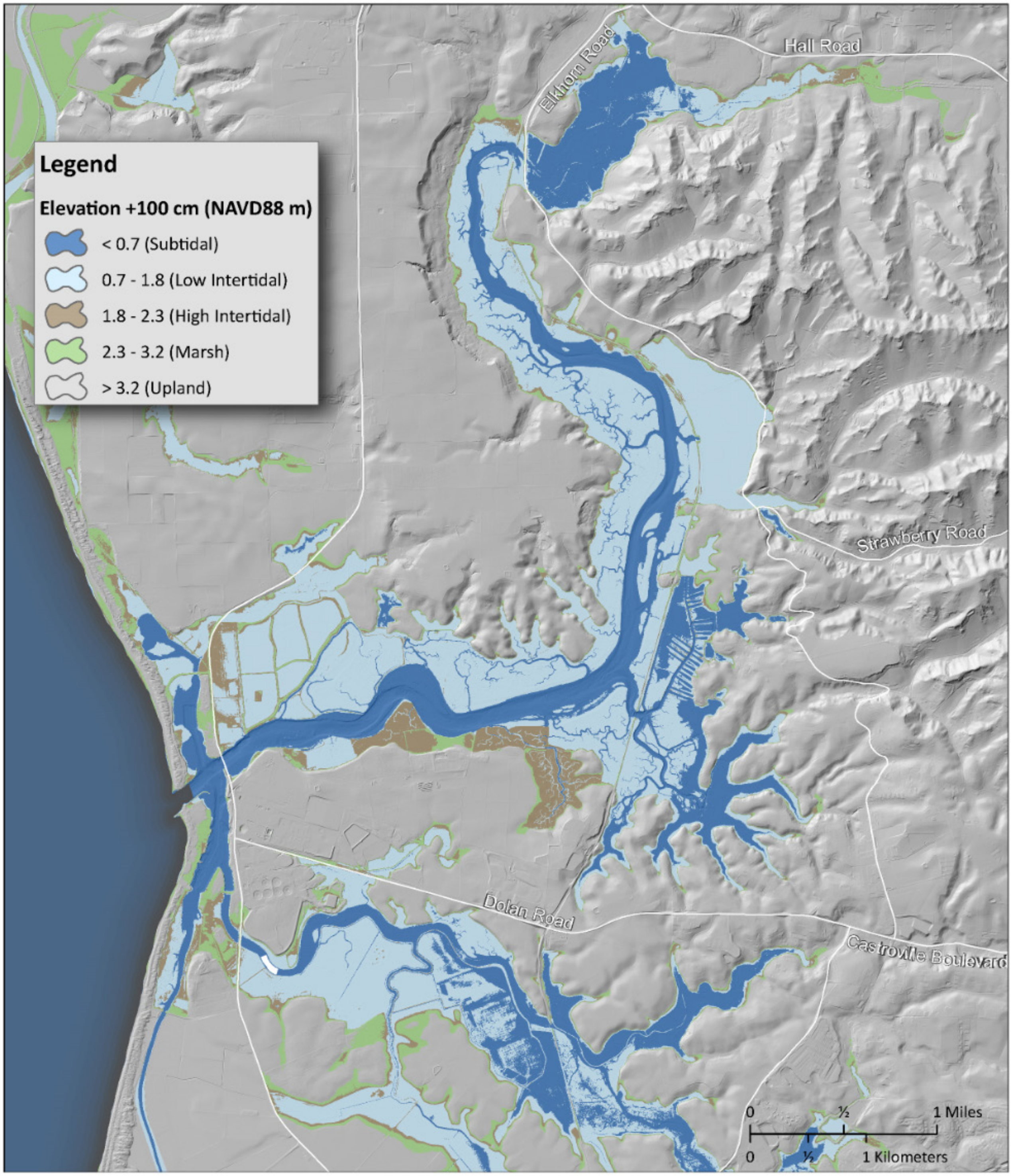

Figure 6. Extent of wetlands after 100 cm of sea level rise. Extent of tidal wetlands in the Elkhorn Slough region assuming no additional action is taken.

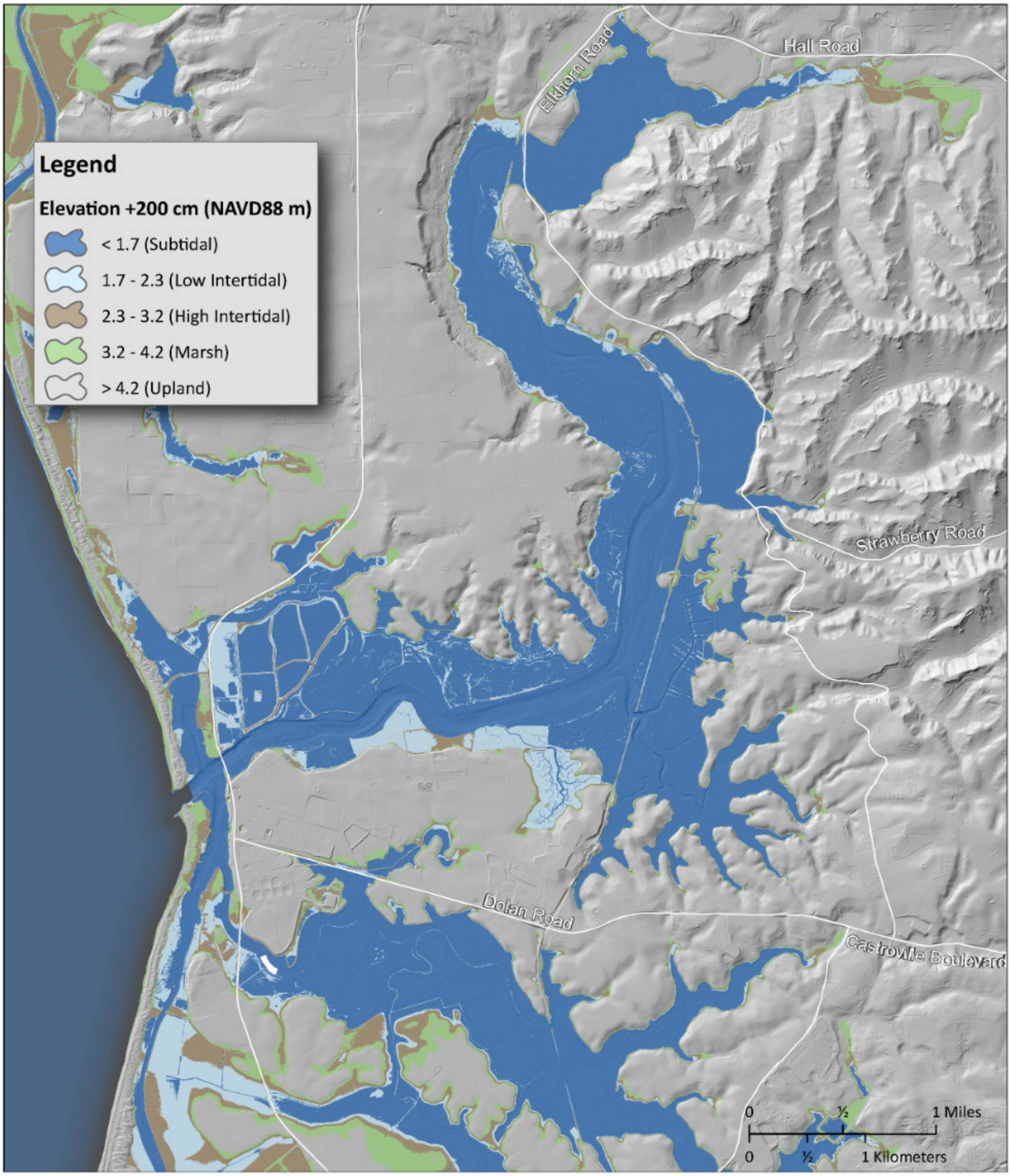

Figure 7. Extent of wetlands after 200 cm of sea level rise. Extent of tidal wetlands in the Elkhorn Slough region assuming no additional action is taken.

Management Options

Below, we introduce three different climate adaptation strategies for marshes: thick sediment addition, thin sediment addition, and facilitating migration. For each, we describe the rationale behind the approach and introduce criteria for selecting sites at which to implement it. Then, we provide a list of potential sites that appear to emerge as high priorities for implementation of each approach based on these criteria. Generally, projects would only occur in places there they fit the needs and goals of land owners, provide connectivity to existing estuarine habitats, provide public access, ensure sustainability, are consistent with regional planning efforts and contribute towards providing a broad diversity of habitat types.

- Compatibility with land owner interests: work with landowners whose lands may be vulnerable to sea level rise by purchasing buffers from willing sellers and assisting with managed retreat. Projects would only occur in places where they fit the needs and goals of landowners.
- Connectivity: focus on marshes that are linked directly to adjacent estuarine habitats will be most valuable to wildlife and for providing services to the whole ecosystem
- Public access: target marshes that can be enjoyed by the public, and/or used to educate the community about marsh processes and resilience, are desirable.
- Sustainability: locate projects in areas where marsh health is likely to be high in the future, due to sediment supply, freshwater inputs, lack of high rates of on-going deep subsidence and ideally have gently sloping land adjacent for future marsh migration.
- Regional planning: look for areas to consolidate planning efforts on a regional scale.
- Habitat heterogeneity: plan for a broad diversity of habitat types in the region including freshwater habitat that can be restored within the footprint of former freshwater wetlands.

Thick sediment addition to create high, resilient marshes in places where they subsided from diking

Background

- Extensive portions of Elkhorn Slough (Parsons Slough, North Marsh, Porter Marsh, Upper Bennett marshes) and the entirety of the surrounding, formerly connected, estuarine arms (Bennett Slough, Moro Cojo Slough, Tembladero Slough, southern Old Salinas River channel) were diked, largely to "reclaim" the wetlands for agriculture, duck hunting or rangeland.
- These areas subsided by 0.3-1.5 meters due to soil oxidation and compaction during drying.
- Sediment addition can be used to raise the elevation of these areas beyond the historic levels to elevations sustainable into the future.
- To provide resilience to SLR, restored habitat can be created near the upper limit of marsh vegetation today. Since salt marsh spans about 1 vertical meter in elevation, such a high new marsh can withstand at least 1 m of SLR (and likely more, due to increases in elevation from organic accumulation below-ground and sediment accumulation on the surface).
- Recently completed Hester Marsh provides one example of such a project that simultaneously restores historic marsh lost to diking and creates an unusually high marsh resilient for the future.
- Such projects could be undertaken in any formerly diked area in the estuary. Projects could also be undertaken in areas that are still currently diked, with artificially restricted tidal exchange. Conducting a sediment addition would be easier prior to return of full tidal exchange, so long as there is a plan to allow natural tidal exchange in the future (otherwise the raised area will not be inundated and will host weedy grassland not marsh).

Criteria
The following criteria, singly or ideally in combination, might be used to select sites in locations with willing landowners:

- Historically hosted marsh (that has now been lost due to diking)
- Adjacent to gentle slopes that will allow for future marsh migration (gentler slopes can also be created by topographic recontouring)
- Win-win opportunities for horizontal levees that can host marshes while also supporting human infrastructure (roads, railroads) intended to remain in current location, requiring wetland fill in the face of SLR
- If still diked now, confidence that natural tidal exchange will be allowed to return in the future
- Accessibility, so that truckloads of sediment can be brought in safely from elsewhere, or sediment can be obtained nearby

Locations
Potential priority locations might include the following (Fig. 8):

- ESNERR's North Marsh complex, where sediment addition and potentially a horizontal levee to Elkhorn Road could allow for increased marsh habitat and better water quality
- Some or all of the ESNERR Parsons complex; in particular, Whistlestop Lagoon and Rookery Lagoon would allow for easy temporary containment and are close to trails, offering interpretive opportunities on climate change issues
- Azevedo Ponds
- Areas of Bennett slough
- The Old Salinas River channel just south of the Sandholdt bridge
- Moss Landing Wildlife Area adjacent to Highway 1 on both east and west, where sediment addition to support marsh restoration could perhaps be linked to climate adaptation for the transportation corridor (such as horizontal levees adjacent to Highway 1)
- Degraded marsh north of Potrero Road
- The Vierra marsh that was historically diked and drained (between ESNERR's Seal Bend area and Highway 1)
- Porter Marsh, where sediment addition could be combined with restoration of tidal exchange, although returning full tidal exchange to this marsh would require raising Elkhorn Road near Hudson Landing

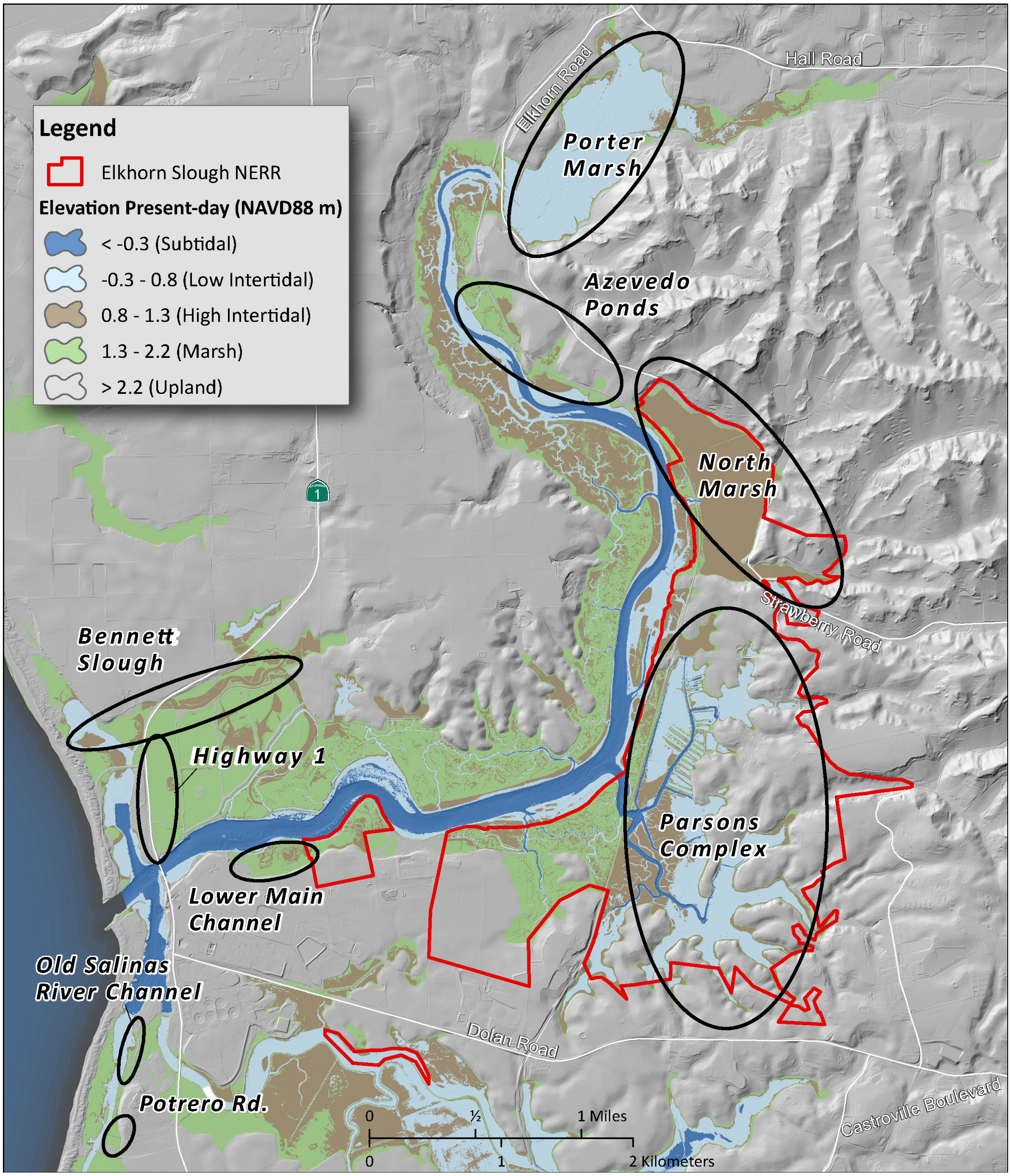

Figure 8. Potential priority locations for sediment addition to formerly diked marshes. Sediment addition can be phased in different areas. These are conceptual starting places for discussion about potential projects and would of course proceed only with willing land owners.

Thin-layer sediment addition to enhance resilience of existing marshes

Background

- While adding a thick layer of sediment to mudflats where marsh was lost due to diking and subsidence, thinner layers of sediment can be added to existing marshes to allow them to track sea level in their current footprint.
- Such an approach has been effectively employed on the Gulf Coast, using dredged sediment piped or sprayed from barges.
- The approach would need to be tested at Elkhorn to determine whether existing plants could recover, or whether there would be initial dieback followed by colonization (which might be considered acceptable).
- This technique could be employed at virtually any existing marsh in Elkhorn Slough currently; after 1 m of SLR, it might also be necessary to maintain restoration marshes such as Hester.
- Caution would need to be taken to ensure sediment does not have toxic levels of contaminants, and that the recipient marsh does not have unique wildlife or values that would be threatened by spraying sediment.
- Further discussion is needed to determine whether thin-layer sediment is a cost-effective approach that should be implemented in Elkhorn Slough; decision-makers may determine that adding thicker layers is a better approach for all sites.

Criteria

The following criteria, singly or ideally in combination, might be used to select sites in locations with willing landowners:

- Travel distance by barge from the harbor, which would be the likely source of sediment (from dredging)
- Ability to contain sediment slurries, for instance making use of natural or artificial levees for temporary containment
- Proximity to existing restoration sites
- Representation of marsh in an area where it would otherwise be entirely lost with SLR (i.e. upper Slough)

Locations

Potential priority locations might include the following (Fig. 9):

- Marshes adjacent to Hester restoration, to create larger contiguous area, such as ESNERR's Yampah Marsh
- ESNERR marshes west of railroad tracks, west of South Marsh
- Azevedo Marsh
- Bennett Slough
- Vierra marsh
- Moss Landing Wildlife Area near Highway 1

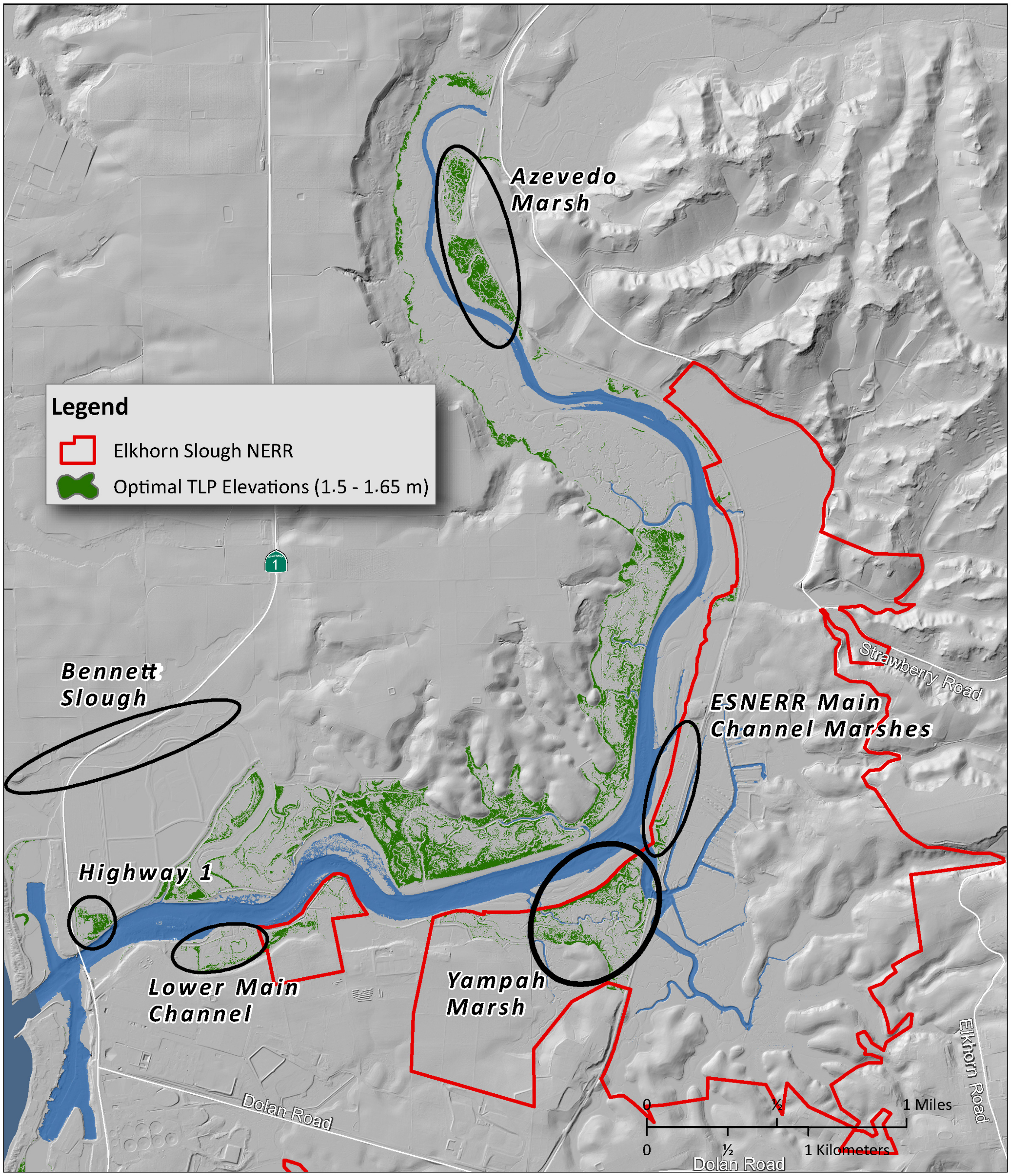

Figure 9. Potential priority areas for thin-layer sediment addition to existing marshes in never-diked areas. These are conceptual starting places for discussion about potential projects and would of course proceed only with willing land owners.

Marsh migration opportunities

Background

- In past millennia, when sea level rose, marsh simply migrated to higher areas.
- This is more complicated now, because of human land uses in the areas just above current sea level.
- Modeling has revealed which areas could support salt marsh under future SLR scenarios (Wasson et al. 2012; NOAA SLR viewer, etc.) (Fig. 6).
- Because of steep slopes surrounding many of Elkhorn Slough's current marshes, there are only limited areas for marsh migration – mostly, there would be a "bathtub ring" of marsh along hillsides.
- The most extensive areas of suitable elevation for marsh under 1 m of SLR are in current farmlands south of Moss Landing (along the Old Salinas River Channel and Tembladero Slough) and near the mouth of the Pajaro River.
- While these areas are not currently available as habitat, they should be considered in future long-range planning for the region, because farming may not be viable in these flood prone areas in the future. Some of these areas could thus be acquisition targets by local land trusts and could potentially figure into mitigation measures associated with regional infrastructure projects.

Criteria

The most important criterion, in addition to the overarching ones listed at the beginning of the "Management Options" section above, is gentle slope; extensive areas with relatively flat topography would be selected in partnership with willing landowners.

Locations

Potential priority locations might include the following (Fig. 10):

- The gently sloped uplands adjacent to the Old Salinas River Channel south of Potrero Road
- Upper Bennett – gentle sloped uplands adjacent to tidal wetlands of east Bennett Slough
- Portions of Moro Cojo including Catellus: here strategy 1, of thick-layer sediment addition to former wetland areas that have subsided could be combined with strategy 3 of marsh migration to adjacent higher areas, resulting in extensive area for new marshes
- Uplands adjacent to ESNERR's North Marsh, along Hidden Valley and Strawberry Road
- Uplands around the mouth of the Pajaro River

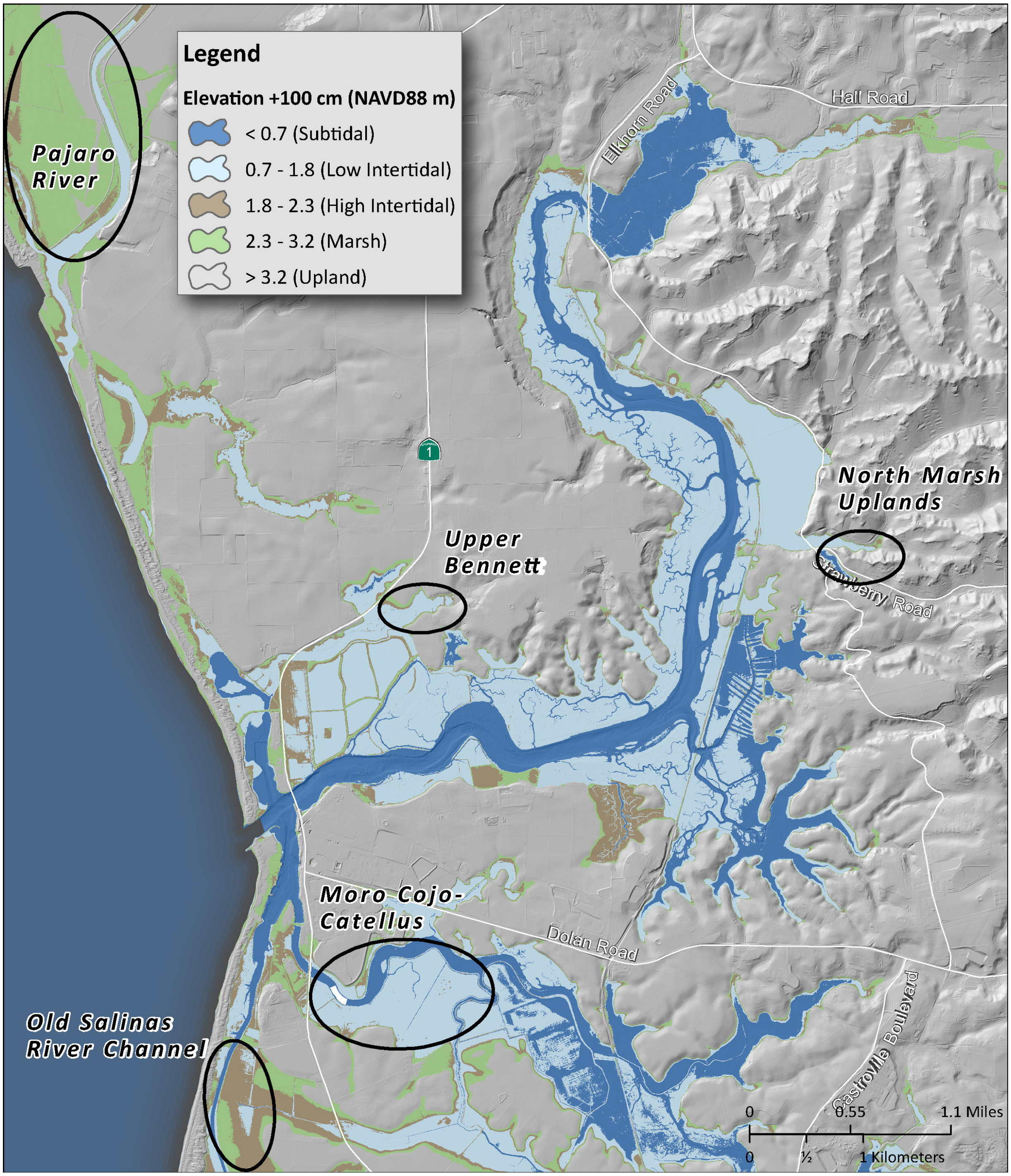

Figure 10. Potential priority areas marsh migration opportunities. These are conceptual starting places for discussion about potential projects and would of course proceed only with willing land owners.

Other factors to enhance marsh resilience

While our focus is on elevations appropriate to support marshes, achieved through sediment addition or migration to higher ground, there are other factors besides elevation that affect marsh resilience.

- Addressing subsidence to help marshes track SLR: Over the last thirteen years, most fully tidal marshes in the estuary appear to have subsided. Hypotheses for this subsidence include groundwater overdraft and nutrient-fueled decomposition of organic matter (Wasson et al. 2012). Groundwater recharge of aquifers connected to the marsh, and decrease in fertilizer inputs might thus enhance health of marshes in the Elkhorn Slough area.
- Decreasing macroalgal blooms to increase marsh resilience: Agricultural fertilizer fuels the production of algae in the estuary. Algal mats have been shown to harm salt marsh and increase bank erosion rates (Wasson et al. 2017). Decreased nutrient-loads will thus also benefit marshes by decreasing algal mats.
- Restoring freshwater inputs to enhance marsh productivity: The most stable marshes in the Elkhorn Slough area (Hudson, Azevedo, Old Salinas River Channel) are ones with substantial freshwater inputs (Woolfolk & Watson 2016). In years of heavy rain, Elkhorn Slough marshes are more productive than in years of drought. Marsh productivity generally is known to be hampered by excessively high salinities. Historically, Elkhorn Slough had many freshwater seeps that likely made its marshes more productive and allowed them to track SLR. In the future, restoring surface and moreover groundwater inputs to the estuary will likely enhance marsh resilience.

Ecosystem-based management

While this document has focused on salt marsh resilience to climate change, it is important to remember that strategic planning for Elkhorn Slough and its watershed should continue to occur in an ecosystem-based management framework, incorporating diverse stakeholders and a watershed perspective. The Elkhorn Slough Tidal Wetland Program Strategic Plan should be revisited with stakeholders at least every decade, and related to other local, regional, and state planning documents. Actions related to nutrient-loading should involve the agricultural community and the organizations that work with them. The relationship between the estuary and saltwater intrusion, a factor of great importance to local landowners, should be further examined. While salt marsh is one important focus of adaptation planning because it is so vulnerable to SLR, other habitats in the estuary and surrounding watershed should be considered too, potentially with spatially explicit habitat goals and planning.

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