Delta Wetland Futures:

Tidal Marsh Resilience to Sea Level Rise

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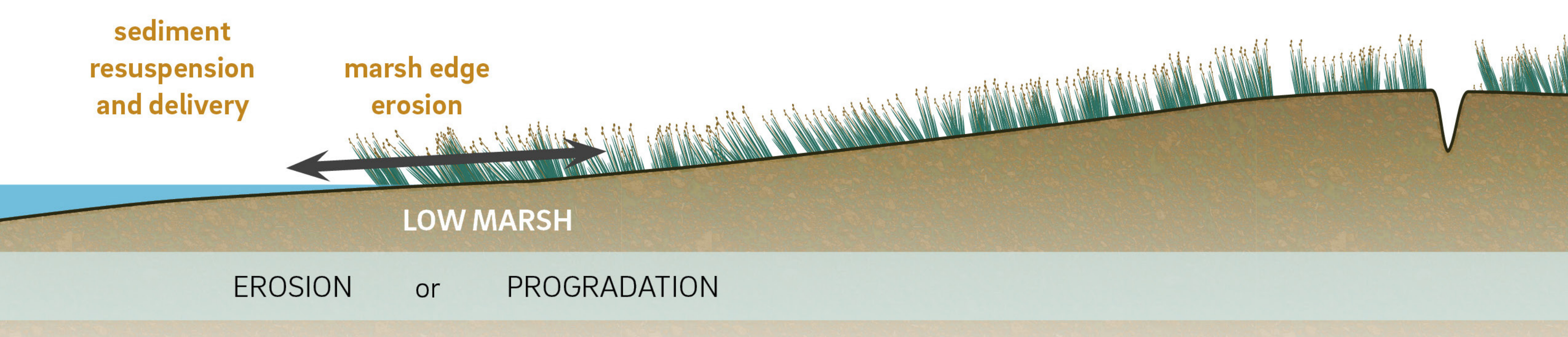
WETLAND RESILIENCE IN THE DELTA

Understanding the potential impacts of sea level rise (SLR) to tidal marshes is critical for conservation planning, restoration and management in the Sacramento-San Joaquin Delta. Tidal wetlands are naturally resilient systems, able to respond to changes in SLR rates via feedbacks between water depth, inorganic sediment accumulation and plant growth. However, excessive SLR and limited sediment supply may exceed the capacity of wetlands to respond in the future (Buffington et al. 2021, Schile et al. 2014, Swanson et al. 2015).

Tidal marshes are a critical component of the Delta ecosystem, and more than 98% of tidal marshes in the Delta have been lost, largely due to the reclamation and leveeing that occurred in the 19th and early 20th century (Whipple et al. 2012). In addition to wetland loss, landscape change in the Delta has resulted in changes to the physical drivers and processes that impart wetland resilience. An extensive network of levees disconnects lands that were previously wetlands from tidal influence, and upstream water management limits the sediment and freshwater from the watershed that reaches the Delta (SFEI-ASC 2014). Climate change may further exacerbate these changes by changing precipitation and sediment delivery patterns (Achete et al. 2017). Currently, marsh restoration is a priority in the Delta to benefit native fish, recreation, and greenhouse gas fluxes (DSC 2022). To maintain Delta tidal marshes into the future, and the benefits associated with those marshes, the physical processes that confer resilience must remain intact.



This study adds to our understanding of resilience by examining Delta-wide spatial patterns in marsh resilience. We used a conceptual framework of marsh resilience processes adapted from the Baylands Ecosystem Habitat Goals Science Update for climate change to guide our analysis (Goals Project 2015; Figure 1). This framework identifies the processes that contribute to marsh resilience, or lack of resilience, as (1) vertical accretion or drowning of the marsh surface, (2) upland migration or squeeze along the backshore of the marsh, and (3) progradation or erosion along the marsh foreshore.

VERTICAL ACCRETION VS. DROWNING

Wetlands increase vertical elevation relative to sea level via vertical accretion. Feedbacks between elevation, plant growth and sediment trapping allow marshes to accumulate organic material and trap suspended sediment at rates which maintain marsh elevations within the tidal frame. When the pace of SLR surpasses the capacity of marsh vertical accretion, the marsh will drown.

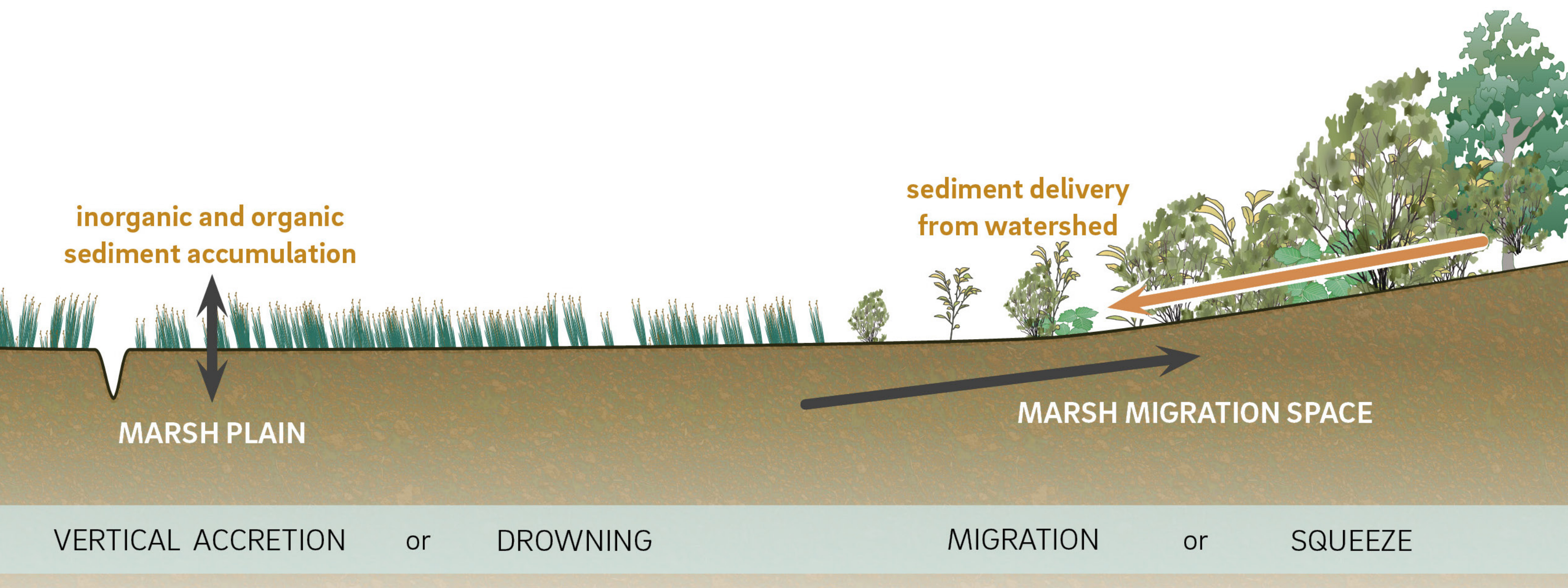
UPLAND MIGRATION VS. SQUEEZE

Marsh migration is the expansion of marshes upslope to low lying areas adjacent to currently existing marsh as sea levels rise. Where the topography does not allow for marsh migration, the area available to support marshes gets squeezed between subtidal areas of open water and steep or disconnected upland areas unsuitable for supporting tidal marshes.

EROSION VS. PROGRADATION

The foreshore of tidal marshes expand or retreat as the marsh either erodes from wind and wave energy or progrades through the growth of marsh plants and accumulation of inorganic sediment.

Figure 1. Conceptual model of tidal marsh resilience. Marsh expansion or retreat determines the location of the marsh foreshore, vertical accretion maintains elevation across the marsh plain, and marsh migration allows marshes to move upslope along the backshore (adapted from PWA).



METHODS

We analyzed wetland resilience by focusing on two key biophysical processes: marsh vertical accretion and marsh migration. We analyzed vertical accretion using the Coastal Wetland Equilibrium Model (CWEM) (Morris et al. 2002) that estimates vertical marsh growth based on the relationship between elevation and plant production and uses depth profiles of percent organic matter and bulk density to initialize sediment cohorts. CWEM modeling results were used to create maps of marsh drowning or survival based on patterns in model parameters, such as elevation, across the landscape. We mapped the potential for marsh migration based on topography. We were unable to quantify erosion and progradation in the Delta due to a lack of Delta-wide spatial data, but consider this an important aspect of wetland resilience that warrants further study.

Both the vertical accretion and migration space analyses used SLR scenarios taken from the Ocean Protection Council guidance for the state (OPC 2018). These scenarios include the 50% and 0.5% probabilistic projections (Table 1). For the vertical accretion analysis, variability in suspended sediment concentration was analyzed by including CWEM permutations that looked at 3 different levels of suspended sediment concentration that fall within expected values for the Delta (10 mg/l, 20 mg/l, and 50 mg/l; Schoellhamer et al. 2012) (Table 1).

Table 1. Scenarios were created based on potential SLR projections and suspended sediment concentrations to understand future tidal marsh vertical accretion and migration patterns in the Delta.

SCENARIO	VALUES	SOURCE NOTES
Moderate SLR	*0.9 ft by 2050, 2.5 ft by 2100*	*Ocean Protection Council guidance for the state (OPC 2018) identifies a 50% likelihood that SLR rates will meet or exceed these numbers.*
High SLR	*1.9 ft by 2050, 6.9 ft by 2100*	*Ocean Protection Council guidance for the state (OPC 2018) identifies a 0.5% likelihood that SLR rates will meet or exceed these numbers.*
Low sediment	*10 mg/L*	*This is the low end of the range of current sediment conditions in the Delta during the dry season (Schoellhamer et al. 2012).*
Medium sediment	*20 mg/L*	*This is a moderate value for current sediment conditions in the Delta (Schoellhamer et al. 2012; Achete et al 2017)*
High sediment	*50 mg/L*	*This is the high end of the range of current sediment conditions in the Delta during the dry season (Schoellhamer et al. 2012).*

VERTICAL ACCRETION

We used CWEM and GIS analysis to map vertical accretion results in the current intertidal elevation zone, which includes both existing tidal marshes and areas that are not currently tidal marsh but are at an elevation appropriate for restoration (Figure 2).

MIGRATION SPACE

The migration space analysis for this report used GIS to identify areas within the Delta that were above the current intertidal elevation zone and were expected to convert to intertidal elevations as sea levels rise.

UNKNOWNS & UNCERTAINTIES

There are many unknowns and uncertainties associated with resilience modeling and mapping, particularly when applying results at a site-specific scale. Key limitations of this study include uncertainty associated with the elevation data layer (Digital Elevation Model (DEM) without vegetation correction) and not accounting for spatial patterns in sediment concentrations or plant productivity. Current land use and feasibility of restoration was not considered.

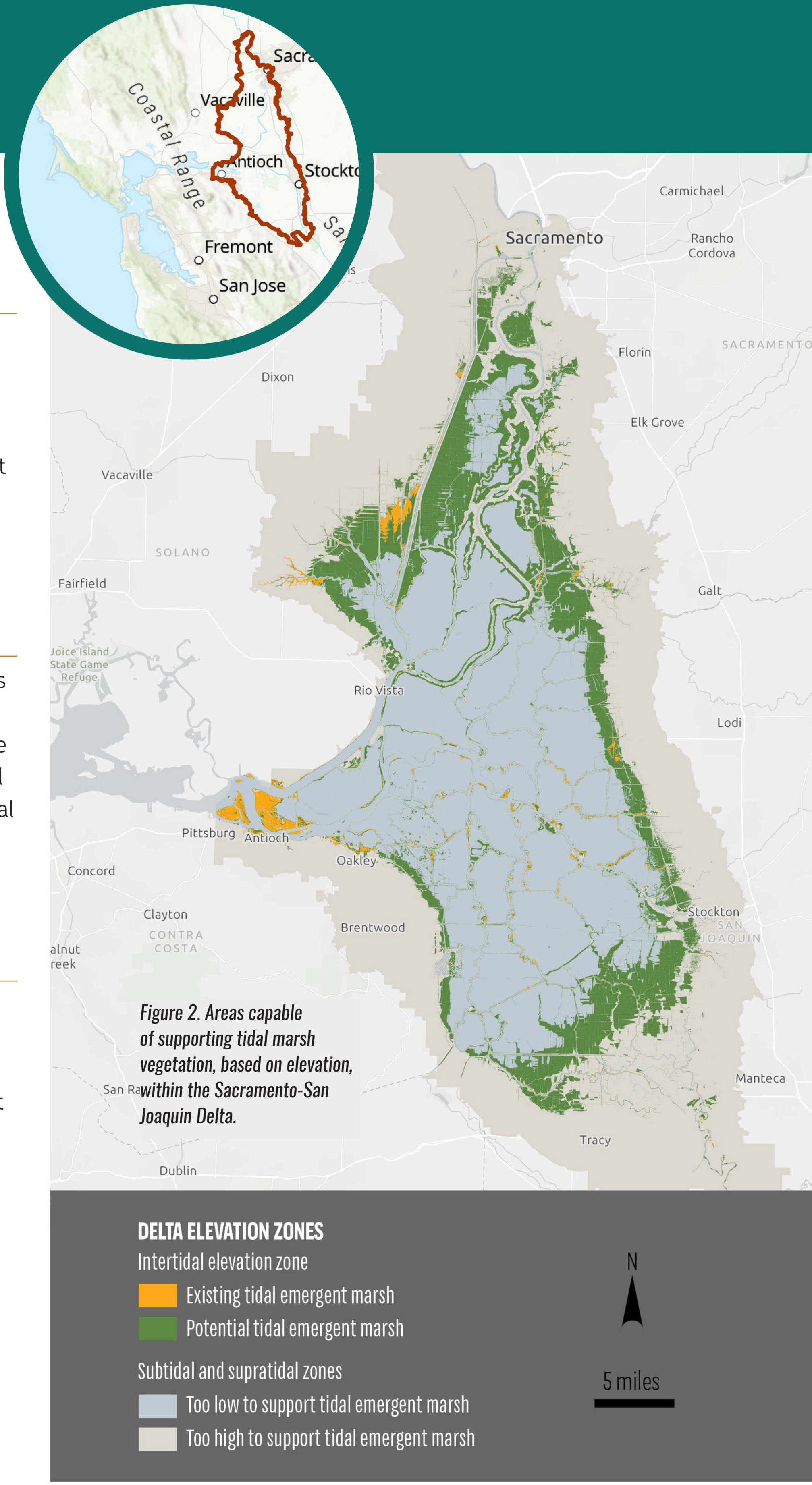


Figure 2. Areas capable of supporting tidal marsh vegetation, based on elevation, within the Sacramento-San Joaquin Delta.

VERTICAL ACCRETION RESULTS: SLR RATES MATTER

Our vertical accretion analysis found that under moderate SLR conditions much of the tidal marsh in the Delta is likely to persist through 2100. Under high SLR conditions, however, most tidal marsh is likely to drown by the end of the century. SLR rates are expected to increase after 2050 (OPC 2018), leading to higher rates of wetland loss by the end of the century (Figure 3). The slower rate of SLR and wetland loss before mid-century may obscure the risk of wetland loss under high SLR scenarios in the near term. Under a moderate rate of SLR (2.5 ft by 2100), with medium suspended sediment concentrations (20 mg/L), 85% of modeled marsh in the Delta would survive until 2050, and 81% would survive until 2100. Under a high rate of SLR (6.9 ft by 2100), 71% of modeled marsh would survive until 2050 but only 0.2% would survive until 2100.

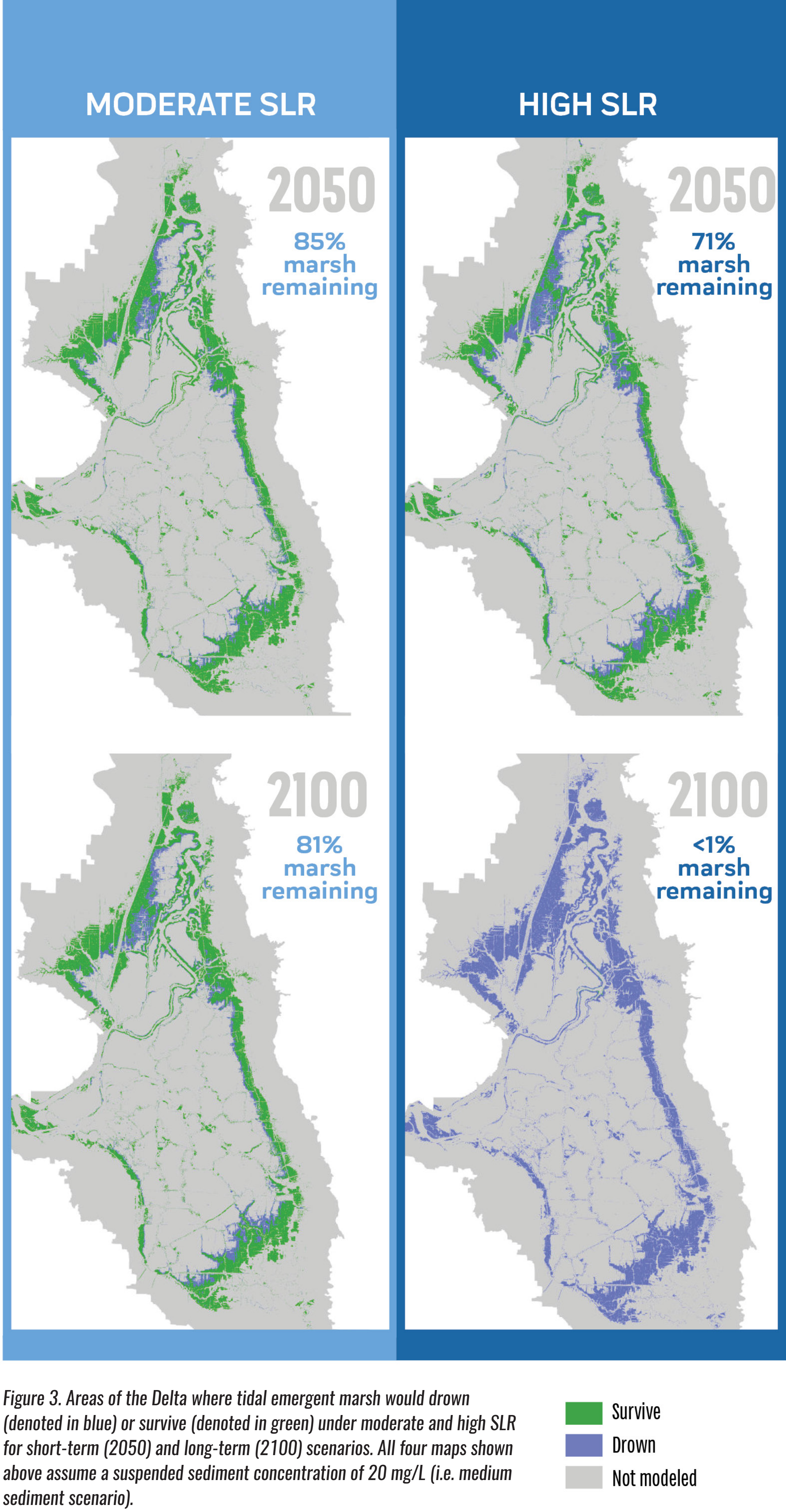
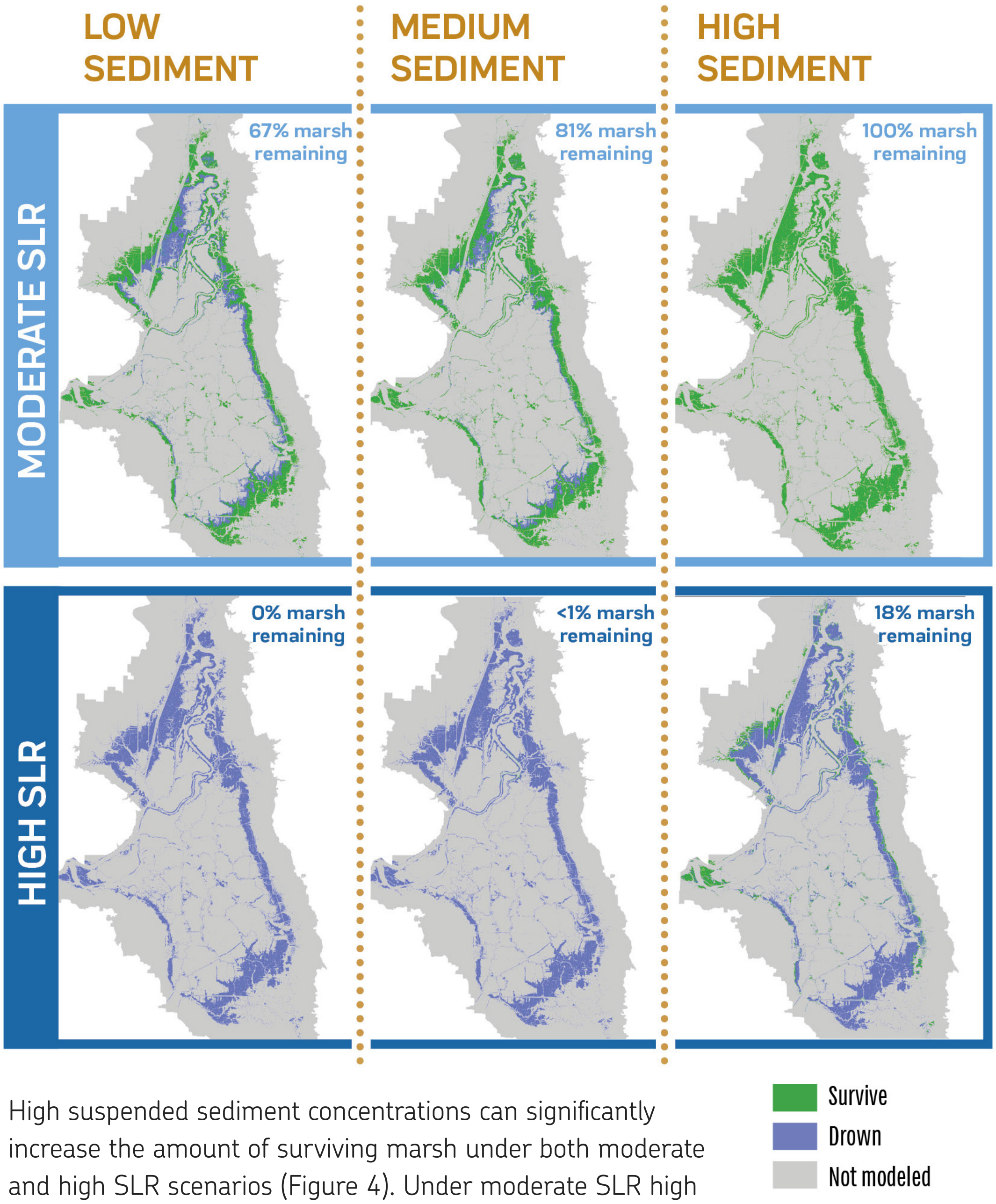


Figure 3. Areas of the Delta where tidal emergent marsh would drown (denoted in blue) or survive (denoted in green) under moderate and high SLR for short-term (2050) and long-term (2100) scenarios. All four maps shown above assume a suspended sediment concentration of 20 mg/L (i.e. medium sediment scenario).

Photo by Kate Roberts, SFEI

SEDIMENT MATTERS: YEAR 2100

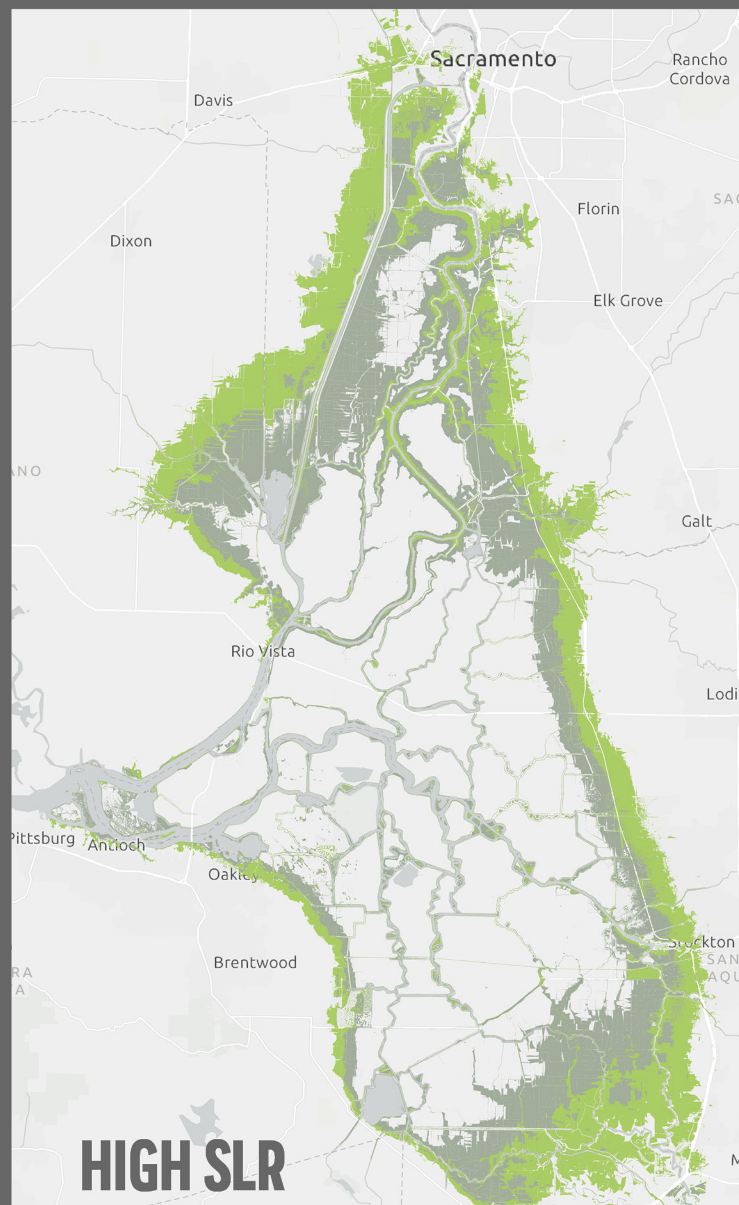


High suspended sediment concentrations can significantly increase the amount of surviving marsh under both moderate and high SLR scenarios (Figure 4). Under moderate SLR high suspended sediment concentrations, 100% of modeled marsh in the Delta survives until 2100, while under moderate SLR with low suspended sediment concentrations only 67% of modeled marsh survived. Under high SLR with high suspended sediment concentrations, 18% of the modeled marsh survived until 2100, while under low suspended sediment conditions none of the modeled marsh survived.

Figure 4. Areas of the Delta where tidal emergent marsh would drown or survive under moderate and high SLR for low, medium, and high sediment scenarios by end of century (2100).

POTENTIAL MARSH MIGRATION SPACE IS EXTENSIVE

The shallowly sloping topography along much of the Delta periphery allows for broad areas of upland to potentially transition to tidal marsh with SLR. However, opportunities for future marsh establishment are limited by competing land use priorities and hydrological barriers such as levees. Our mapping identified 48,100 acres of migration space under a moderate SLR



ELEVATION FOR MIGRATION BY 2100

- 2.5 ft migration space
- Intertidal elevation zone

ELEVATION FOR MIGRATION BY 2100

- 6.9 ft migration space
- Intertidal elevation zone

scenario (2.5 ft by 2100) and 129,600 hectares under high SLR (6.9 ft by 2100; Figure 5 and Table 2).

Land use in the migration space will be a major determinant in whether these areas will be able to support tidal marsh in the future. Lands in these low lying areas will be important for many competing land uses in the Delta. The majority of the migration space is currently agriculture or urban land (63.5% and 12.7% respectively under moderate SLR; 62.2% and 15.2% under high SLR). This study did not assess barriers to marsh migration such as levees, or connections between migration space and the current location of tidal marsh, which will be key considerations for marsh migration in the Delta.

Photo by Amy Richey, SFEI

Table 2. Approximate area (acres) of current habitat types within the marsh migration space zone under moderate (2.5 ft) and high (6.9 ft) SLR scenarios.

HABITAT TYPE	MODERATE SLR SCENARIO	HIGH SLR SCENARIO
Agriculture/ruderal	*31,400*	*80,550*
Alkali seasonal wetland complex	*100*	*310*
Emergent wetland	*1960*	*4,110*
Grassland	*80*	*340*
Oak woodland/savanna	*<10*	*1,110*
Open water	*1,280*	*2,530*
Urban/barren	*6,100*	*19,640*
Valley foothill riparian	*1,220*	*3,440*
Vernal pool complex	*1,430*	*4,740*
Wet meadow/seasonal wetland	*2,630*	*9,900*
Willow riparian scrub/shrub	*1,610*	*2,640*
Willow thicket	*270*	*270*
TOTAL	***48,100***	***129,600***

Figure 5 (facing page). Maps showing areas of tidal marsh migration space, based on elevation. Migration space under moderate SLR (2.5 ft) is shown in green on the left, and under high SLR (6.9 ft) on the right.

MARSH RESILIENCE CONCEPTUAL MAP

KEY FINDINGS

- High sediment inputs from the Sacramento River (Schoellhamer et al. 2012) likely increase the resilience of marshes in the North Delta.
- Areas that can support tidal marshes resilient to moderate SLR occur mostly along the periphery of the Delta.
- Most existing marshes are resilient to moderate SLR by 2100, including small remnant marshes in the Central Delta.
- Areas that can support tidal marshes resilient to high SLR occur mostly in the Northwest and West Delta.
- Large open areas where wind waves can develop and high boat traffic likely increase the potential for erosion, and decrease resilience, in the Central Delta (not modeled).
- Migration space is limited by urban development, especially near Sacramento and Stockton.
- The low lying areas adjacent to the current intertidal elevation zone offer many opportunities to support migration space, particularly with high SLR (Figure 6).

Figure 6 (facing page). Conceptual map of spatial patterns in tidal marsh resilience in the Delta. This map is based on modeling and mapping results and identification of key drivers of resilience.

PROCESSES

- Freshwater & sediment flow
- Potential high erosion zone

EXISTING CONDITIONS

- Road
- Creek
- City boundary
- Open water
- Subtidal elevation
- Existing tidal marsh
- Dam

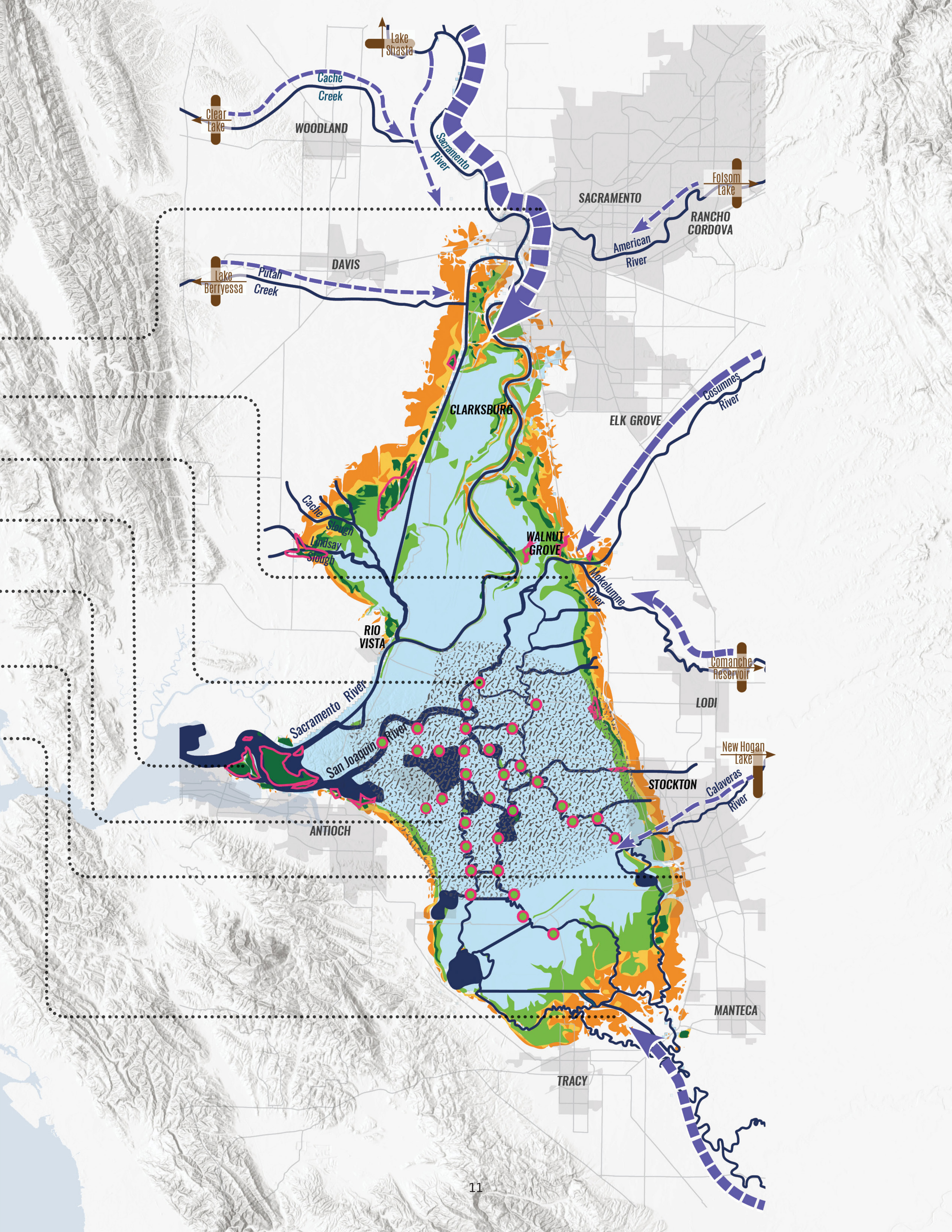
HABITAT TYPES

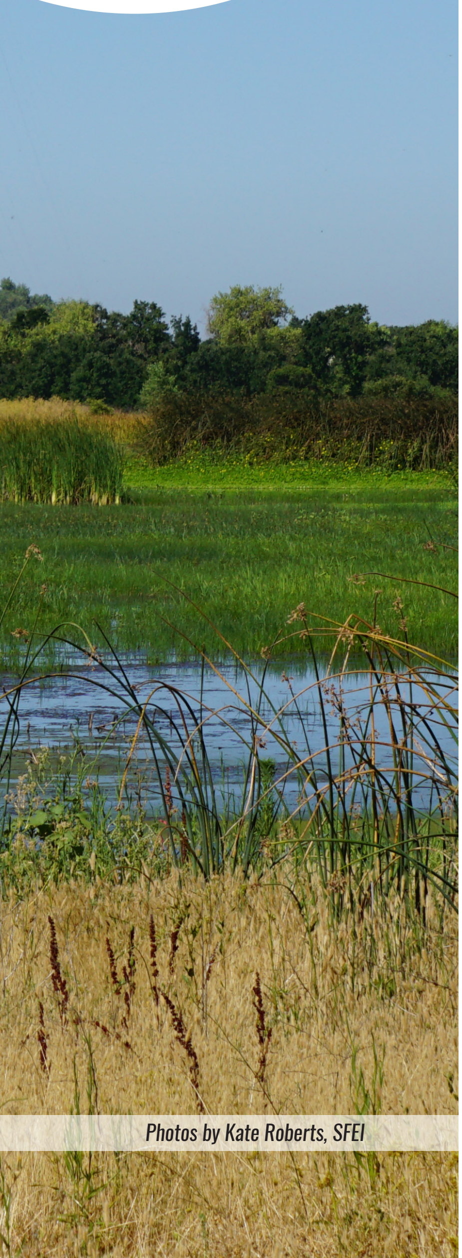
MARSH MIGRATION SPACE (MMS)

- MMS under high SLR (6.9′ by 2100)
- MMS under moderate SLR (2.5′ by 2100)

TIDAL MARSH (TM)

- TM resilient to high SLR (6.9′ by 2100)
- TM resilient to moderate SLR (2.5′ by 2100)
- Remnant marsh islands (approx. location)


Lake Shasta
Cache Creek
Clear Lake
WOODLAND
Sacramento River
SACRAMENTO
Folsom Lake
RANCHO CORDOVA
American River
DAVIS
Lake Berryessa
Putah Creek
CLARKSBURG
ELK GROVE
Cosumnes River
Cache Slough
Lindsay Slough
WALNUT GROVE
Mokelumne River
RIO VISTA
Comanche Reservoir
LODI
Sacramento River
San Joaquin River
New Hogan Lake
STOCKTON
Calaveras River
ANTIOCH
MANTECA
TRACY



Photos by Kate Roberts, SFEI

RECOMMENDATIONS AND FUTURE DIRECTIONS

Results from this study indicate that restoration efforts should pursue a balanced portfolio of maintaining current marsh (for high SLR), restoring new marsh (to allow for extensive future marsh under moderate SLR), and planning for marsh establishment and migration into new areas (migration space) to survive high SLR conditions. The areas where these priorities can be pursued are largely around the Delta periphery and also include some remnant and restored marshes in the interior. The prominence of elevation as a driving factor of determining marsh resilience means that there is and will be competition between agriculture and wetlands for the same real estate.

Creative options to promote marsh resilience and build elevation include thin layer sediment placement and peat farming. More modeling and planning to envision the future Delta and how to balance different ecosystem services and ecological functions across the landscape will be needed to create the most beneficial outcomes.

While this study showed broad patterns where existing and future tidal marshes are most resilient, future analysis could build on this work by addressing the key knowledge and data gaps identified in this study. This includes developing a vegetation-corrected DEM for the entire Delta to allow for more precision in elevation estimates, a better understanding of spatial patterns and relative risk from erosion, and a better understanding of sediment dynamics affecting local marsh resilience. Despite the remaining uncertainties, the increasing pace of SLR and the scale of planning and restoration needed necessitates moving forward despite uncertainties. Interventions such as sediment placement (Parker and Boyer 2019) and managing tule growth to maximize peat formation (Miller et al. 2008) may have the potential to increase vertical accretion rates and resilience beyond what the modeling in this study shows.

The question of where wetlands are most likely to persist, and where the physical processes that support resilience can be maintained, are critical for supporting marsh wildlife and marsh associated ecosystem services. However, maintaining resilient marsh wildlife populations and integrating wetlands into the socioecological resilience of the region will require additional considerations of spatial patterns.

RESOURCES AND RELATED EFFORTS

Download the Landscape Scenario Planning Tool (LSPT): The maps created in this effort are available for conservation planners to use in the LSPT. The LSPT is a set of resources to assist users with developing, analyzing, and evaluating different land use scenarios in California's Suisun-Delta region. The tool is designed to inform ongoing and future restoration planning efforts by assessing how proposed projects will affect a suite of landscape metrics relating to desired ecosystem functions and services. Maps from this study are incorporated into the newly added wetland resilience module.

Access the full report: More details on the methods and findings of this study can be found in the published journal article (manuscript submitted for publication).

- Robinson A, Harris K, Morris J, McKnight K, Vaughn L, Safran S, Panlasigui S, Grenier L, Ball D. submitted. Spatial patterns in wetland resilience in the Sacramento-San Joaquin Delta.

Read the other reports from the Blue Carbon and Wetland Resilience Project: This study is part of a larger project that looked at carbon sequestration and wetland resilience in the Delta. The following resources provide more information on the other studies in this project.

Published journal articles:

- Vaughn L, Deverel S, Panlasigui S, Drexler J, Olds M, Dia J, Harris K, Morris J, Grenier L, Robinson A, Ball D. submitted. Marshes and farmed wetlands can build resilience in the Sacramento-San Joaquin Delta: quantification of potential greenhouse gas and subsidence mitigation benefits.

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