Petaluma River Baylands Strategy: Appendices

Appendix A: Guiding Principles

1. Conservation and restoration in the Petaluma River Baylands is dependent upon the willingness of public and private property owners to participate and is constrained by transportation infrastructure running through adjacent to the baylands. Therefore, the Petaluma River Baylands Strategy (Strategy) must provide a vision with multiple scenarios as opposed to a specific action plan.

2. The Strategy recognizes that the Petaluma River Baylands have been inhabited and valued by Native American peoples for thousands of years and all actions that result from this Strategy must be done in coordination with local tribes.

3. The Strategy will be informed by processes and inputs not only inside of the study area, but also those outside of it – west in the Rush Creek and San Antonio Creek watersheds, north in the Petaluma River watershed, and south in San Pablo Bay.

4. The Strategy will consider a planning horizon of 100 years and it is understood that the conditions within the study area will change over time. Within this period, environmental conditions such as relative sea-level rise, sediment supply, subsidence, etc. will be based on the latest scientific information and state projections, where applicable.

5. Assumptions about persistence of marshes, likelihood of successful marsh restoration, vulnerability of diked baylands to overtopping and flooding, and others are based on models powered by the best available data. Models are best guesses based on the available data and are not predictions of the future.

6. The Strategy will seek to integrate other stakeholders' activities and plans within the baylands and watershed as feasible, and incorporate natural geomorphic processes.

7. The Strategy recognizes and articulates the urgency of implementing adaptation and resilience measures as soon as possible to increase the success of marsh restoration and reduce risk to infrastructure in light of sea-level rise and identify intermediate implementation steps.

6. Stakeholder input is important to the success of the Strategy and outreach to stakeholders will be undertaken at varying stages of the Plan to gather information, develop alternatives, and communicate findings, as appropriate.

7. The Plan will be guided by the findings and applicable general recommendations, made in the Baylands Ecosystem Habitat Goals Science Update (BEHGU, 2015), including the specific recommended actions for BEHGU's segment F (Petaluma River Area.

8. The Plan recognizes that public access is an important consideration as projects are developed. Because this Strategy is not a plan, specific recommendations for public access will not be given.

Appendix B: Outreach

This plan relies on conservation of lands already in public ownership in addition to partnering with private landowners for conservation and restoration actions on privately owned lands. For our purposes the term “stakeholder” represents entities with an interest or concern relating to our efforts with this Strategy, including private land ownership.

Methods and Timeline

The project team’s outreach efforts began in November 2019 by determining parcels of interest for this project's goals and objectives. The project team determined that one on one meetings with landowners of bayland and adjacent upland parcels in the study area would be vitally important in disseminating information about our efforts and having meaningful conversations to hear perspectives from the people with innate connections to the land, many with generational knowledge from family lineages residing and working the land for decades. The first landowner meeting was held in February of 2020.

The project team then met with several public landowning stakeholders in the area including the City of Petaluma, managers of California Department of Fish and Wildlife lands, and representatives from the Sonoma Marin Area Rail Transit, in addition to Laurel Collins of Watershed Sciences and Barbara Salzman of Marin Audubon – local experts with many years of working knowledge about the landscape.

On March 11, 2020 the World Health Organization declared COVID-19 a pandemic and following on March 18, 2020 the virus was determined a public health emergency by the Sonoma County Health Officer by issuing a Health Order for Sonoma County mandating that all members of the public (except for essential workers) shelter-in-place within the safety of their homes. Unfortunately, this situation occurred at a crucial time for the outreach work that was occurring on the project. The project team strictly followed the Health Orders for the safety of colleagues and stakeholders. The pandemic drastically changed the way the project team pursued outreach efforts from late March 2020 onward. The project team requested virtual meetings and phone calls with key stakeholders. We were able to connect with multiple public and private landowners and land managers via phone and video calls rather than in-person interviews.

As continued one on one communication became difficult in a virtual world, we decided that a new approach to reaching our target audience was necessary. To reach additional stakeholders, tribes, and a wider-reaching audience, the project team then held several outreach meetings. The goals of the meetings were to discuss our planning efforts and ultimate vision with the strategy development, advise participants of the actions that may result from these efforts, obtain input, and share projections for the study area in the absence of planning and/or restoration efforts taking place.

Federated Indians of Graton Rancheria Meeting

Project team members met with representatives from the Federated Indians of Graton Rancheria (FIGR) to discuss the Petaluma River Baylands Strategy and how to proceed in a culturally sensitive manner. FIGR recommended working with the Far Western Anthropological Research Group, Inc. to conduct a geoarchaeological survey of the study area. This survey (not field based) was completed in spring 2023. Far Western provided the cultural resources text in Sections 1.4, 2.11, and 8.3. The Cultural Resources Report derived from the geoarchaeological assessment is confidential and is not included with this document. Sonoma Land Trust paid for the survey using private funds and will use the document to guide future conservation planning and implementation in the study area.

Private Meeting

The goal with this private meeting was to share information about our planning efforts and to provide landowners and lessees working the land an opportunity to contribute candidly to the process. All ideas and concerns were to be received openly and considered while developing the Strategy.

We presented this meeting as an informal discussion related to our conservation planning efforts in the Petaluma River Baylands that included a brief overview of our work followed by an open invitation for participants to express questions, ideas, concerns, and interest for involvement. We conveyed to attendees that there are no easy answers, we are committed to taking a broader view, and that together we can create strategies that incorporate the perspective and long-term goals of tribal partners, farmers and ranchers, land managers, multi-generational landowners, conservationists, preservationists, in combination with the needs of fish and wildlife into one comprehensive document.

We explained the actions that spurred this work, why it is important, how this study will be used once complete, and how landowners can voluntarily be involved. This was an invitation-only meeting reserved for landowners of larger properties in the study area with no regulatory agency representatives present at the meeting. We aimed to provide a confidential and welcoming space for expressing sensitive viewpoints on our project efforts and property specific considerations with this work.

Forty-four private landowners were directly invited, 20 responded to the invitation, and 15 attended the meeting. After the meeting, follow up conversations were held with several property owners to gain greater insights and clarity. Of the landowners and managers we spoke with, we had representation from various agricultural land uses including dairy, rangeland, equine facilities, viticulture, and crop production. In addition, private property owners with commercial business operations on their riverside properties attended and contributed to the conversation.

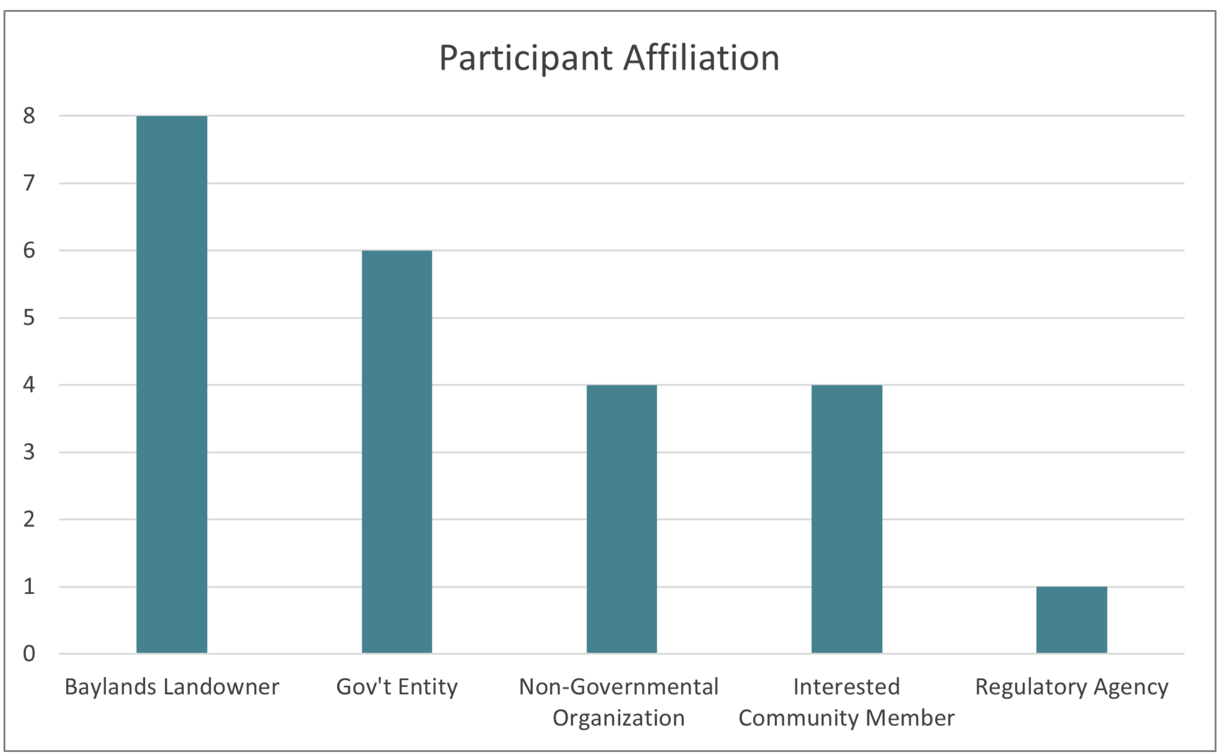
Public Meeting

Much like our first meeting, we had a goal of providing a platform to share information about our planning process early in the development phase to openly receive information, hear concerns, and answer questions from tribal partners, landowners in the study area that were not previously contacted, regulatory agency and local organization personnel, watershed stewards, and the community at large.

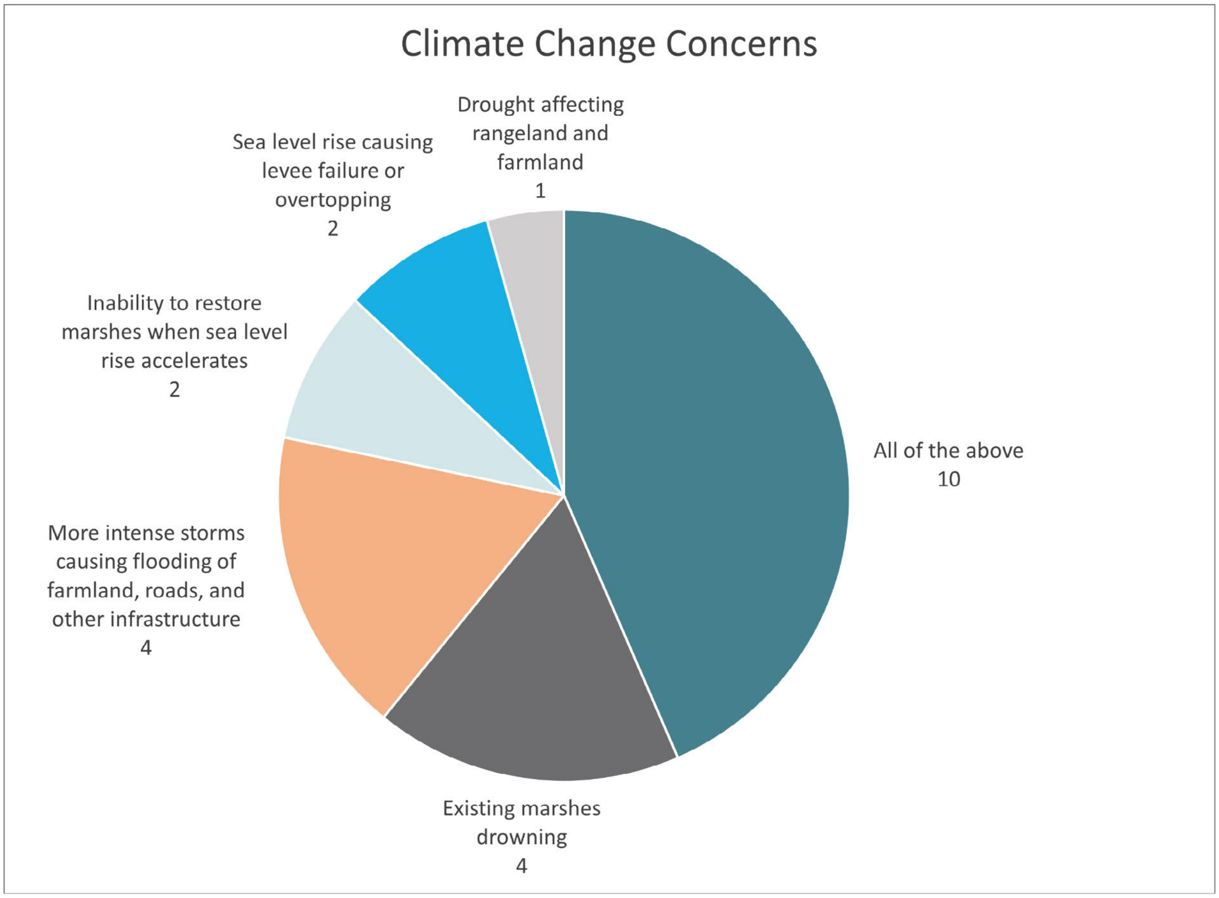
During this meeting we continued to prioritize respectful, open, and honest communication regarding the issues at hand in the Petaluma River Baylands region. As this meeting was in a public format (not confidential in nature as our first meeting), the meeting was recorded and shared with both meeting attendees and interested parties that were unable to join the live conversation.

We specifically invited property owning stakeholders of land located from the river bank up to the Highest Astronomical Tide elevation (excluding parcels north of the Highway 101 crossing) with parcels of 50 acres or larger, and representatives from the surrounding city and counties, regulatory agencies, local nonprofits and community organizations, local Tribes either with ancestral lands or fee lands within the Petaluma Watershed, community members, and interested parties involved in similar work throughout the watershed. Forty-five direct responses were received following our invitation to participate, and 35 individuals participated in the conversation. During the meeting we utilized an online polling platform to interact with participants, below are results from the discussion points offered.

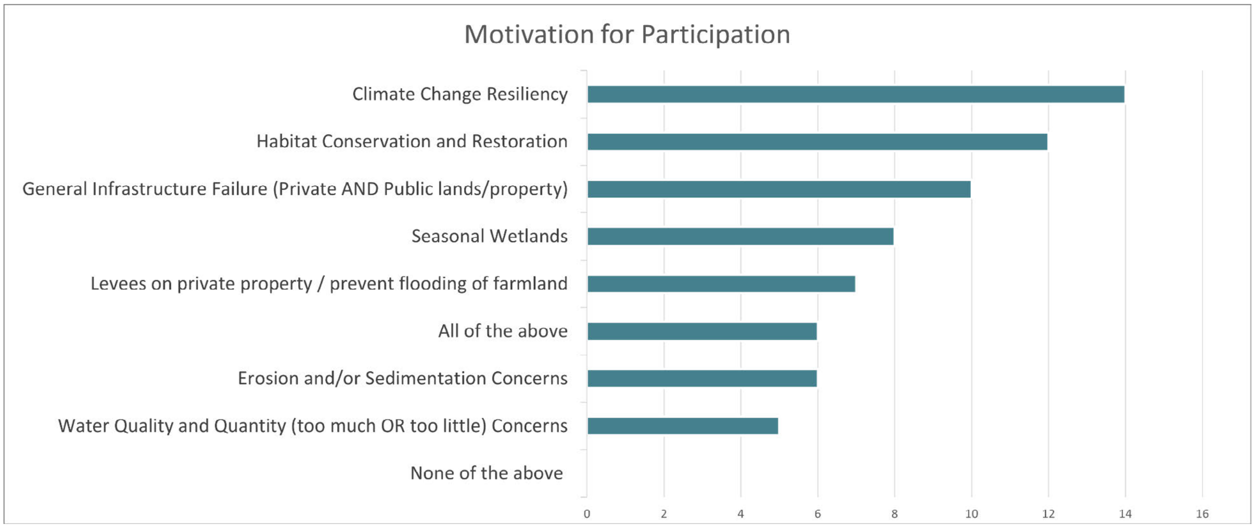
Of the participants that participated in the poll during the Public Meeting, the below are results indicating how participants self-identified their affiliation to the Petaluma baylands region.



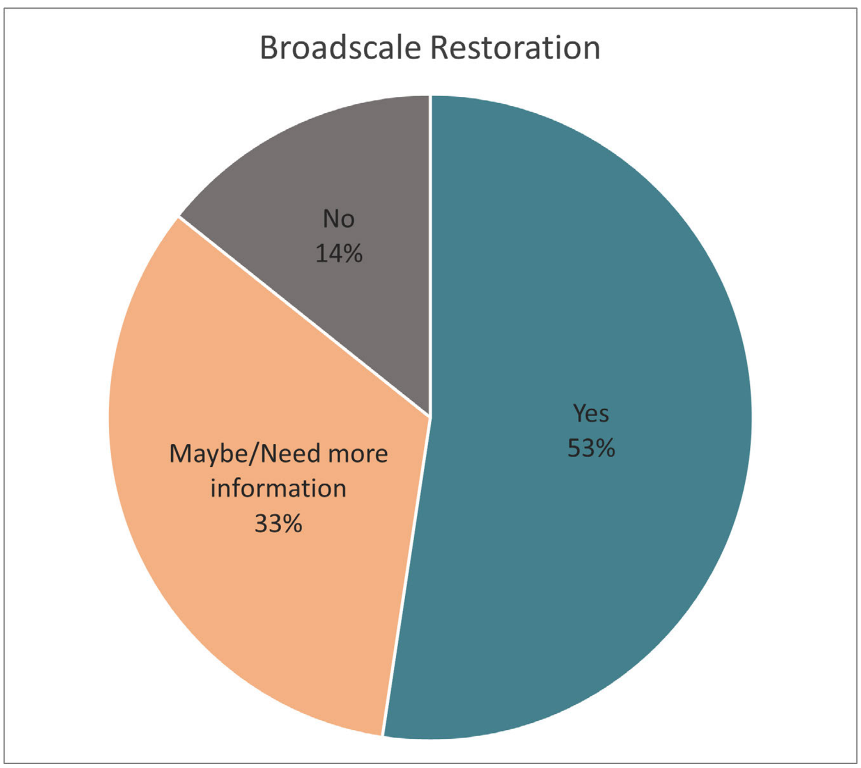
Of the participants that participated in the poll, the below are responses to the question, “What concerns you about climate change in the Petaluma River Baylands?” Responses were limited to one answer per participant.



Of the participants that participated in the poll, the below are responses to the question, “Which of the below are motivating factors for your participation tonight and/or future engagement of work within the Petaluma River Baylands region?” Respondents were able to select all that apply.



When asked if meeting participants would like to see broadscale restoration in the lower Petaluma River on a similar scale of restoration to what has occurred in the lower Napa River, 53% of respondents indicated “yes”, 33% indicated “maybe or that they needed more information”, and 14% indicated “no”.



Outcomes

Based on the feedback we received at the public and private meeting(s) and during individual conversations, we recognize the feasibility of implementation strategies will depend on on-the-ground site conditions as well as landowner/manager goals and interests. In brief, we summarize the points shared with us in our conversations held throughout our outreach processes below. These statements do not represent the entirety of conversations, may generalize sensitive topics that were discussed, and do not necessarily represent every opinion shared in the watershed. This summary is our attempt to synthesize and share a summary of the major themes we heard.

Stakeholders are indeed concerned about the future of the land. There are varying motivations that compel each stakeholder's level of interest in restoration and/or conservation practices on their property. Overwhelmingly, we heard that stakeholders in the Petaluma River Baylands region have seen significant changes over time and recognize the need for action now and in the future. Stakeholders understand the potential for partnering with restoration practitioners and appear amenable to working with such organizations. However, stakeholders also have widely varying goals for land management, and thus varying ideas of what constitutes a desirable restoration action. Because the willing participation of landowners and managers is needed for any conservation or restoration project, respect for and understanding of individual perspectives is essential to move forward action in the watershed.

Stakeholders recognize the function that land acquisition serves in this work and we as a project team recognize that complete acquisition is not always feasible, or desirable, for a variety of reasons. Stakeholders have been presented with examples of how alternatives to fee title acquisition, like conservation easements, can be financially advantageous for landowners wishing to retain ownership while also protecting natural resources. From these meetings and conversations, owners of several properties with high conservation value have come forward and inquired about the potential of conservation easements for restoration of the Petaluma River Baylands landscape that can also promote resiliency for continued property operations.

In this region, there is a long history of farmers, ranchers, and land managers cooperatively managing stormwater and flooding issues each year with little to no recognition or compensation for the public benefit this provides. Without the independently operated water pumps and equipment, major transportation thoroughfares such as portions of State Route 37 would be flooded. The cost to maintain and power these systems is borne by the private landowners. Stakeholders we spoke to expressed that this unspoken public service is often undervalued until an issue arises such as equipment failure or major storm surges. Owners of riverfront parcels recognize the threat of increased winter flooding in the face of increasing storm intensity, but may not view these issues as being exacerbated by sea-level rise. As current pumping efforts and limited levee maintenance have largely been able to keep up with influxes of stormwater, and limited levee overtopping has occurred, efforts to adapt to sea-level rise may not come to the fore until existing operations and infrastructure are no longer adequate to handle storm event conditions.

Over the last several decades, a major challenge for riverfront landowners has been the lack of maintenance of current levee infrastructure. Frustrations have emerged amongst some in the riverfront community due to the possible threat posed by the condition of levees and drainage systems outside of private ownership control. And, even within private control, regulatory complexities add challenges to the process of levee maintenance. The overriding concern expressed by those operating and maintaining pumps and levees was the disconnect between the public services provided by private landowners (ranging from flood mitigation to habitat creation on private lands), and the significant financial and compliance burden resulting from increasingly stringent regulations concerning how levees can be maintained. Continued efforts are needed to bridge the divide between regulators and levee owners so that these resources can be managed for the greatest public benefit.

Agencies with regulatory divisions should prioritize communication across all branches under the organization with a goal of attaining workable solutions. Stakeholders in the area have historically been dissatisfied by the challenges encountered while working with non-regulatory agency branches that appear to have perspectives and priorities vastly different than their regulatory counterparts, showcasing a legacy of unaligned thinking within one agency.

Similarly, public land managers sometimes have restoration objectives that are unattainable due to challenging permitting requirements from their regulatory counterparts. The disconnect of objectives and suitable restoration practices by and between both regulatory agencies and separate branches of the same agency is a testament to the misaligned thinking within the regulatory world that delays and/or stops restoration work needed to address a quickly changing landscape and climate. A uniform approach between restoration, permitting, and regulatory priorities with a common goal of solution-based pathways would incentivize stakeholders – both public and private – to embark upon collaborative conservation actions for the Petaluma River Baylands region.

A common concern iterated to our project team was that regulations do not easily allow for the "better solution." Land managers are often faced with, for example, protecting marsh habitat on their property *or* maintaining their levees. Middle ground solutions are not often accessible to land managers. For example, reasonable maintenance activity exceptions, financial resources, and/or technical assistance offered by resource agencies acknowledging that land managers may be willing to conduct solutions beneficial for both outcomes (habitat and farming) would provide a pathway for "better solutions" in land management to be identified and acted upon. For land managers, a choice between one of two divergent outcomes without space for creativity is not a constructive starting point. We suggest that working with stakeholders to create and implement multi-benefit projects is an exceptional starting point.

Stakeholders have a strong connection to the land that often involves generations of farming and cultivation, business operation, and cohabitation within the Petaluma River Baylands landscape that is unlikely to be abandoned in the near future. Given these ongoing relationships with the land, determining practices that can feasibly combine recommendations within this Strategy and current land management practices will take creative thinking and collaboration.

Voluntary multi-benefit practices and projects – from acquisition potentials, shifts in land management practices, innovative stormwater management, and financial assistance for this work - will be the key to successful working partnerships that allow for landscapes that adapt to and are resilient of climate change. The opportunities for partnership on private lands will be fluid over time, presenting new and differing opportunities as the effects of climate change continue to be felt. We aspire to keep open minds with partnerships and revisit opportunities as circumstances and on-the-ground conditions change.

We anticipate based on feedback we have received at these stakeholder workshops and in individual follow up conversations that there may be a variety of ways landowners and land managers can partner with us to implement the vision, strategies, and goals laid out in this plan.

Appendix C: Geomorphic Analysis

Robust assessments of marsh resilience, and its trajectory as sea-level rises, are critical for informing conservation and management decisions. Wasson et al. (2019) reviewed a number of metrics derived from monitoring and modeling to develop indicators that signal which tidal marshes are likely to persist into the future. No single metric universally predicted marsh trajectories, and therefore a more robust approach includes a suite of spatially-integrated, landscape-scale metrics that are mostly obtainable from remote sensing. Wasson et al. (2019) identified the following metrics as measures of marsh resilience:

Marsh elevation

Marshes with the majority of the vegetation low in the elevation range for salt marsh species are likely to degrade (Wasson et al. 2019). Higher marshes are likely to be more stable and more resilient to sea-level rise. Therefore, metrics characterizing the distribution of marsh vegetation with elevation could be good indicators of how a marsh is likely to respond to sea-level rise.

Marsh accretion

Marsh accretion (the vertical accumulation of mineral sediment or organic matter) on its own is not necessarily an indicator of resilience - it can be an indicator of degradation. Low elevation marshes, which are degrading marshes, can have higher rates of vertical accretion and elevation gain than more intact counterparts, likely due to longer inundation times and deeper water columns potentially combined with internal recycling of material (Wasson et al. 2019).

Unvegetated-to-vegetated ratio

Ganju et al. (2017) identified the unvegetated-to-vegetated ratio (UVVR) as an indicator of tidal marsh trajectory. A stable tidal marsh, with intact marsh plains and little deterioration, tends to be 90% marsh, 10% unvegetated (a UVVR~0.11); a marsh with a UVVR greater than 2 (i.e., 67% unvegetated) would be classified as an intertidal flat.

Sediment differential

The difference in suspended-sediment concentration (SSC) on flood and ebb tides has been shown to indicate the directionality of tidal marsh channel sediment flux over time scales of months to years (Ganju et al. 2017). The sediment differential, defined as the mean SSC on flood tides minus the mean SSC on ebb tides as determined by velocity direction, is representative of whether a marsh channel imports or exports sediment (Nowacki and Ganju 2019). A positive value greater than 0 means a net import of sediment to the marsh; a negative value less than 0 indicates a net export; a value of 0 indicates a balance between import and export.

Wasson et al. (2019) discuss these metrics in terms of degradation of a mature marsh. A degrading marsh could show an increasing proportion of low marsh elevation and a corresponding change in vegetation by loss of high marsh species, and perhaps recolonization of low marsh species. Accretion rates may increase as elevation lowers due to longer and deeper water over the site allowing more sediment to settle. As water depths increase, the loss of vegetation and increased wave action erodes more of the marsh and increases the proportion of open water (UVVR). This erosion liberates sediment that could accrete elsewhere in the marsh or is exported from the site. The sediment differential would become negative, with a net export of sediment from the site.

In the Petaluma River, there are both mature high marshes and newly restored low marshes which could have different trajectories—these different trajectories may be measured by tracking how the resilience metrics change over time.

A newly restored marsh is likely to have the majority of vegetation at lower elevations. The low elevations would mean longer and deeper water over the site allowing more sediment to settle and lead to higher accretion rates. The sediment differential would be greater than zero, with net import to the site. Over time the elevation of the site would increase, be colonized by more high marsh vegetation and the proportion of open water (UVVR) would decrease.

The full range of metrics are shown in the table below which provides a summary of metrics and approaches from Wasson et al. 2019.

Category	Metric	Data needs
MARS metrics (Raposa *et al* 2016)		
Marsh elevation distributions	Percent of marsh below MHW	Frequency distribution of marsh elevations; estimate of mean high water
	Percent of marsh in lowest third of plant distribution	Frequency distribution of marsh elevations
	Skewness	Frequency distribution of marsh elevations
Marsh elevation change	Elevation change rate (mm yr^{-1})	Time series data from surface elevations tables (SETs)
Sediment/accretion	Short-term accretion rate (mm yr^{-1})	Time-series data from marker horizons
	Long-term accretion rate (mm yr^{-1})	Soil cores for radiometric dating
	Turbidity(NTU)	Mean turbidity from water quality sondes
Tidal range	Tidal range (m)	Mean daily tidal range from water quality sondes
Sea-level rise	Long-term rate of SLR (mm yr^{-1})	Long-term data from NWLON station
	Short-term inter-annual variability in water levels (mm)	Inter-annual variability data from NWLON station
Ganju *et al* (2017) metrics		
	Flood-ebb turbidity differential	Mean suspended sediment concentrations on flood and ebb tides
	UVVR	Relative area of vegetated marsh and unvegetated areas from aerial photographs
Observed change in vegetation		
	Decadal change in UVVR	UVVR (see above) assessed at 2 + points spanning ~10 years
	Percent of marsh plain with vegetation	Area of vegetated marsh divided by total marsh landscape area (vegetated+unvegetated) × 100
	Decadal change in percent vegetated	Change in above, assessed at 2 + points spanning ~10 year

Wasson (2019) found the five most reliable indicators of marsh persistence and degradation to be: (1) percent of marsh below MHW; (2) percent of marsh in the lower third of vegetation tolerance; (3) skewness of the distribution of vegetation across elevations; (4) sediment differential; and (5) UVVR (Wasson et al. 2019). These five factors have been analyzed in this report for the Petaluma River Baylands.

Application of Marsh Resilience Metrics in the Petaluma River Baylands

Three of the five metrics for marsh persistence are based on analysis of the distribution of elevation values. This report uses the LEAN-corrected digital elevation model (DEM) developed by Buffington and Thorne (2019), which is based on a 1-m LiDAR-derived DEM from 2010 and accounts for the height of vegetation to more accurately represent true marsh elevation. The distribution of ground elevations within the tidal range for each of the subunits was analyzed (Figure C-1). A first analysis was performed on existing tidal marsh (areas classified as tidal marsh flat, tidal ditch, tidal panne, or tidal vegetation in the Bay Area Aquatic Resources Inventory, SFEI 2017, Figure C-2). A second analysis was performed for the entire area in each subunit below Highest Astronomical Tide (HAT =MHHW+0.31 m or 1 ft) which includes tidal marsh as well as diked baylands—the area that would be inundated by the tides in the absence of levees (Figure C-2). A third analysis was performed for areas that were formerly diked and have now been restored to tidal action (Figure C-3). By using these three separate geographic subsets, we were able to better analyze the resilience of each subunit within comparable areas. With some overlap, these three categories encompass the range of land cover within the Petaluma baylands today: extant marsh, diked baylands, and recent restoration sites. The DEM used for analysis is shown with a tidally-referenced elevation scale in Figure C-1.

NOTE ON ELEVATION DATA:

The analyses in this chapter are based on a 2019 vegetation-corrected DEM (Buffington and Thorne 2019), which itself is based on LiDAR data collected in 2010. Elevations in many parts of the study area may have changed since 2010. In particular, the elevations of recent tidal restorations such as Dickson Unit (Sears Point) and Sonoma Baylands are far lower in this analysis than they actually are today, due to sediment accretion since the levees were breached. For example, Sears Point accreted 2-4 feet in elevation between 2015-2020 (Siegel Environmental 2022).

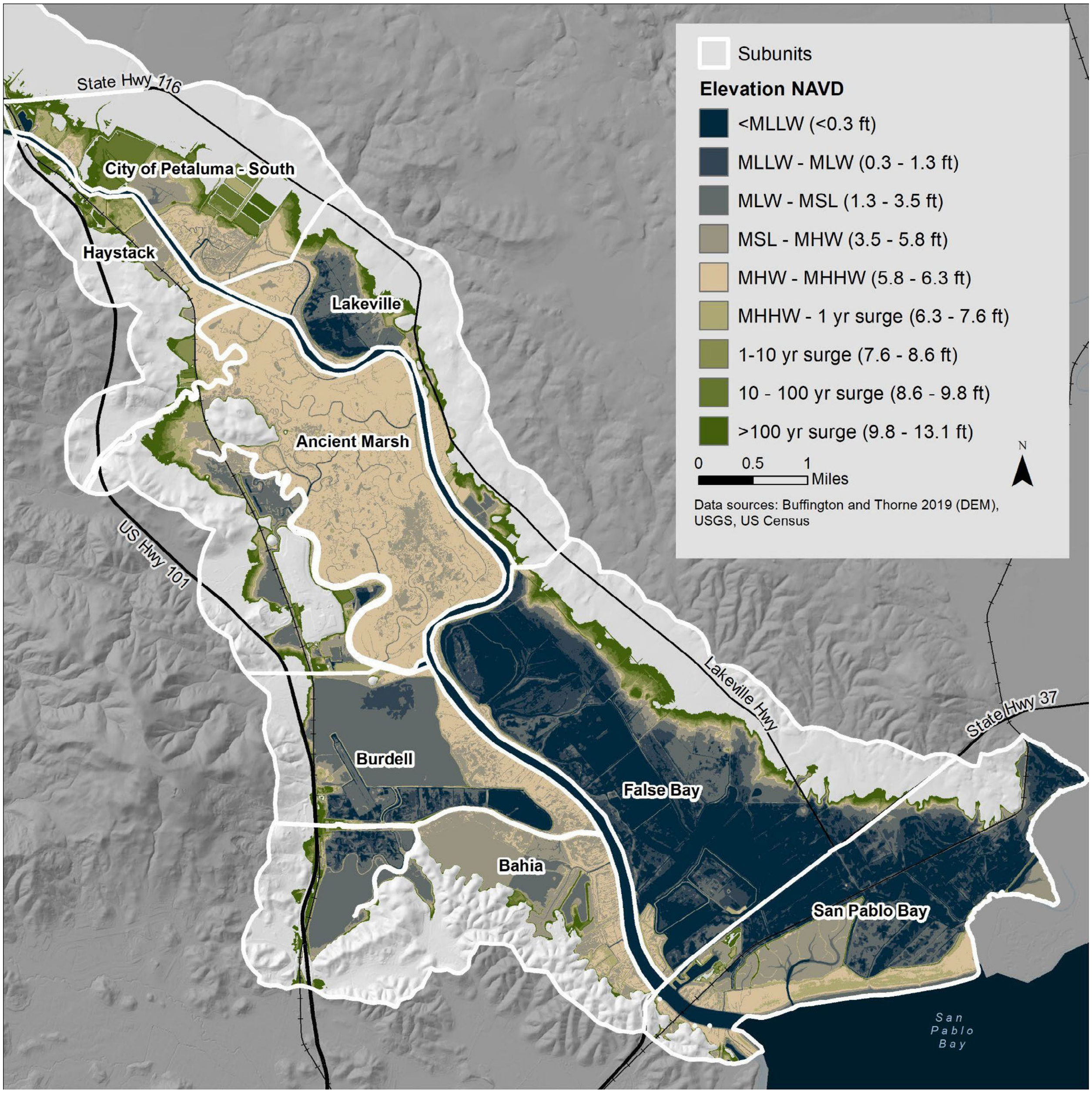


Figure C-1. Analysis subunits and digital elevation model (DEM) used for calculation of marsh resilience metrics.

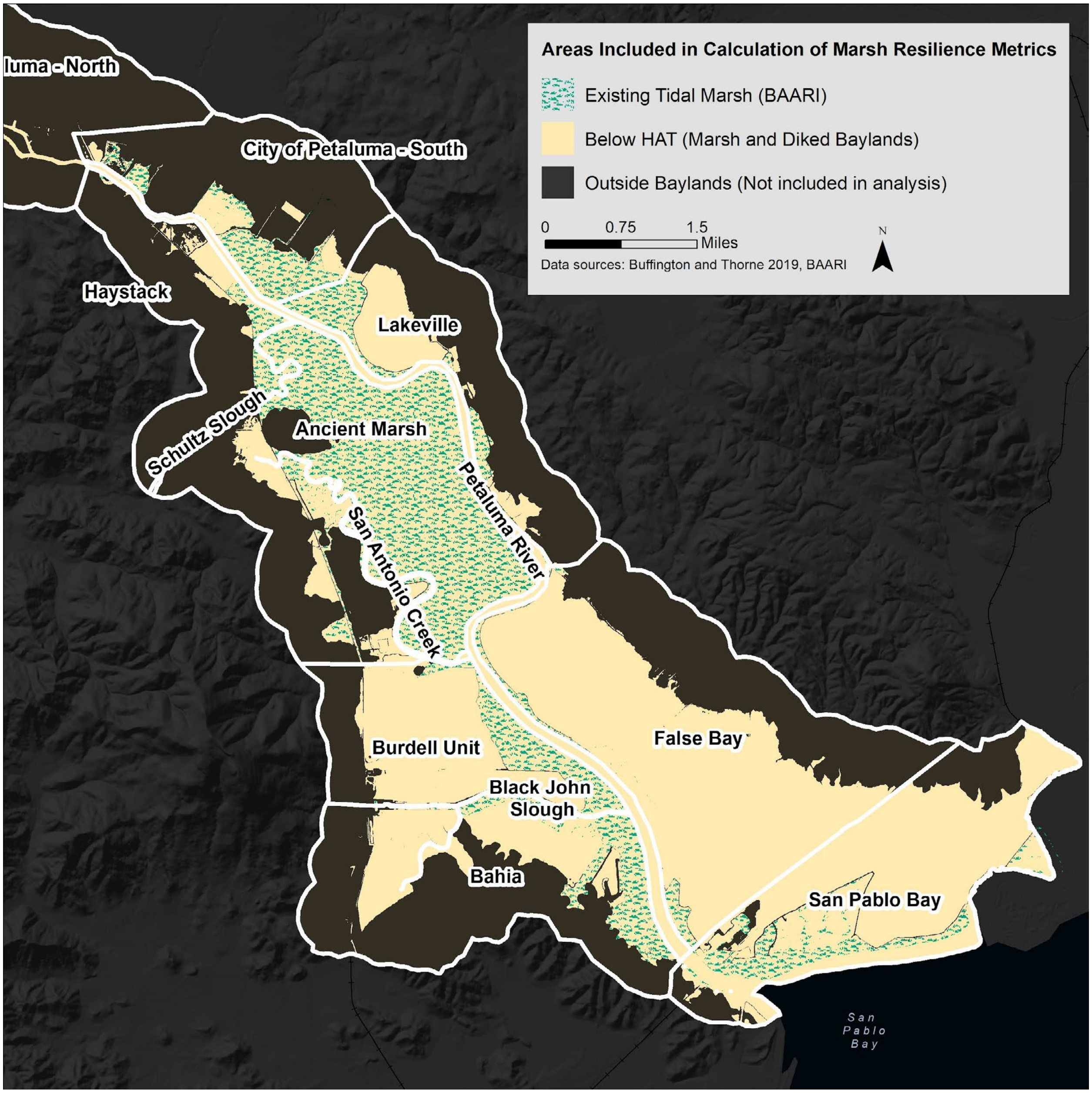


Figure C-2. Marsh resilience metrics were calculated for (1) all of the marsh and diked baylands below Highest Astronomical Tide (HAT), and (2) for existing tidal marsh, a subset of the "Below HAT" area. A third analysis was conducted for recently restored sites (see Figure 3 below).

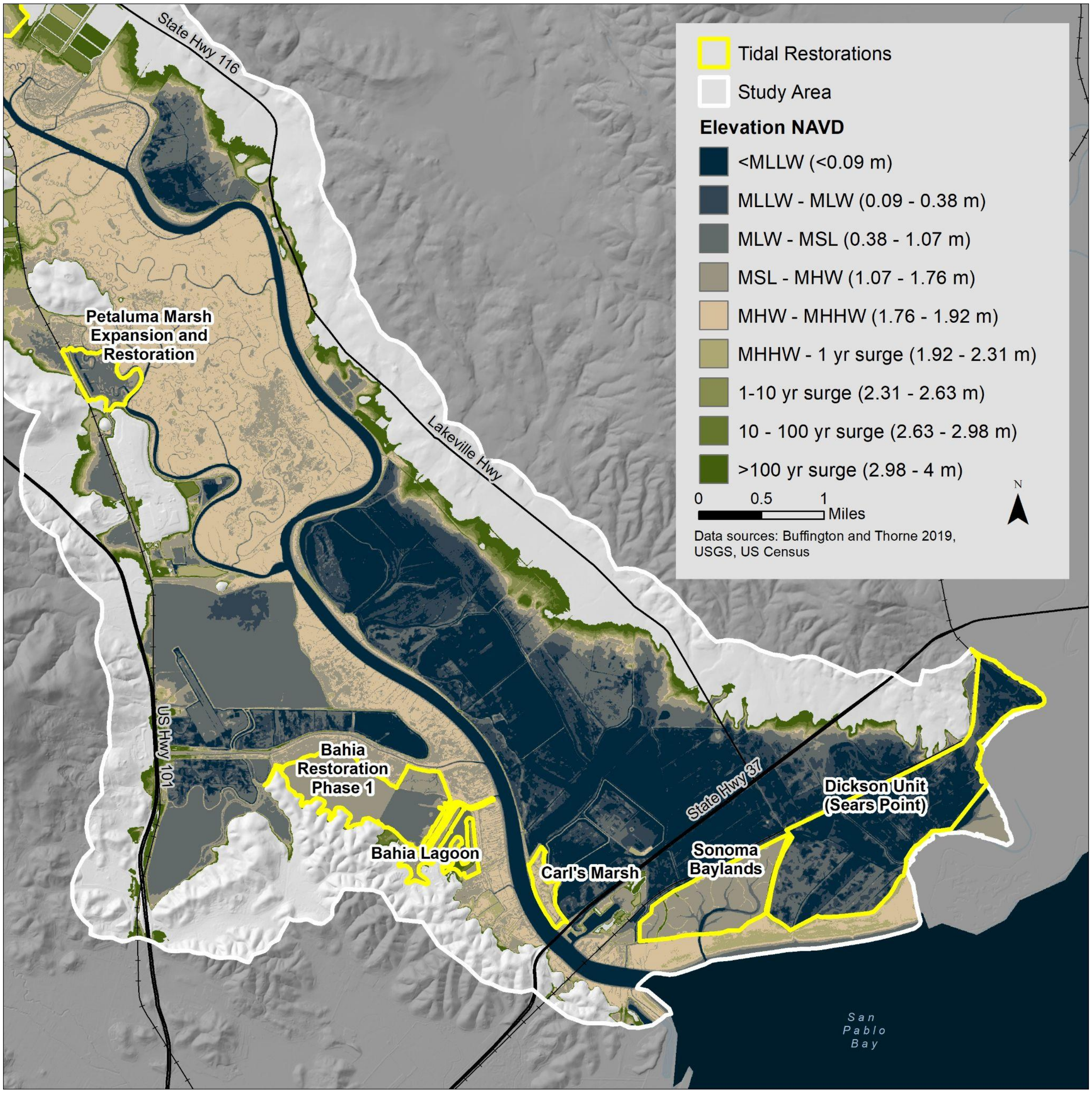


Figure C-3. Boundaries of tidal restoration areas used to calculate marsh resilience metrics for restoration sites.

The following histograms show the distribution of elevation values for each subunit within existing tidal marsh (Figure C-4), within the marsh and diked baylands as a whole (less than HAT) (Figure C-5), and within tidal restoration sites (Figure C-6).

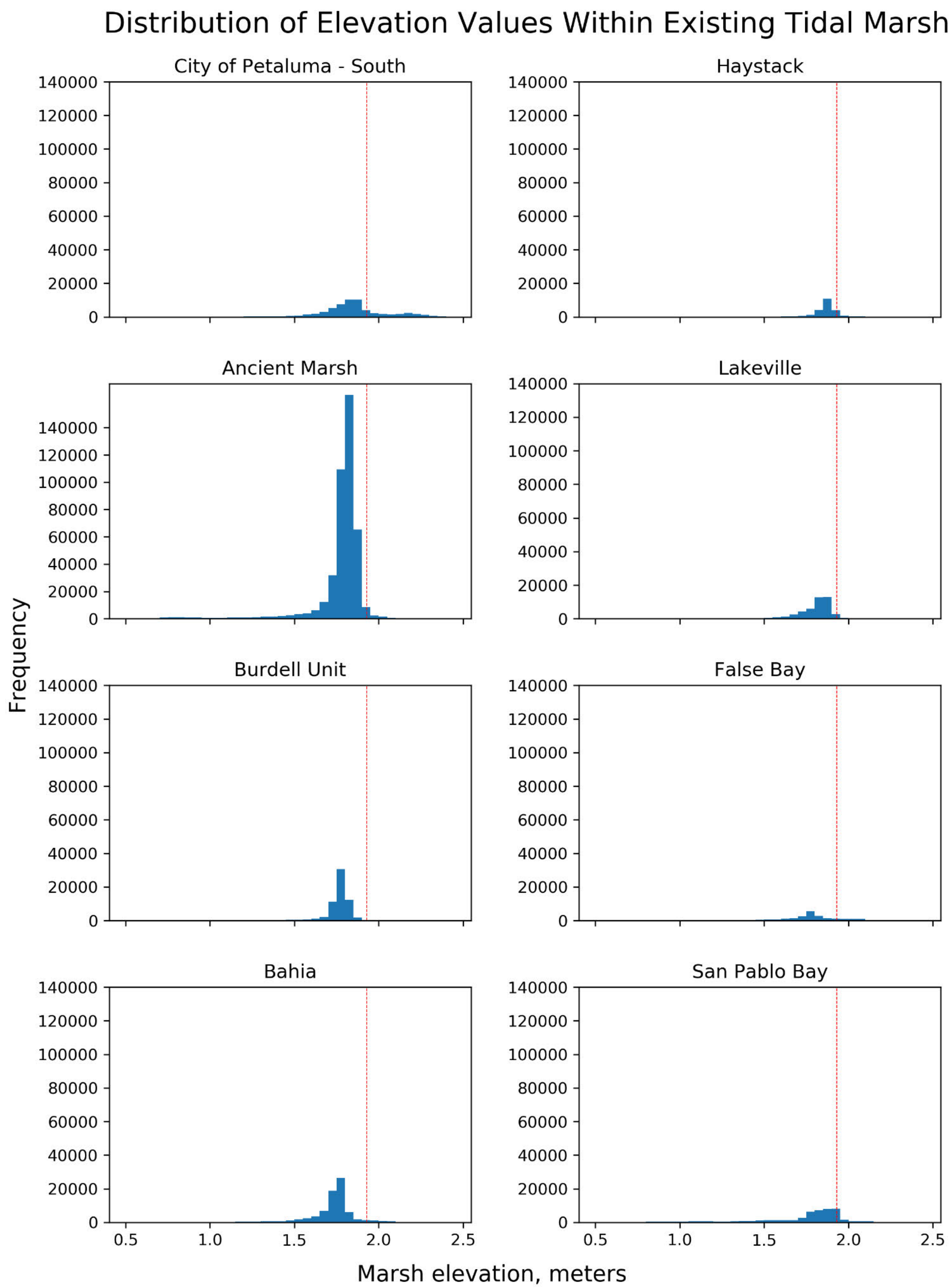


Figure C-4. Histograms showing the distribution of elevation values for areas classified as marsh (BAARI) within each subunit. The red dashed lines indicate MHHW elevation (1.93 m NAVD). The y-axis “Frequency” represents the number of raster cells in each elevation bucket.

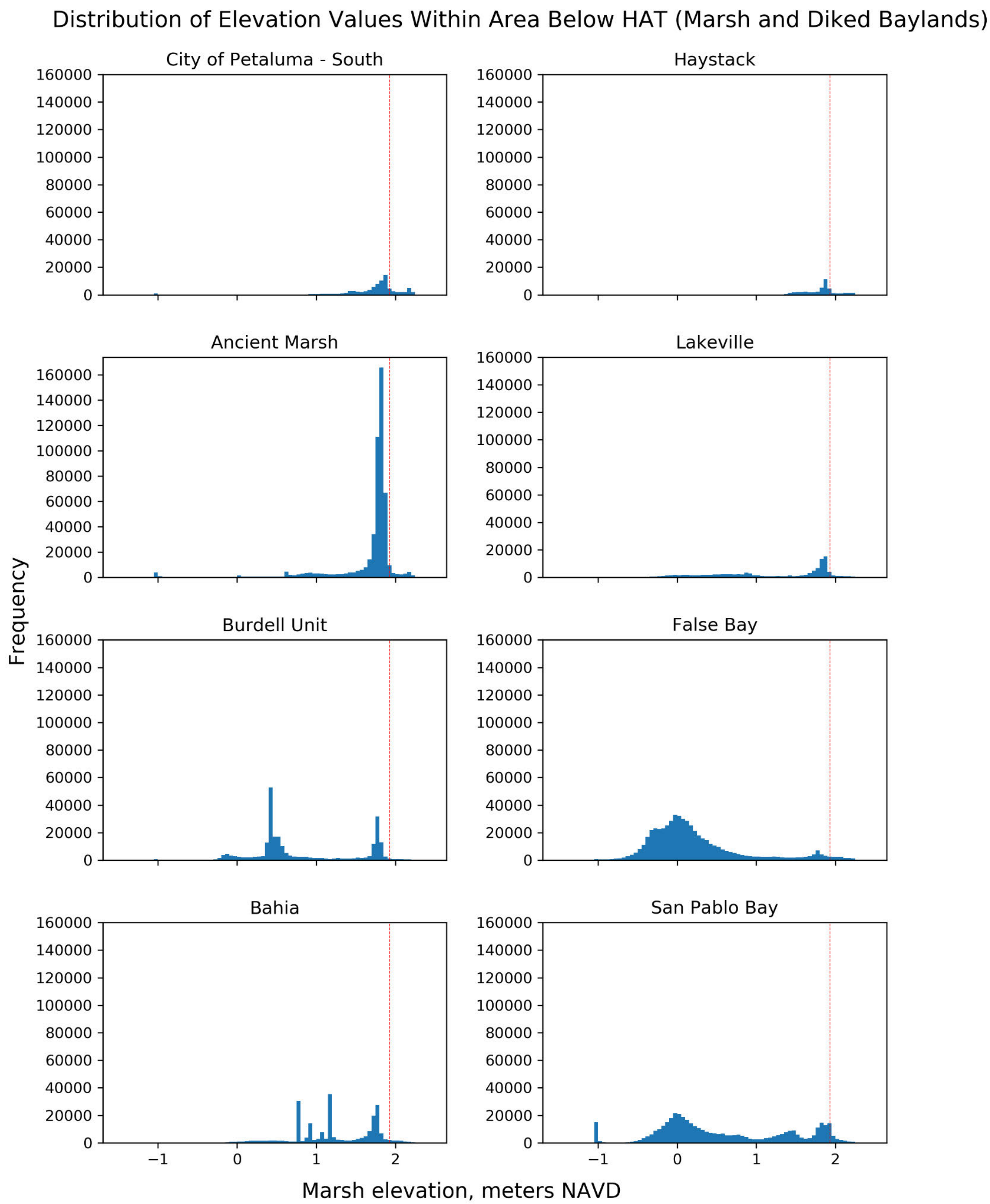


Figure C-5. Histograms showing the distribution of elevation values for areas below Highest Astronomical Tide elevation (this includes marsh, recent restorations, and diked baylands). The red dashed lines indicate MHHW elevation (1.93 m NAVD). The y-axis "Frequency" represents the number of raster cells in each elevation bucket.

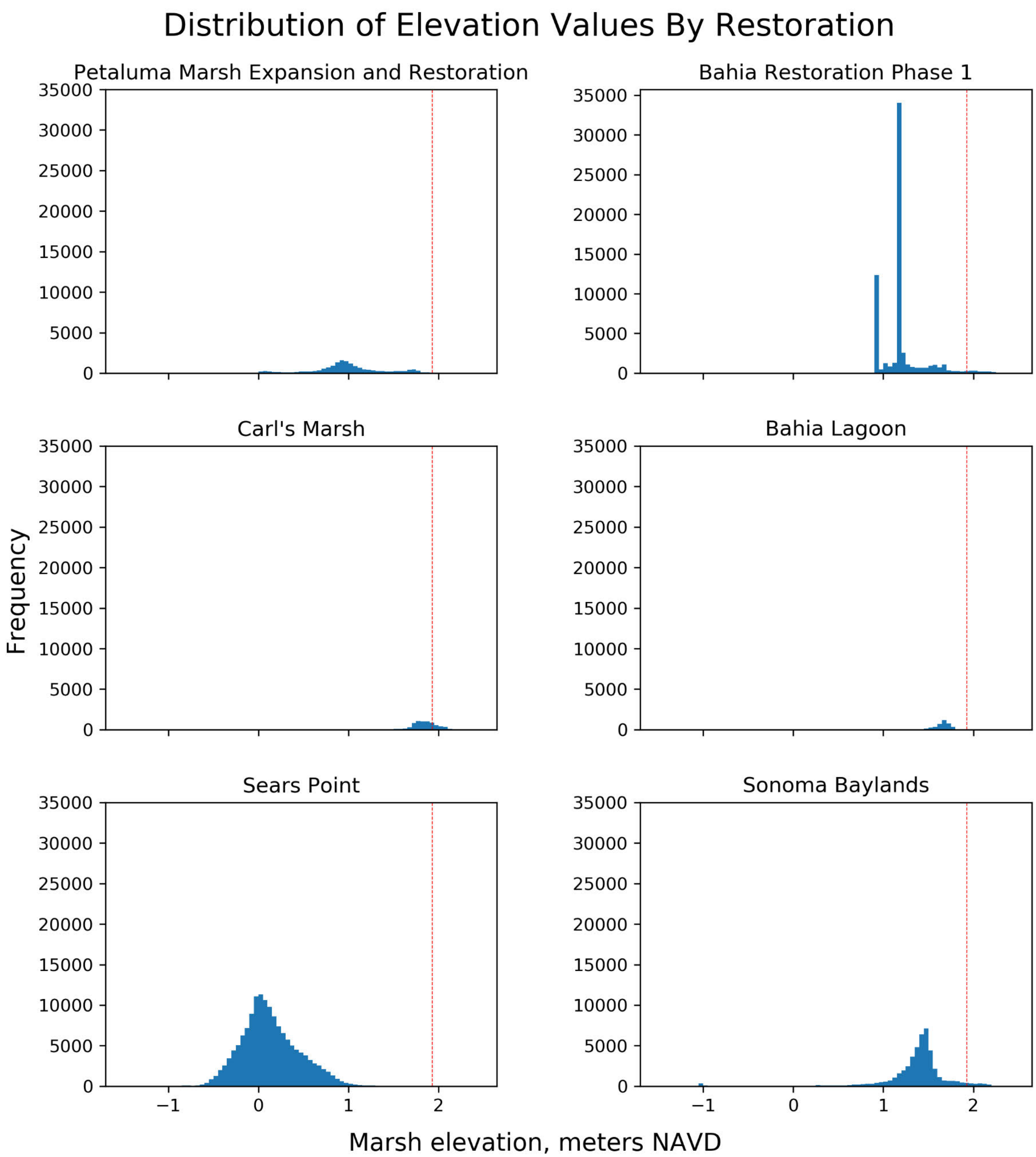


Figure C-6. Histograms showing the distribution of elevation values as of 2010 for recent tidal restoration projects. The Petaluma Marsh Expansion and Restoration project is in the Ancient Marsh subunit; the Bahia Restoration Phase 1 and Bahia Lagoon are in the Bahia subunit; Carl's Marsh is in the False Bay subunit; Sears Point (now known as Dickson Unit since transfer to USFWS) and Sonoma Baylands are in the San Pablo Bay subunit. The red dashed lines indicate MHHW elevation (1.93 m NAVD). The y-axis "Frequency" represents the number of raster cells in each elevation bucket.

1. Percent of marsh below MHW

The percentages shown in Table C-1 represent the percent of elevation points (raster cells from the DEM) that are below MHW (1.775 m/5.82 ft NAVD - the average of values at the Upper Drawbridge and Petaluma River Entrance gauges). Lower percentages in shades of green indicate more area above MHW (more resilient), while higher percentages in orange and red indicate more area below MHW (less resilient). Haystack and Ancient Marsh, with few diked areas and large swaths of high marsh, are most resilient according to this metric. False Bay, Bahia, San Pablo Bay, and Burdell are least resilient; these areas have more diked baylands, more recent restorations that are still low in elevation, and less extant high marsh. For restoration sites, Ancient Marsh (Petaluma Marsh Enhancement and Restoration project), San Pablo Bay (Sonoma Baylands and Sears Point), and Bahia all had similarly high values for percent below MHW. False Bay (Carl's Marsh) had a much lower percent below MHW, an expected result as this site was restored earlier and has had more time to accrete to higher elevation. As mentioned previously, elevations are based on the 2010 DEM and do not accurately represent todays' elevation. For example, Sears Point accreted 2-4 feet in elevation between 2015-2020 (Siegel Environmental 2022)

Table C-1. Percent of elevation points within each subunit below MHW (1.78 m/5.82 ft NAVD). Subunits highlighted in green have the lowest relative percentages of area below MHW (more resilient), while subunits highlighted in red have the highest relative percentages of area below MHW (less resilient). Subunits with moderate percentages relative to other subunits are highlighted in yellow.

	Percent Below MHW (Below HAT-Marsh and Diked Baylands)	Percent Below MHW (Existing Tidal Marsh)	Percent Below MHW (Restorations)
Haystack	34%	11%	N/A
Ancient Marsh	35%	28%	96%
City of Petaluma - South	43%	33%	N/A
Lakeville	65%	31%	N/A
Burdell Unit	86%	54%	N/A

San Pablo Bay	86%	43%	98%
Bahia	87%	70%	96%
False Bay	96%	49%	34%

2. Percent of marsh in the lower third of vegetation tolerance

The percentages shown in Table C-2 represent the percent of elevation points (raster cells from the DEM) that are in the lower third of marsh vegetation tolerance.The lower end of the plant range is at the mudflat/low marsh boundary: -0.6m MHHW (1.33m NAVD elevation in the study area) is the mudflat/low marsh boundary. The high marsh/upland boundary or the upper end of the plant range is 0.3m MHHW (2.23m NAVD in the study area) (Stralberg et al. 2011). Therefore, the lower third of the plant range falls between -0.6 and -0.3m MHHW (1.33 and 1.63 m NAVD) in the study area. The table below shows the percent of points in this lower third relative to the total range of vegetation tolerance. Lower percentages indicate more area in the upper end of the vegetation tolerance range (more resilient) while higher percentages indicate more area in the lower end of the vegetation tolerance range (less resilient). The Ancient Marsh, Burdell, and Lakeville, and Haystack subunits are most resilient according to this metric, while the False Bay and San Pablo Bay subunits are least resilient.

Table C-2. Percent of elevation points (raster cells from the DEM) within each subunit that are in the lower third of marsh vegetation tolerance. Subunits highlighted in green have the lowest percentage of area in the lower third of marsh vegetation tolerance, while subunits highlighted in red have the highest percentage of area in the lower third of marsh vegetation tolerance. Subunits with moderate percentages relative to other subunits are highlighted in yellow.

	Percent in Lower Third of Vegetation Tolerance (Below HAT - Marsh and Diked Baylands)	Percent in Lower Third of Vegetation Tolerance (Existing Tidal Marsh)	Percent in Lower Third of Vegetation Tolerance (Restorations)
Ancient Marsh	6%	4%	44%
Burdell Unit	11%	5%	N/A
Lakeville	11%	7%	N/A
Bahia	17%	12%	47%
City of Petaluma - South	18%	9%	N/A
Haystack	20%	4%	N/A
False Bay	25%	14%	6%
San Pablo Bay	34%	15%	83%

3. Skewness of the distribution of vegetation across elevations

Skewness is a measure of the difference in the distribution of values from a symmetrical “normal” distribution. A high or low skewness value indicates that one “tail” of the distribution is longer than the other, while a skewness value of 0 indicates a symmetrical distribution. Applied as a marsh resilience metric, negative skewness indicates that the distribution of values is concentrated toward the higher end of the range (more resilient), while positive skewness indicates that the distribution of elevation values is concentrated at the lower end of the range (less resilient). The values in Table C-3 represent the skewness of the distribution of elevation values for each subunit. The metric's results differ for the area including diked baylands and the area restricted to existing tidal marsh. Ancient Marsh and City of Petaluma - South are most resilient when considering the area below HAT, but the existing marshes of the Ancient Marsh and Burdell units are most resilient according to this metric. Least resilient according to this metric are False Bay (marsh and diked baylands) and Bahia (existing marsh). Among restoration sites, False Bay (Carl's Marsh) was again most resilient, the only restoration site with a negative skewness value. Ancient Marsh (Petaluma Marsh Expansion and Restoration) had the next lowest skewness value, with Bahia and San Pablo Bay unit restorations the highest.

Table C-3. Skewness of the distribution of elevation values within each subunit. Subunits with the most negative skewness values (more resilient) are highlighted in green, while subunits with the most positive skewness values (least resilient) are highlighted in red. Subunits with moderate skewness values relative to other subunits are highlighted in yellow.

	Skewness of the Distribution (Below HAT - Marsh and Diked Baylands)	Skewness of the Distribution (Existing Tidal Marsh)	Skewness of the Distribution (Restorations)
Ancient Marsh	-3.6	-3.9	0.2
City of Petaluma - South	-3.2	1.9	N/A
Haystack	-1.0	5.0	N/A
Lakeville	-0.5	3.8	N/A
Bahia	-0.4	50.0	1.2
San Pablo Bay	0.3	-2.8	0.7
Burdell Unit	0.4	-5.7	N/A
False Bay	1.4	-2.6	-2.2

4. Unvegetated to vegetated ratio within tidal areas of each subunit

Following the method in Ganju et al. (2017), the unvegetated to vegetated ratio (UVVR) for each Petaluma bayland subunit was calculated using NAIP imagery from 2018. Using the Iso Cluster Unsupervised Classification tool in ArcGIS, the imagery was separated into 10 classes based on spectral similarities in the 4-band imagery (includes infrared). By comparing each class with aerial imagery, we could determine whether the class represented marsh vegetation or unvegetated marsh panne/marsh flat. We then summarized the area of unvegetated versus vegetated tidal areas in each subunit. The analysis area for this metric included both existing marsh and recent restorations that have not yet reached marsh elevation.

Fringing marshes generally have fewer tidal pannes and marsh flats, so units with only fringing marsh tended to have lower UVVR than the units with larger and older marsh patches such as Ancient Marsh, which has many marsh pannes (Figure C-7, Table C-4). UVVR is high in the San Pablo Bay and Bahia subunits due to recent restoration.

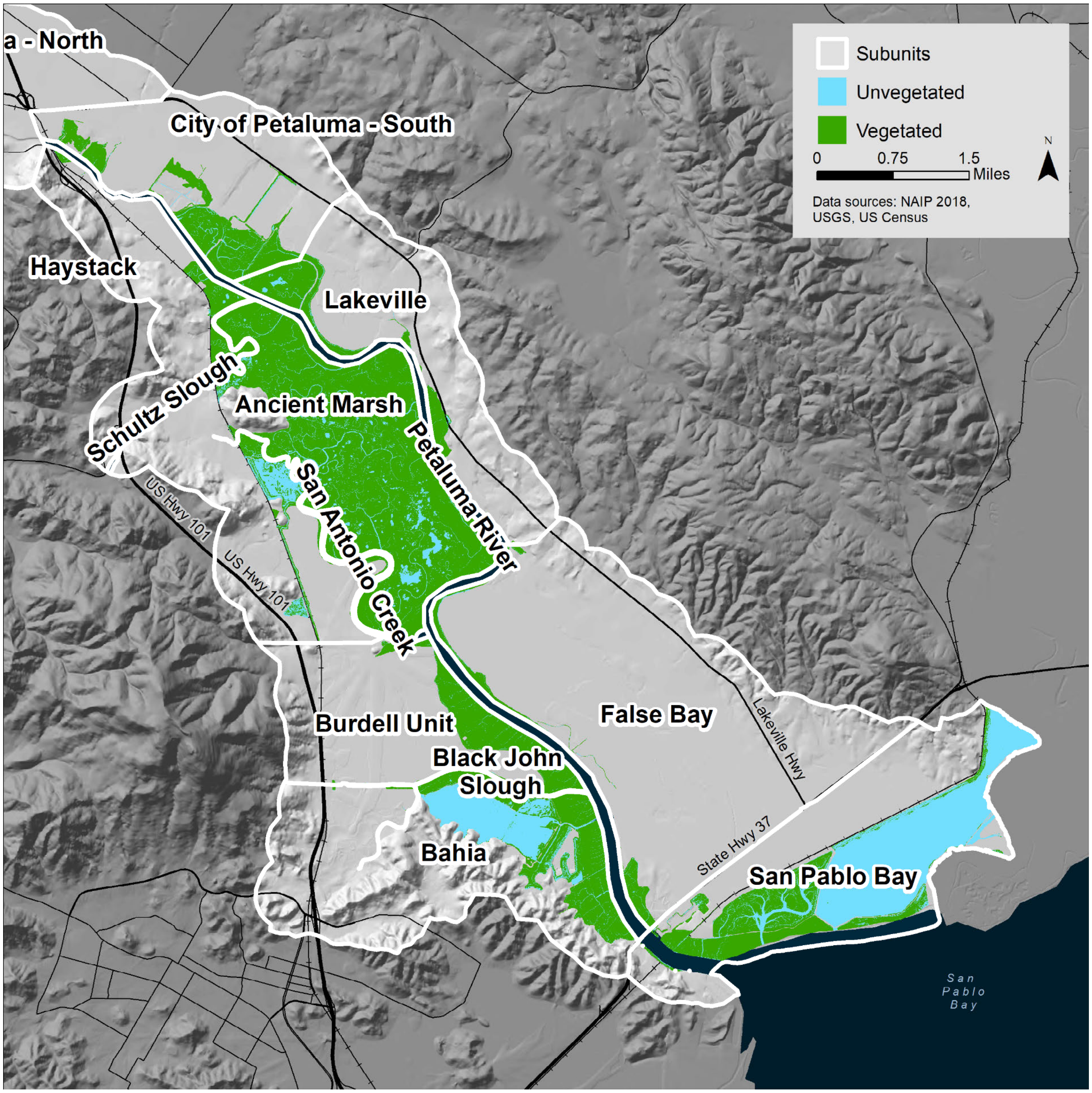


Figure C-7. Unvegetated and vegetated areas within tidally-connected areas used to calculate UVVR. Based on unsupervised classification of 2018 NAIP imagery.

Table C-4. Unvegetated to vegetated ratio (UVVR) within tidal areas of each subunit. Subunits with the lowest UVVR (most resilient) are highlighted in green, while subunits with the highest UVVR (least resilient) are highlighted in red.

	UVVR = Unvegetated area ---------------------- Vegetated area
Burdell Unit	0.03
False Bay	0.06
Haystack	0.06
Lakeville	0.07
City of Petaluma - South	0.07
Ancient Marsh	0.12
Bahia	0.73
San Pablo Bay	1.96

Marsh migration barriers

Bayland habitats are more likely to persist as climate changes if there is a protected transition zone at the upper edge of the marsh with accommodation space for upland migration. The following map and description summarize migration space and barriers by subunit. The SMART rail line and US 101 form a barrier to marsh migration on the western side of the river (Figure 8). Lakeville Highway is built at a higher elevation than US 101, so there is some room for marsh migration on the eastern side of the river. The SMART rail line and State Route 37 crossing through the southern part of the project area present a barrier to connectivity and marsh migration for newly restored areas in the San Pablo Bay subunit.

We mapped the transition zone boundary at 500 m (1,640 ft) horizontally inland from the approximate elevation of today's Highest Astronomical Tide (0.31m/1ft above MHHW). This buffer includes the space over which most key physical and biological transition-zone processes occur (SFEI T-zone Project, Robinson et al. 2017). We used mapped migration space from SFEI and SPUR's SF Bay Shoreline Adaptation Atlas. Migration space is the area at the appropriate topographic elevation adjacent to present and potential marshes that could be protected, enhanced, or restored to allow marshes to migrate landward as sea levels rise (SFEI and SPUR, 2019). This layer includes undeveloped areas expected to be inundated with 2 m (6.6ft) of sea-level rise that are above today's Highest Astronomical Tide, and excludes areas of existing tidal marsh. "Developed" vs "undeveloped" area was classified according to the 2011 National Land Cover Database (NLCD) and "protected" vs "unprotected" area was classified according to the 2017 California Protected Areas Database (CPAD). Further details can be found in the SF Bay Shoreline Adaptation Atlas (SFEI and SPUR, 2019).

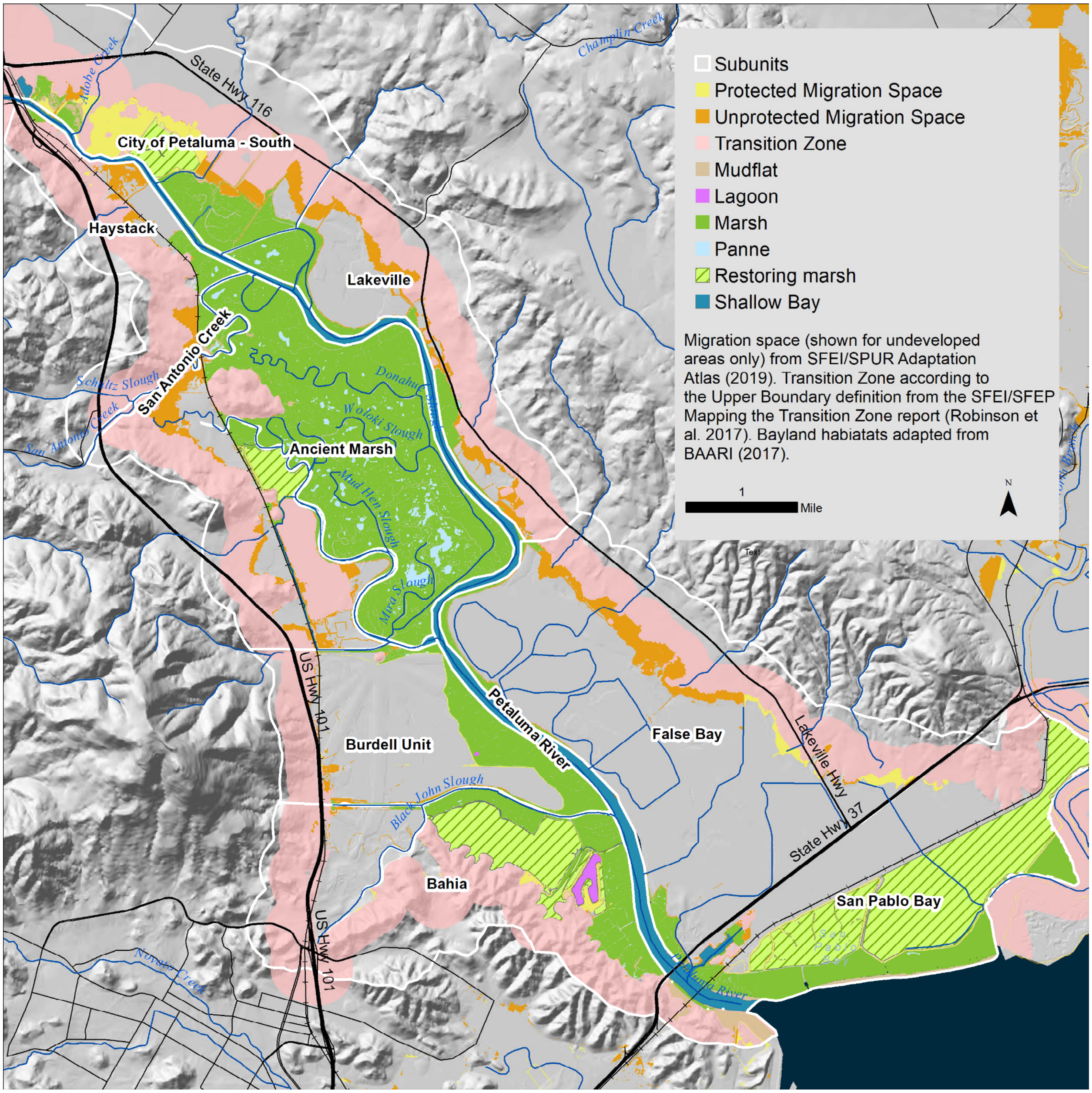


Figure C-8. Calculated migration space and transition zone, based on elevation data. Much of the area shown as transition zone in the map is not currently protected as transition zone habitat; in fact, much of it is urbanized, as in the City of Petaluma - North subunit.

To compare the relative availability of undeveloped migration space between subunits, the back edge of the marsh (existing tidal marsh and recently restored tidal areas) in each subunit was selected. Then, the approximate percentage of this edge adjacent to relatively large patches of undeveloped migration space (i.e. not levees or isolated pockets) was calculated. The migration space included in this analysis includes both protected and unprotected migration space, as shown in Figure C-8 above. Figure C-9 and Table C-5 below show the relative availability of adjacent marsh migration space in each subunit. City of Petaluma - South has the most migration space available adjacent to tidal marsh, while San Pablo Bay, False Bay, Burdell Unit, Ancient Marsh, and Bahia have very little.

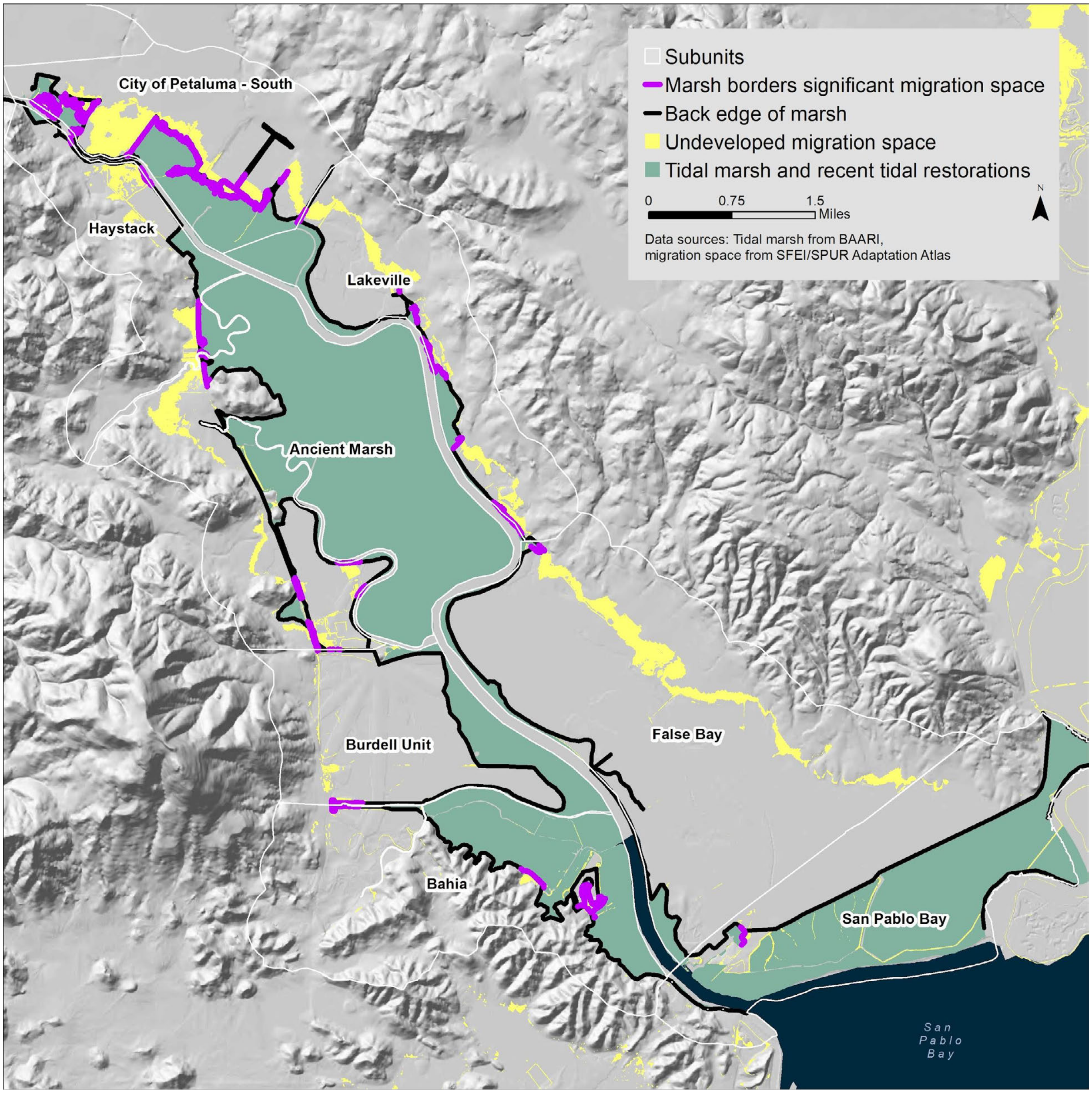


Figure C-9. Visualization of marsh migration space by subunit, with marsh edges adjacent to significant patches of migration space highlighted in purple. Not all "adjacent" migration space is available due to barriers that hinder marsh migration.

Table C-5. Availability of marsh migration space by subunit. Subunits with relatively lower percentages of marsh edge bordering undeveloped migration space are highlighted in red, while subunits with relatively higher percentages of marsh edge bordering undeveloped migration space are highlighted in green.

	Approximate percentage of marsh edge bordering undeveloped migration space
San Pablo Bay	<10%
False Bay	<10%
Burdell Unit	<10%
Ancient Marsh	10-20%
Bahia	10-20%
Lakeville	20-30%
Haystack	40-50%
City of Petaluma - South	>50%

Measures of Diked Baylands Resilience

Percent of area below mean sea level

Heavily subsided units are more vulnerable to flooding and, over time, will presumably accumulate increased pumping and maintenance costs to stay dry. Figure C-10 shows elevations below mean sea level within the study area. False Bay, San Pablo Bay, and the Burdell Unit have the highest proportions of subsided land below mean sea level, with 89%, 68%, and 67% of diked baylands area below mean sea level, respectively (Table C-6). Diked baylands kept dry by levees tend to subside over time as organic soil compacts and oxidizes. Areas below sea level protected by levees are vulnerable to levee breaches. The lower the parcel, the deeper the resulting flooding will be. At the other end of the spectrum are areas that have not been diked off from tidal action and have maintained their elevation relative to the tides through accumulation of organic and inorganic sediment (e.g. Haystack, City of Petaluma - South, Ancient Marsh).

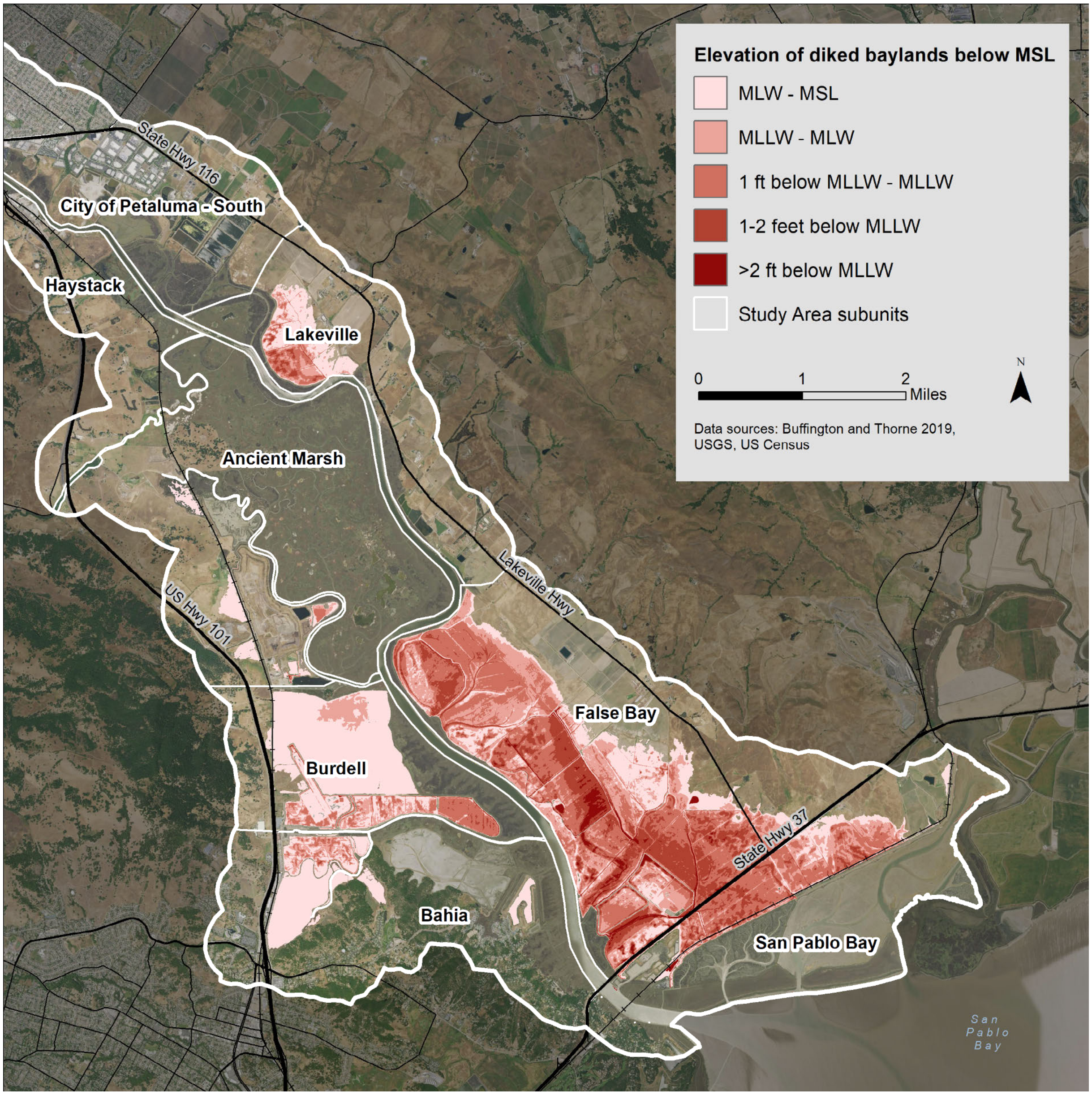


Figure C-10. Areas subsided to elevation below mean sea level (shown for analysis sub-units only; channels are below mean sea level as well).

Table C-6. Percentage of subsided land below mean sea level within each subunit. Subunits with relatively lower percentages of bayland area below MSL are highlighted in green, while subunits with relatively higher percentages of bayland area below MSL are highlighted in red. Subunits with moderate percentages relative to other subunits are highlighted in yellow.

	Proportion of baylands below MSL

	(relative to all area below HAT)
Haystack	0%
City of Petaluma - South	6%
Ancient Marsh	9%
Bahia	35%
Lakeville	44%
Burdell Unit	67%
San Pablo Bay	68%
False Bay	89%

Overtopping

Overtopping occurs when the elevation of sea level exceeds the crest height of a levee or berm protecting a diked bayland. At first, overtopping will occur during rare and sporadic flood events, with the frequency of overtopping increasing as sea levels rise (Figure C-11). Overtopping elevations were mapped as a part of BCDC's *Adapting to Rising tides Bay Area* project using data from SFEI's San Francisco Bay Shore Inventory. Segments were assigned overtopping values based on elevation relative to MHHW. Figures C-12 and C-13 below show low points on levees protecting diked baylands. Diked baylands with more low points in protective levees will overtop sooner than areas with more robust protective levees, and are less resilient to rising sea level. Areas that overtop at 12" likely overtop today during king tides (predictable extreme tides that occur a few times a year), and are likely to overtop on a daily basis by 2030-2040 according to CA OPC's medium-high risk aversion planning timeline (CA OPC 2018). Areas that overtop at 24" will likely overtop on a daily basis between 2050-2060, with overtopping during king tides and storm events occurring sooner. Without adaptation, these sporadic flooding events will occur more and more frequently as sea-level rise until inundation becomes permanent.

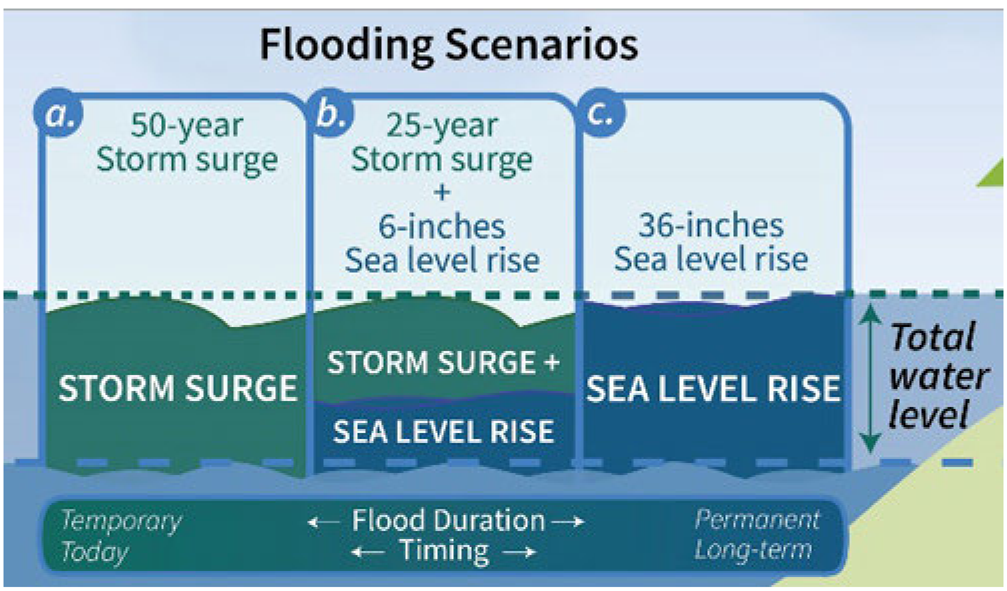


Figure C-11. Vulnerable areas will be exposed to temporary flooding on a sporadic basis even before they are permanently inundated by sea-level rise. Figure from BCDC's Art Bay Area program.

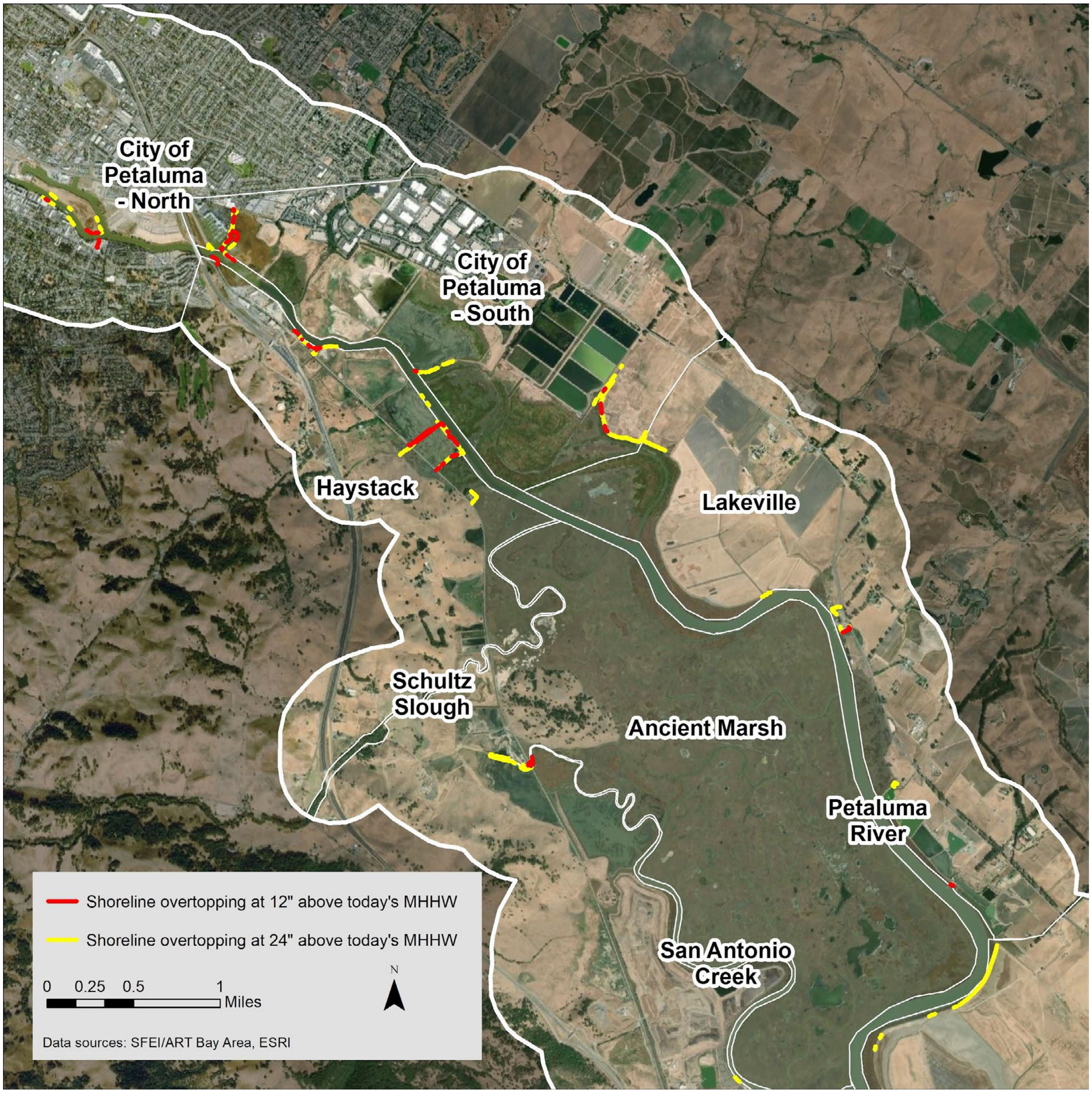


Figure C-12. Shoreline overtopping at 12” and 24” above today’s MHHW for selected levees in the northern half of the study area. Segments symbolized in the map were selected based on proximity to main channels and diked baylands. Some segments shown are not the first line of defense and therefore may not be subject to overtopping at these levels unless external levees are compromised.

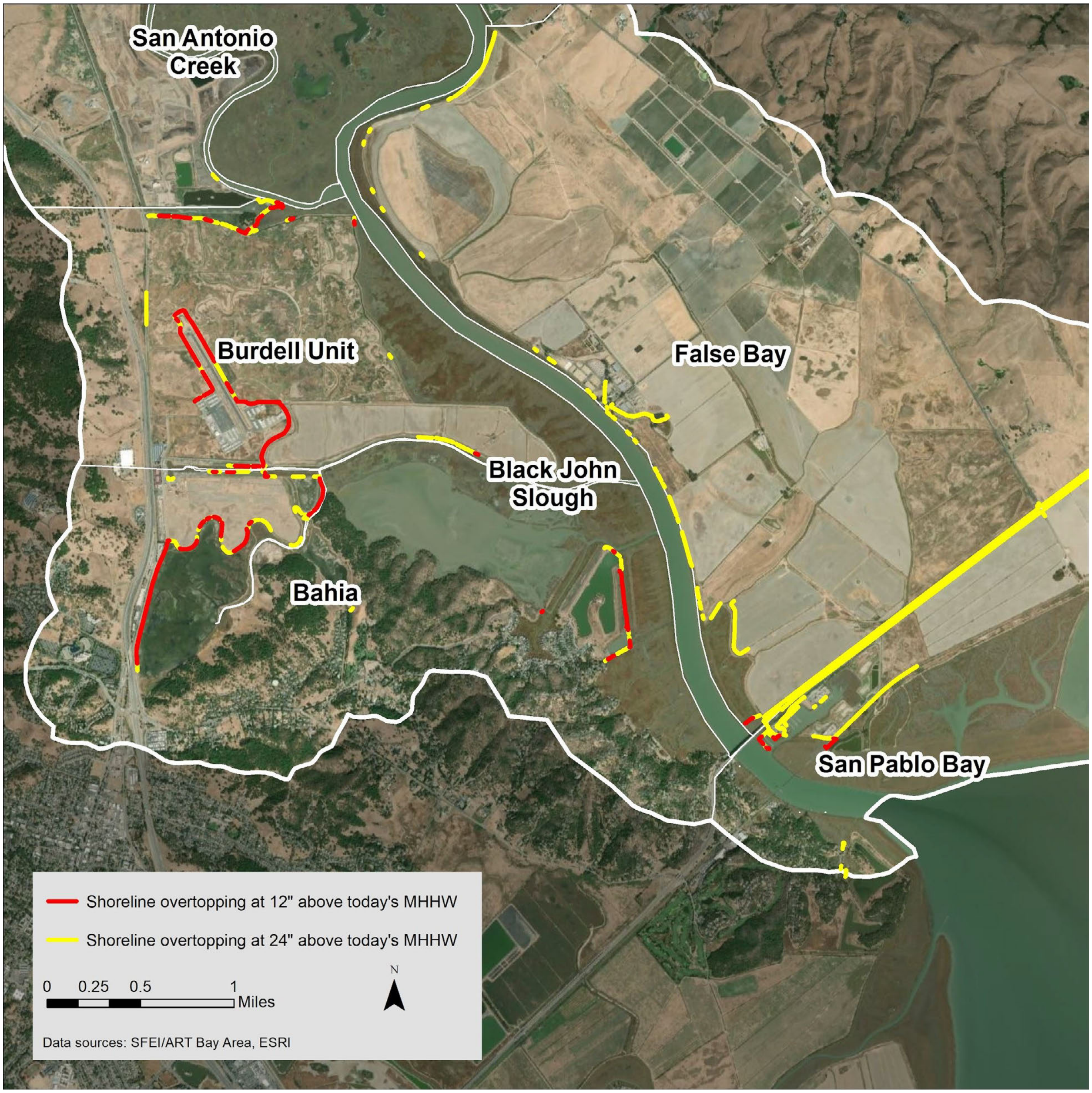


Figure C-13. Shoreline overtopping at 12” and 24” above today’s MHHW for selected levees in the southern half of the study area. Segments symbolized in the map were selected based on proximity to main channels and diked baylands. Some segments shown are not the first line of defense and therefore may not be subject to overtopping at these levels unless external levees are compromised.

The following tables allow a direct comparison of relative marsh resilience between subunits according to the metrics studied for this report. For the area below HAT (tidal areas and diked baylands), Ancient Marsh, City of Petaluma - South, and Haystack rank as the most resilient subunits, based on elevation metrics (Table C-7). With large areas at low elevations relative to the tides, False Bay and San Pablo Bay rank lowest in resilience based on these metrics.

Table C-7. Comparison of relative resilience across subunits, for area below HAT (which includes both marsh and diked baylands). The Ancient Marsh subunit is most resilient according to these metrics and the False Bay subunit is least resilient. The subunits are sorted according to the sum of their relative resilience rankings across the three metrics.

	% below MHW	% in lower third of vegetation tolerance	Skewness
Ancient Marsh	35%	6%	-3.6
City of Petaluma - South	43%	18%	-3.2
Haystack	34%	20%	-1
Lakeville	65%	11%	-0.5
Burdell	86%	11%	0.4
Bahia	87%	17%	-0.4
San Pablo Bay	86%	34%	0.3
False Bay	96%	25%	1.4

For existing tidal marsh, Haystack, Ancient Marsh, and Lakeville rank highest in resilience (Table C-8). Existing marshes with lower resilience based on elevation and vegetation metrics are located in the San Pablo Bay, Bahia, and False Bay subunits. Extensive restorations in these subunits mean existing marshes are relatively lower in elevation compared to more established marshes.

Table C-8. Comparison of relative resilience across subunits, for existing tidal marsh. Existing marsh in the Ancient Marsh, Burdell, and Haystack subunits is most resilient according to these metrics and existing marsh in the San Pablo Bay subunit is least resilient. The subunits are sorted according to the sum of their relative resilience rankings across the three metrics; in this case, the top three subunits received the same score.

	% below MHW	% in lower third of	Skewness	UVVR

		vegetation tolerance		
Ancient Marsh	28%	4%	-3.9	0.12
Burdell	54%	5%	-5.7	0.03
Haystack	11%	4%	5.0	0.06
Lakeville	31%	7%	3.8	0.07
City of Petaluma - South	33%	9%	1.9	0.07
False Bay	49%	14%	-2.6	0.06
San Pablo Bay	43%	15%	-2.8	1.96
Bahia	70%	12%	50.0	0.73

*The UVVR metric includes marsh and tidally-connected, recently restored areas that have yet to reach marsh elevation; the other metrics include only existing tidal marsh.

Summary by Unit

Ancient Marsh

With 86% of area below HAT remaining as tidal marsh, the baylands of the Ancient Marsh are the least disturbed of any subunit. This is reflected in the resilience metrics, where Ancient Marsh scores highly. Ancient Marsh had the lowest skewness of any subunit, indicating its elevation distribution is concentrated in the high end of the range. This concentration at high marsh elevations also reveals itself in the proportion below MHW metric (35%, second lowest among subunits) and the proportion of marsh vegetation in the lower third of the vegetation range (6%, lowest among subunits). Ancient Marsh did not score as well in the UVVR metric (third highest at 0.12), indicating a higher proportion of unvegetated marsh pannes and flats in the expansive marsh plain compared to the fringing marshes in other subunits. Because the UVVR metric also includes tidally-connected restorations, the Petaluma Marsh Expansion and Restoration Project's unvegetated area also raises the Ancient Marsh subunit's UVVR.

While most of the Ancient Marsh subunit was never diked, one area (the Petaluma Marsh Expansion and Restoration Project) was formerly diked and was recently restored to tidal action in 2006-2007. Ninety six percent of the site is still below MHW in elevation, and 44% is in the lower third of vegetation tolerance. This recent restoration also contributes to the relatively high UVVR for the Ancient Marsh subunit.

Despite high elevation capital in the Ancient Marsh subunit, resilience is hindered by lack of migration space. Migration space and sediment differential may be better indicators of persistence over time than elevation capital alone, and Petaluma Marsh does not score well for migration space (Thorne et al. 2018). Redwood Landfill may present a unique but challenging transition zone restoration opportunity in the Ancient Marsh Unit. But much of the transition zone elevation (other than at Neils Island and the landfill) is cut off by the rail line. There may be an opportunity to restore transition zone habitat by enhancing tidal connectivity under the rail line, for instance at San Antonio Creek. Measures of diked bayland resilience do not apply in the Ancient Marsh subunit, which remains connected to the tides.

Bahia

Though much of the Bahia subunit is relatively low in elevation today, a large area has been restored to tidal action. In this recently-restored area, elevation is low (96% below MHW, 47% in lower third of vegetation tolerance), but elevation is increasing as sediment accretes. Among tidally-connected subunits, Bahia scores relatively low on the scale for marsh resilience metrics given its recent restoration and subsided condition prior to breaching. For the area below Highest Astronomical Tide, skewness in the Bahia unit is slightly negative, indicating that there is more area at the higher end of the elevation range than the lower end. However, even if the skew is toward higher elevations, 87% of these elevations are below MHW (second highest among subunits). Bahia is mid-range for the vegetation range metric, with 12% of vegetation in existing tidal marsh falling in the lower third of the range.

While existing fringing marsh in the Bahia unit has very few unvegetated marsh pannes and flats, overall the subunit has a high UVVR relative to other subunits because of the large Bahia restoration, which still remains largely unvegetated more than 10 years after tidal action was restored to the area.Transition zone on the western edge of the Bahia unit is cut off from bayland elevations by US Hwy 101 and the rail line, which are built along the edge of the baylands. There is subsided diked bayland in the Bahia unit at the Leveroni property, as well as low-elevation muted tidal marsh at Cemetery Marsh. Levees along the eastern side of the Leveroni property north of Cemetery Marsh overtop at 12” above today’s MHHW, indicating high vulnerability of this parcel to rising sea level.

Burdell Unit

The Burdell Unit, much of which is diked bayland, scores relatively low in marsh resilience metrics, though existing fringing marsh along the Petaluma River is in good condition. For the area below Highest Astronomical Tide, the Burdell Unit has slightly positive skewness (elevations concentrated at the lower end of the range) and 86% of the area is below MHW. However, for existing marsh, skewness is the lowest of any subunit, indicating that the fringing marsh fronting the Burdell Unit is very concentrated in high marsh plain elevations. The resilience of the fringing marsh is also reflected in the percent of this marsh in the lower third of vegetation tolerance, which is among the lowest of any subunit at 5%. The marsh is also highly vegetated, with the lowest UVVR of any subunit.

CDFW is currently exploring options for restoring tidal action to the Burdell Unit. If this were to occur and the unit were to reach marsh elevation, opportunity for marsh transgression as sea-level rises would require substantial infrastructure changes to the rail line and Hwy 101 to allow reconnection to the transition zone. Transition zone is separated west of the Burdell Unit by US Hwy 101 and the rail line, which are built along the edge of the baylands. Currently, the Burdell Unit's diked baylands are not resilient to sea-level rise due to low elevations and poorly maintained levees. As reported in stakeholder interviews, diked baylands in the Burdell unit are subject to frequent overtopping, with levees along the northern side of the property overtopping at 12" above today's MHHW.

City of Petaluma - South

The City of Petaluma - South unit has almost no subsided areas below mean sea level. Second only to Ancient Marsh, 77% of the area below Highest Astronomical Tide is existing tidal marsh. For the area below HAT, just 43% is below MHW and the skewness is -3.2, among the lowest (most resilient) values. The City of Petaluma - South unit scores in the middle of the range for percent in the lower third of vegetation tolerance and UVVR. A rare opportunity for transition zone management exists in this unit, as baylands are adjacent to undeveloped migration space (protected and unprotected) in this subunit. There may also be an opportunity to integrate with the treatment process at the Ellis Creek wastewater facility and create a transition zone with a salt-to-brackish marsh gradient using treated wastewater. Diked baylands exist in this unit but are not as low-elevation as those in other units. While some diked baylands in the City of Petaluma - South subunit are subject to flooding at lower levels, the area south of Lakeville Highway along the Petaluma River east of US 101 is generally protected to 48", with a few low spots at 24."

False Bay

False Bay is perhaps the least resilient subunit to rising sea level based on the metrics analyzed here. Today, just 4% of the area below the Highest Astronomical Tide is tidal marsh, and 96% of the False Bay subunit is below MHW. The distribution of elevation values is skewed toward the lower end of the range. The small band of fringing marsh is not as resilient as that of other subunits, with percentage in the lower third of the vegetation range among the highest of all subunits and nearly half of this fringing marsh below MHW. UVVR for False Bay fringing marshes falls in the low in the range (more resilient) at 0.06. Though there is some undeveloped migration space in the subunit, there is a significant area of diked baylands separating this migration space from tidal marsh along the Petaluma River. The False Bay area itself is so low that tidal marsh may not be the habitat restoration target except at the higher-elevation inland edges.

One positive resilience story in the False Bay subunit is Carl's Marsh, restored to tidal action in 1994. The site has quickly accreted to elevations comparable to much older marshes in the study area, with just 34% of elevation below MHW and just 6% in the lower third of vegetation tolerance.

This unit is the most dramatic example of a subsided diked bayland, with 89% of the unit below mean sea level, making it vulnerable to deeper flooding when levees are overtopped. False Bay has some low points in levees along the Petaluma River, though none as low as at Burdell. Low points in the levee along this subunit overtop at 24"above today's MHHW, with much of the levee length overtopping at 36."

Haystack

In the Haystack unit, Gambinini Marsh is contiguous with the Ancient Marsh, divided only by Schultz Slough. Therefore, Gambinini Marsh metrics closely match those of Ancient Marsh. Just 34% of the area below HAT is below MHW in the Haystack unit, the lowest of any unit. At just 4%, the percentage of existing marsh in the lower third of the vegetation range is also the lowest of any unit. Skewness falls mid-range relative to the other subunits, and UVVR is quite low (more resilient) at 0.06. Overall, the metrics calculated here indicate that the marsh in the Haystack unit is in good condition and likely to be more resilient to sea-level rise than the marsh in other subunits. However, this resilience may be compromised by lack of migration space, as there are major barriers to marsh migration in this unit, with much of the transition zone sandwiched between US 101 and the rail line. Some land at appropriate elevation for marsh migration as sea levels rise does exist between the river and the SMART rail line. The diked baylands of the Haystack subunit are fairly resilient relative to other diked baylands in the study area; the entire Haystack unit is above MSL. In the Haystack subunit, one small developed parcel and one section of the railroad embankment are subject to overtopping at 24" TWL.

Lakeville

The Lakeville subunit is characterized by diked agricultural baylands fronted by fringing marsh along the Petaluma River, with one larger patch of marsh just north of Cloudy Bend. Lakeville falls mid-range among subunits for percent of area below MHW and skewness, both for existing marsh and area below HAT. Existing marsh is fairly high-elevation relative to other subunits, with 31% below MHW and just 7% in the lower third of vegetation tolerance. UVVR is mid-range at 0.07. Opportunities for migration space and transition zone protection exist in the Lakeville subunit, where existing marsh is bordered by agricultural land rather than backed by a highway or railroad. Though heavily subsided at Cloudy Bend, the diked baylands of the Lakeville subunit are slightly better-protected than False Bay and Burdell, with a few low spots overtopping at 24" but most of the levee overtopping at 48" or more above today's MHHW.

San Pablo Bay

Like in the Bahia subunit, a large portion of the San Pablo Bay subunit has been recently restored through planned breaches at the Sonoma Baylands and Dickson Unit (Sears Point) restoration sites. Levees at Sonoma Baylands were breached in 1995, and Dickson Unit levees were breached 20 years later in 2015. The DEM used for this analysis does not account for any of the recent accretion at Dickson Unit. However, even 10+ years ago Sonoma Baylands had some area in the vegetation range, even if 84% of vegetated area fell within the lower third of the range. These elevation metrics indicate that marsh resilience is increasing over time.

Overall, 86% of the San Pablo Bay unit falls below MHW (including restoration sites, strip marsh, and diked baylands). This unit also scores poorly for percent of existing marsh in the lower third of vegetation tolerance (highest among subunits at 15%). Skewness falls mid-range, while UVVR is very high because recently restored areas are still unvegetated. The rail line and State Route 37 present barriers to habitat connectivity and marsh migration in the San Pablo Bay unit. This will reduce long-term resilience unless the transportation infrastructure is redesigned to promote better connectivity (i.e. elevated on a causeway). Resilience of the unit as a whole has been improved through tidal restoration on the bayward side of the rail line, but diked baylands behind the rail line are very low-lying, below MLLW. Some levees along State Route 37 in the San Pablo Bay overtop at 24” above today’s MHHW.

Appendix D. Marsh Evolution

Introduction

In order to prepare for future sea-level rise, we must understand how habitats in the study area will evolve in response to environmental changes. Previous studies have indicated that the Petaluma River tidal marshes are some of the most resilient in the San Francisco Estuary because of the high sediment supply (Stralberg et al. 2011) and recent work suggests that sediment supply will roughly equal sediment demand under several future climate change scenarios (Dusterhoff et al. 2021). However, compared to other estuaries along the west coast, these same marshes are the least resilient because there is very little room for marsh migration into currently upland habitats (Thorne et al. 2018). This chapter will evaluate how the existing marshes within the study area and proposed restoration and adaptation actions will evolve in response to more recent sea-level rise projections. In addition, we use existing models to understand how a representative sample of species responds to these changes in habitat.

Methods

We are taking advantage of existing models of habitat and wildlife response to sea-level rise to assess the performance of each of the management scenarios. Stralberg et al. (2011) used a hybrid approach to marsh accretion modeling in which projections from a point based accretion model were spatially interpolated across the San Francisco Estuary. Hayden et al. (2019) modified these models to incorporate more extreme sea-level rise projections and to allow variation of timing of restoration within an evolving landscape.

Here we provide a brief description of the Marsh98 accretion model we applied in the study, although Stralberg et al. (2011) provides additional detail. Marsh98 models accretion (the vertical accumulation of organic material and inorganic sediment) as a function of the availability of suspended sediment, depth and periods of inundation by tides and the addition of organic material. For this analysis we used constant values of 225 mg/L of suspended sediment and 2 mm/year of contribution from organic material, values that are in between the high and low scenarios in Stralberg et al. (2011) for the study region. Compared to the rest of the Estuary, 225 mg/L is very high suspended sediment concentration. The model does not include the effects of erosion that are likely to occur due to changes in tidal prism or from wind wave forces. We applied a “medium-high risk” sea-level rise curve from the 2018 State of California sea-level rise guidance which projects an increase in sea level by 1.9’ by 2050 and 6.9’ by 2100 (California Ocean Protection Council 2018). The starting elevation of each model run was based on the LEAN-corrected digital elevation model (DEM) developed by Buffington et al. (2019), which corrects elevation errors due to vegetation.

In all cases, the model starts marsh evolution in 2010 for all areas that are currently open to tides and continues until 2100. Because it starts in 2010, accretion that occurred between 2010 and 2022 is not captured in this analysis. We used habitat classes from Stralberg et al. (2011) to categorize the marsh surface into habitat classes. We then summed the acreage of each habitat class within each potential subunit.

Management scenarios

In the No-action scenario, we assume areas currently protected by flood control structures will be maintained. Thus only areas currently open to tidal exchange are allowed to accrete in the model. Marshes are able to migrate horizontally where there are no barriers (i.e. levees) to tidal exchange.

We also examined a Landscape Vision in which we assumed all areas in the study area with potential connections to tidal action are restored. We tested several iterations of this scenario in which restoration in all areas was initiated in 2010, 2030, 2040 and 2050. These iterations allowed us to assess the sensitivity of marsh accretion to the timing of restoration within the study area.

Results

Marsh habitat evolution

Our models project that the acres of bayland habitats will evolve in a dynamic nature throughout this century. We project an increase in low and mid-marsh habitat through 2050 (Figure D-1). These increases in marsh habitat are the result of mudflat accreting to marsh elevations and from marshes migrating into formerly upland elevations. Following 2050, we project a continued increase in low marsh habitat that results from additional mudflats accreting to low marsh elevation. Between 2050 - 2080, the area of mid-marsh habitat is relatively stable, with some continued marsh migration into formerly upland habitats. Between 2080 and 2090, we project conversion of mid-marsh habitats to low marsh habitat as sea-level rise rates increase.

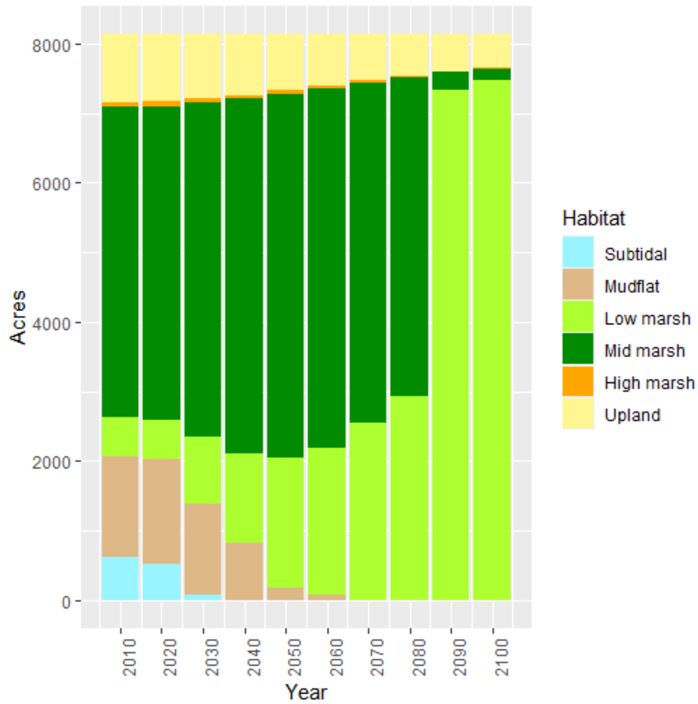


Figure D-1. The acres of bayland habitat for observed (2010) and modeled future conditions (2020-2100). Each column indicates the results for the year indicated on the x axis. Only areas that are open to potential tidal exchange are included in the analysis.

Skewness of marsh elevations

We examined the skewness of marsh elevations within each subunit and included only areas that are open to tidal action. Note that the footprint that we include in the analysis is different than the numbers in the geomorphic evolution chapter (Appendix C) as we are including areas where upland marsh migration is possible (not constrained by levees, highways, railroad, etc) in future projections as opposed to existing marshes only. In general, the skewness of marsh elevations increases (more areas with lower elevations) in all subunits as sea levels rise (Figure D-2).

We find substantial variation in the change in skewness values across the subunits in the study area (Figure D-2). Skewness values start off negative at Ancient Marsh (more higher elevation areas) between 2010 and 2030 then remain with relatively low positive values through 2060. After 2060, the skewness values increase dramatically, particularly after 2080 as the marshes convert to primarily low elevations (Figure D-2). In contrast, many of the subunits that begin with a relatively low proportion of high elevations in 2010 (e.g.San Pablo Bay and Marin), retain skewness values near 0 throughout the study period (Figure D-2). This is probably due to the fact that elevations in newly restored sites have uniformly low elevations and then accrete in a uniform fashion. Thus the skewness of the distribution of elevations doesn't really change even though the elevations do as the restored marshes evolve with sea-level rise. The values in Bahia are much higher than in the other subunits because of the large area of mudflats and relatively little low marsh or upland area.

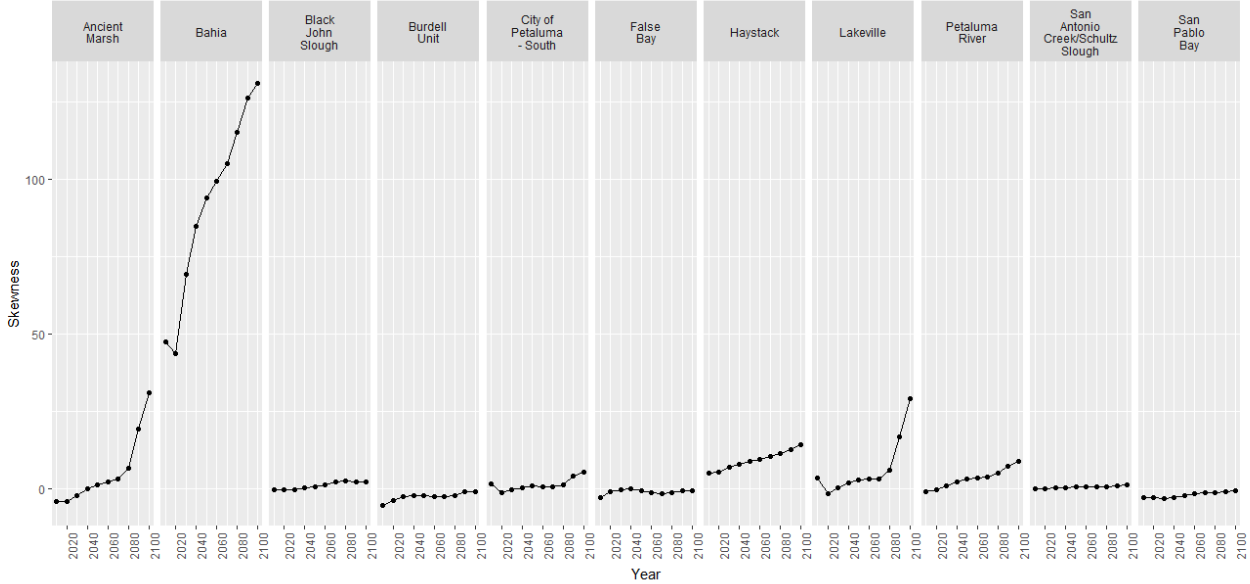


Figure D-2. Skewness of the distribution of tidal marsh elevation values within each subunit (vertical panels). Negative values indicate where the distribution of elevations includes higher elevations (more resilient) while greater positive values indicate where the distribution of elevations includes more lower elevations (less resilient). Values close to 0 indicate a relatively symmetrical distribution of both high and low elevations.

Percent of marsh in the lower third of vegetation tolerance

Similar to the skewness analysis above, we examined the percentage of marsh pixels within the lowest third of the vegetation tolerance across the entire study period. All subunits show a "J" shaped change in this metric. All subunits start with 25% or less of marsh elevations within the lower third of the vegetation tolerance zone and remain relatively constant through 2060 (FIgure D-3). By 2080, most subunits have greater than 75% of marsh pixels within the lower third of the vegetation tolerance zone and by 2090 many subunits are greater than 90% (Figure D-3).

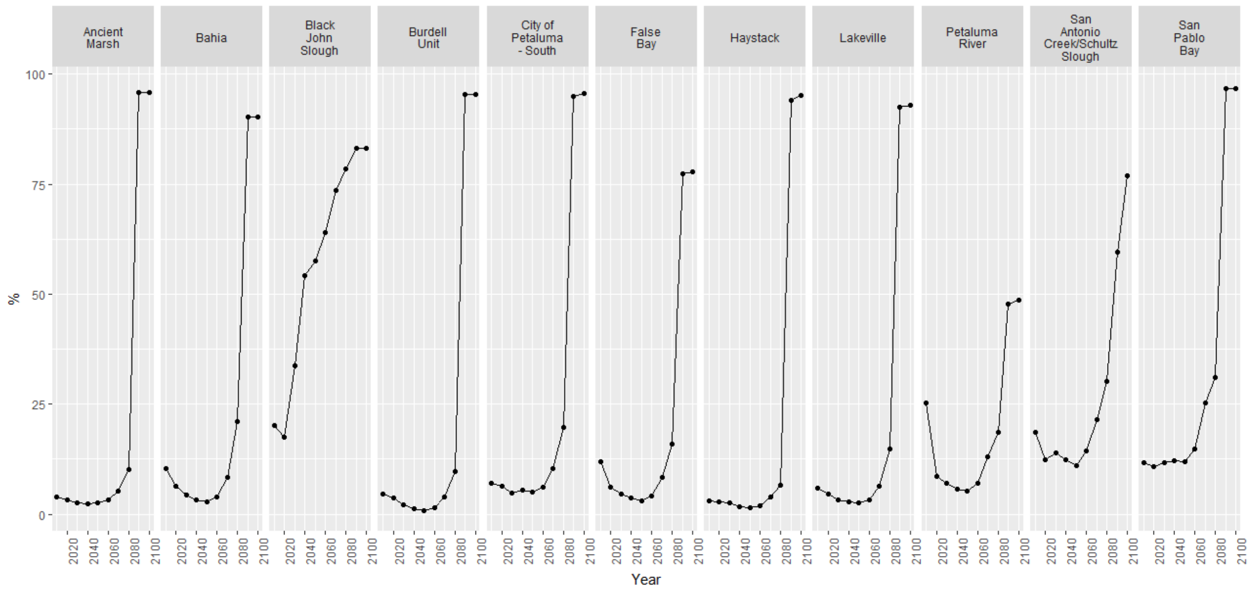


Figure D-3. The percent of raster cells within the lower third of the vegetation tolerance zone within each sub-unit (vertical panels).

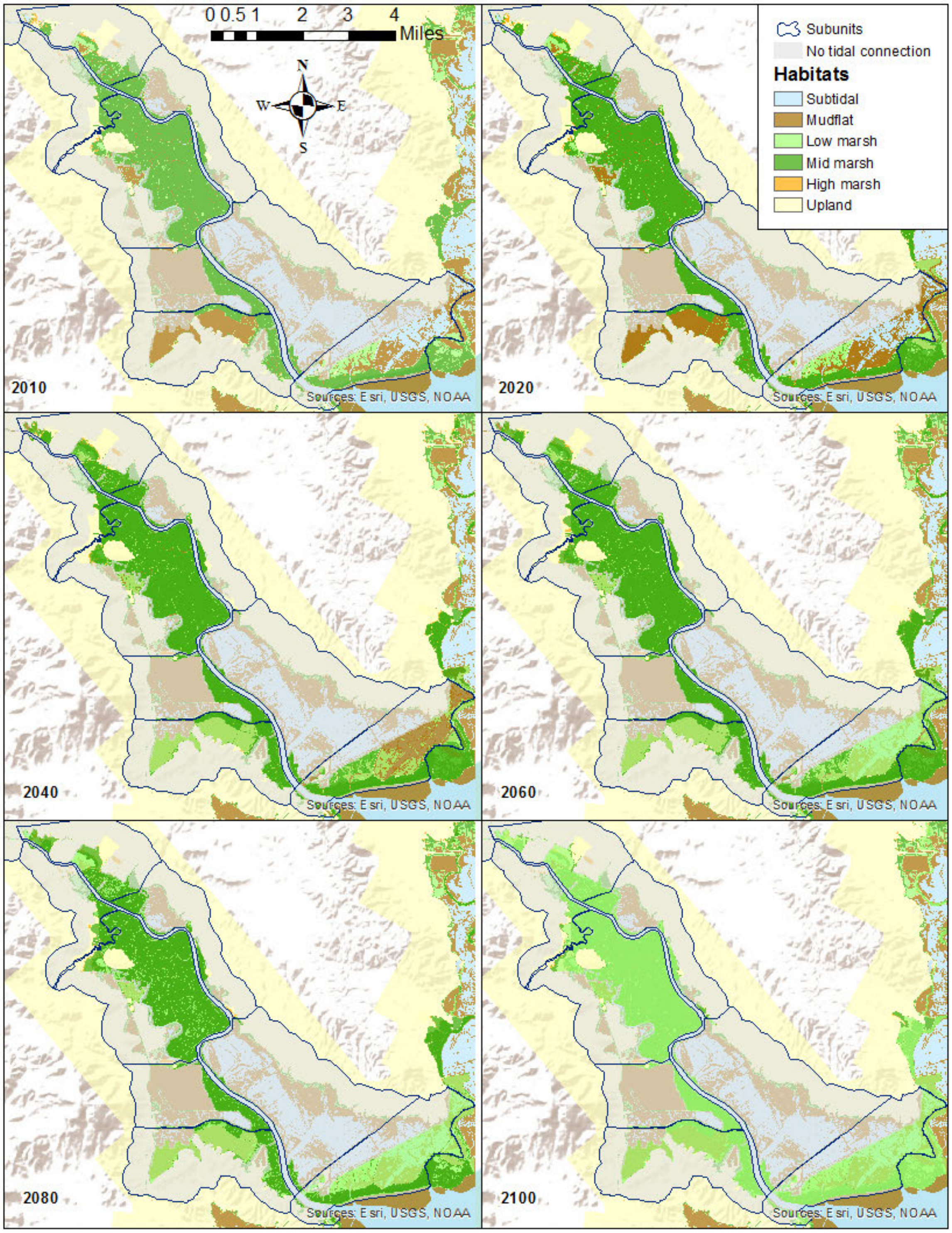


Figure D-4. Maps of tidal marsh habitat evolution from 2010 to 2100. Marshes were only allowed to evolve in areas that are currently connected to tidal exchange.

Subunit summary

Below we provide more detailed summaries for each of the subunits that have substantial marsh habitat during the study period. Because there isn't much habitat available, we do not provide detailed subunit summaries for the sloughs and Petaluma River subunits.

Ancient Marsh

The evolution of bayland habitats within the Ancient Marsh subunit largely follow the patterns of the study area as a whole according to the model projections (Figures D-4 - D-6). The subunit has by far the most marsh habitat available within the study area and we project that marsh habitats will be retained through 2100 but most of this habitat will convert to low marsh and some remaining high marsh by the end of the century. We project that approximately 100 acres of currently upland habitat will transition to tidal marsh within the Ancient marsh subunit during this century. We project that some of this transition will occur in a thin band around Neils Island (Figure D-7). There is additional potential transition habitat that occurs across three other private parcels west of Neils Island (Figure D-7). However, the model may be underestimating the constraints to tidal potential exchange by the SMART rail line or overestimating future tidal exchange through Schultz Slough.

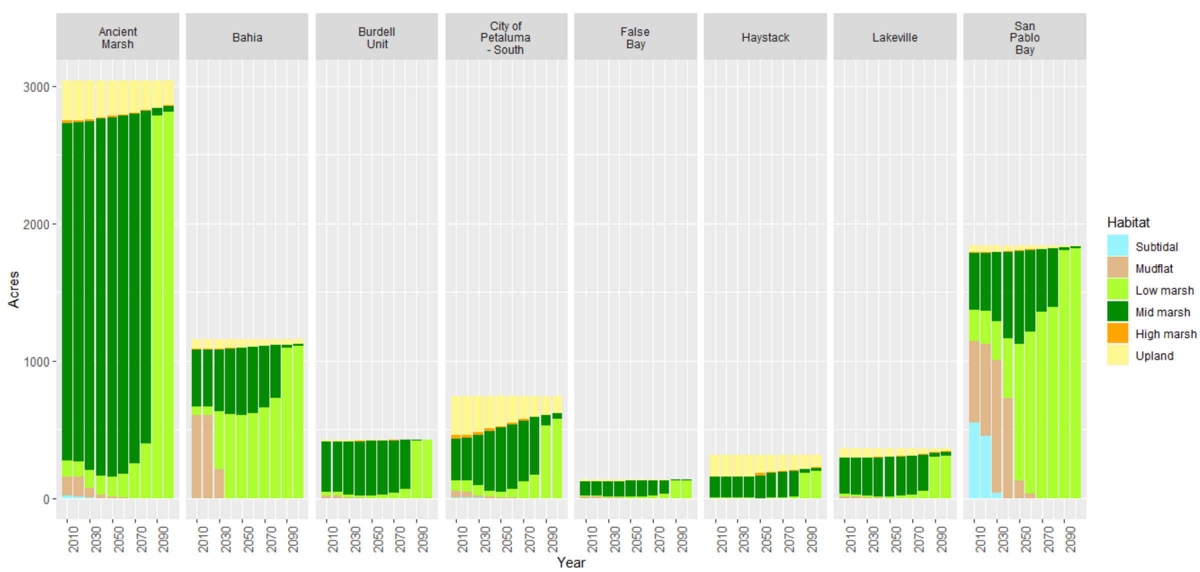


Figure D-5. Acres of bayland habitats in each subunit of the study area. Each site is represented by a panel. Model years are represented on the horizontal axis.

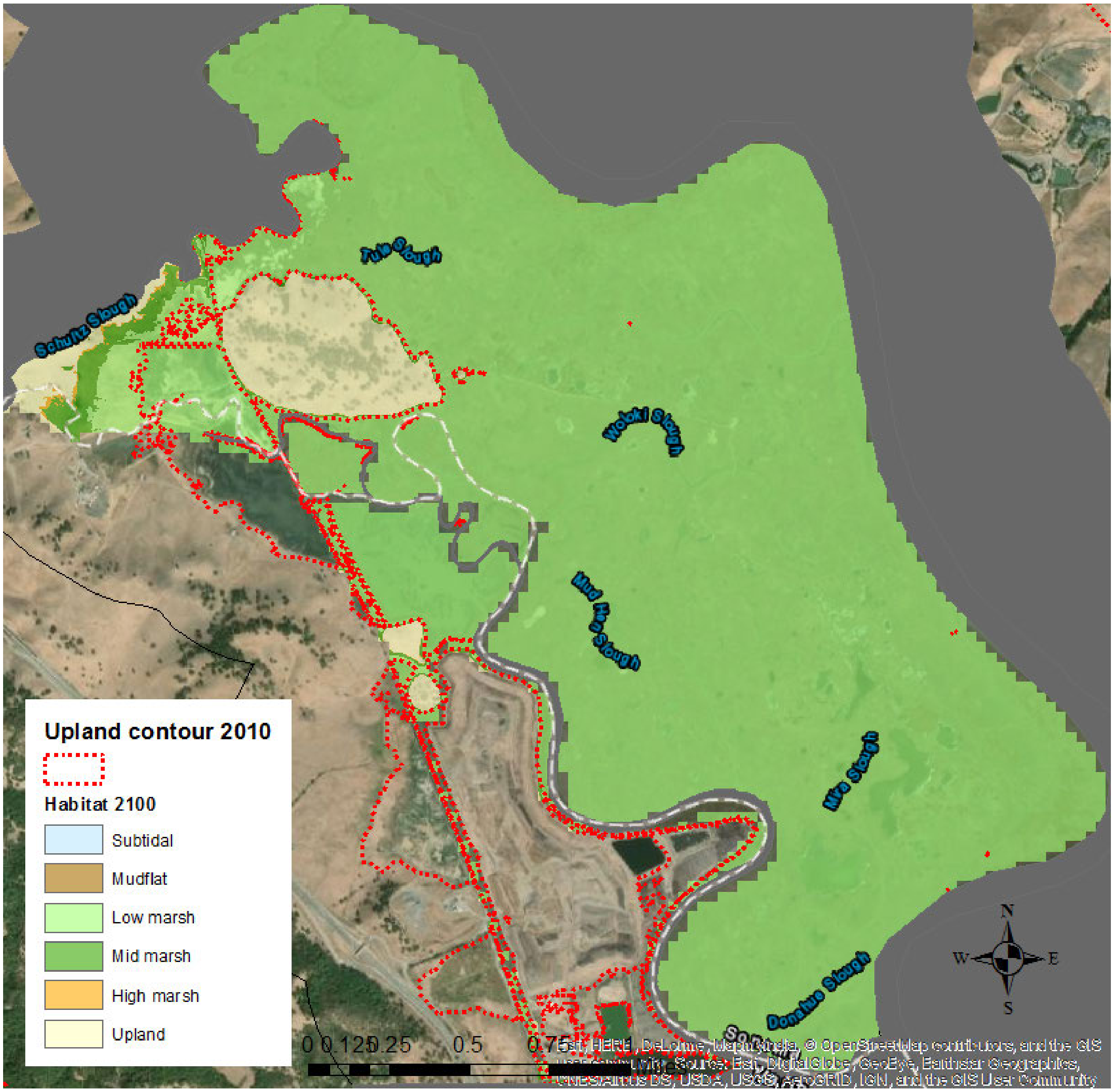


Figure D-6: Projected bayland habitats in 2100 in the Ancient Marsh subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

Lakeville

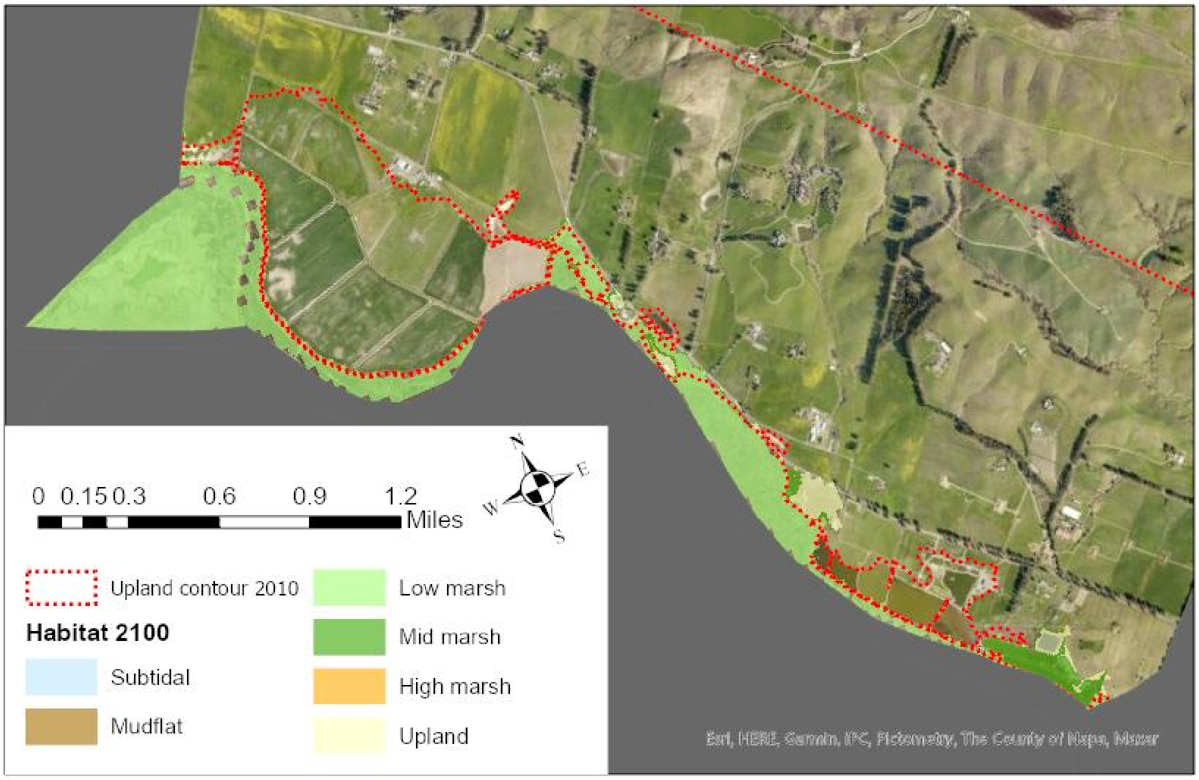


Figure D-7: Projected bayland habitats in 2100 in the Lakeville subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

Bahia

There are currently large areas of mudflat elevation habitat within Bahia corresponding to the recently restored areas.The model projects that this mudflat will accrete to low marsh elevation between 2030-2040. We project that the area of mid and high-marsh habitat will remain relatively stable until 2080 and then we project large areas of low marsh habitat through the end of the century. We project less than 50 acres of marsh migration into upland habitats (Figure D-8).

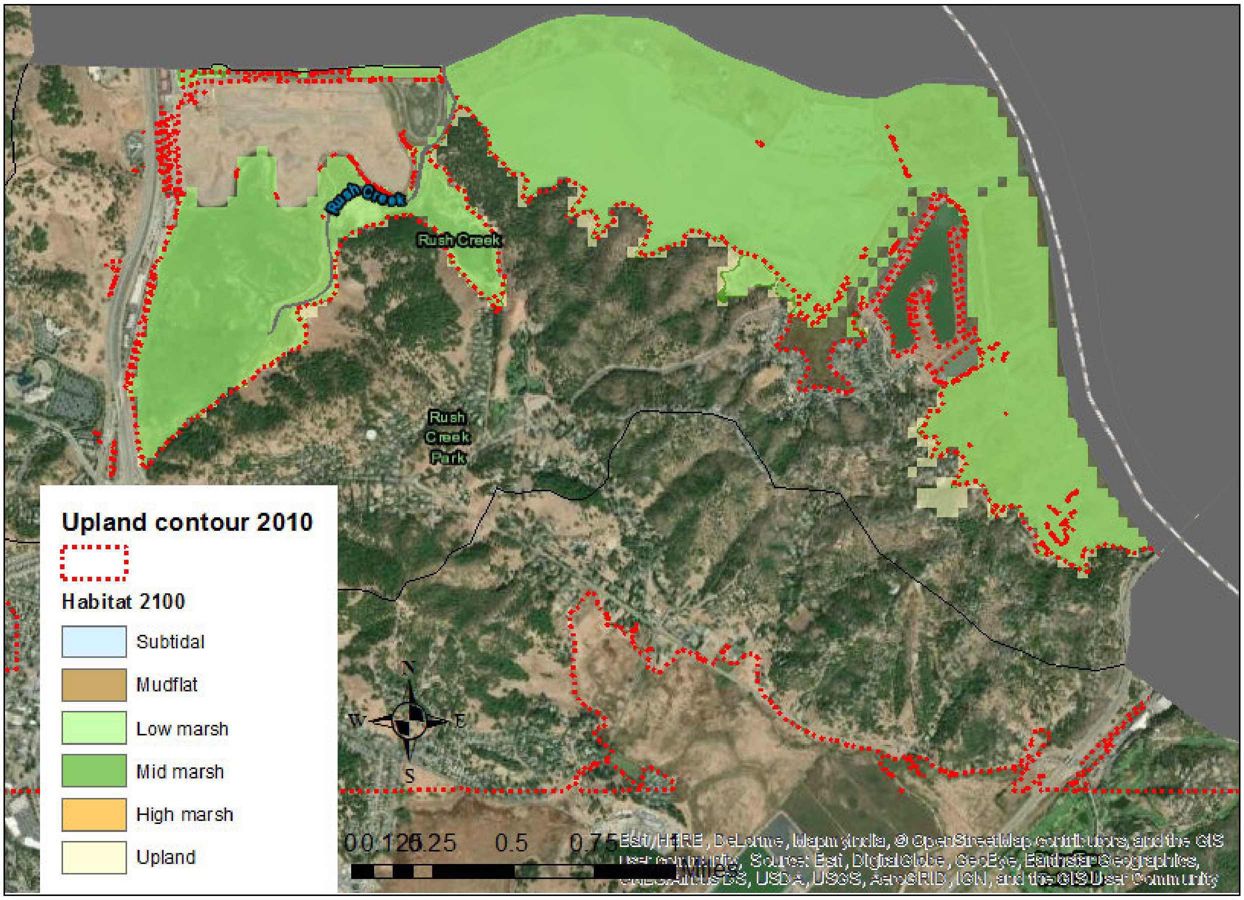


Figure D-8: Projected bayland habitats in 2100 in the Bahia subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

Burdell

We project that, without additional restoration, the Burdell unit will largely follow the general patterns of marsh evolution for the study area. The area of each bayland habitat will remain relatively stable until 2070. Between 2070 and 2080, we project that mid and high marsh habitats will convert to low marsh. In addition, without restoration or other enhancements, there is little marsh migration space available in the Burdell Unit (Figure D-9).

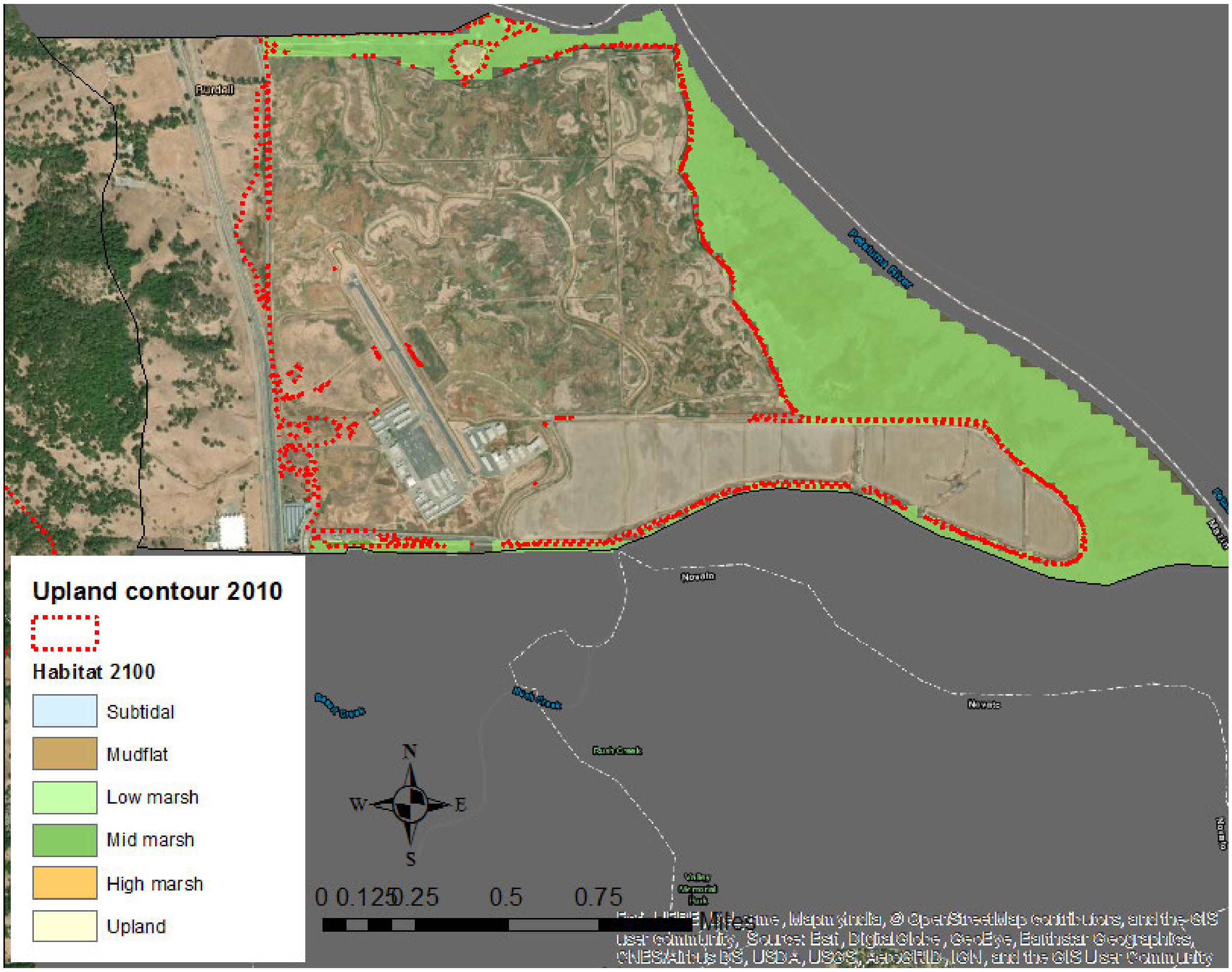


Figure D-9: Projected bayland habitats in 2100 in the Burdell subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

City of Petaluma South

The City of Petaluma South subunit currently has the most high marsh habitat of any subunit in the study area. However, the model projects declines in the area of high marsh beyond 2020, with only a slight increase in 2070. Much of the remaining high-marsh habitats within the subunit will be from marsh migration into upland habitat. This subunit has the greatest opportunities for marsh migration upslope and we project that approximately 150 acres of currently upland habitat could be converted to marsh habitat by 2100. The largest areas currently available for marsh migration are on private and City of Petaluma owned property just south of Rocky Memorial dog park and areas between Gray's Ranch restoration and the Ellis Creek Wastewater treatment plant (Figure D-10).

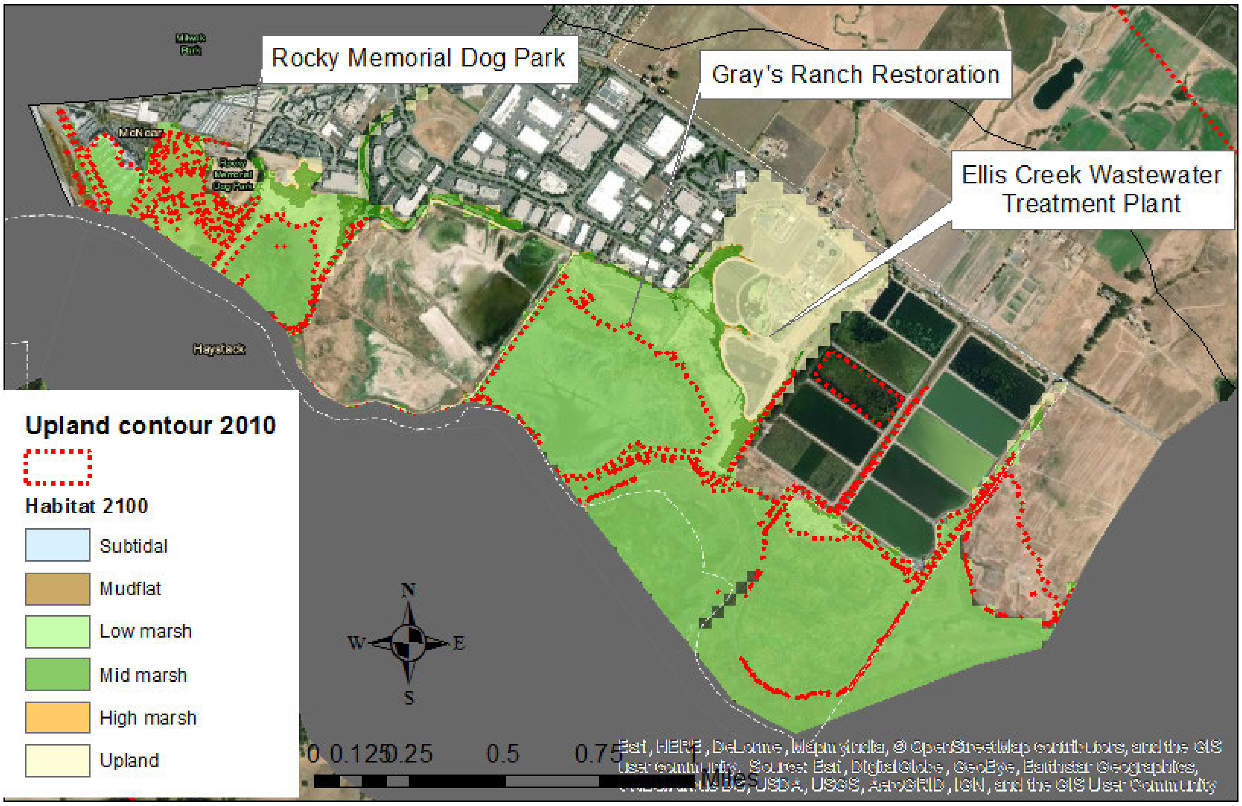


Figure D-10: Projected bayland habitats in 2100 in the City of Petaluma South subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

Haystack

The projections for Haystack follow the general projections within the study area with one exception. Between 2040 and 2050, we project an increase in over 15 acres of high marsh habitat within Haystack. This increase seems to result from mid-marsh accretion to high-marsh elevations as well as marsh migration into former upland habitats. There are some relatively large areas of marsh migration space just north of Schultz Slough, the southern boundary of the Haystack Unit. The SMART rail line is largely a barrier to marsh migration in this location as the upland boundary in the unit is defined by SMART rail line Figure D-11 but there are several culverts that do allow some muted hydrologic exchange.

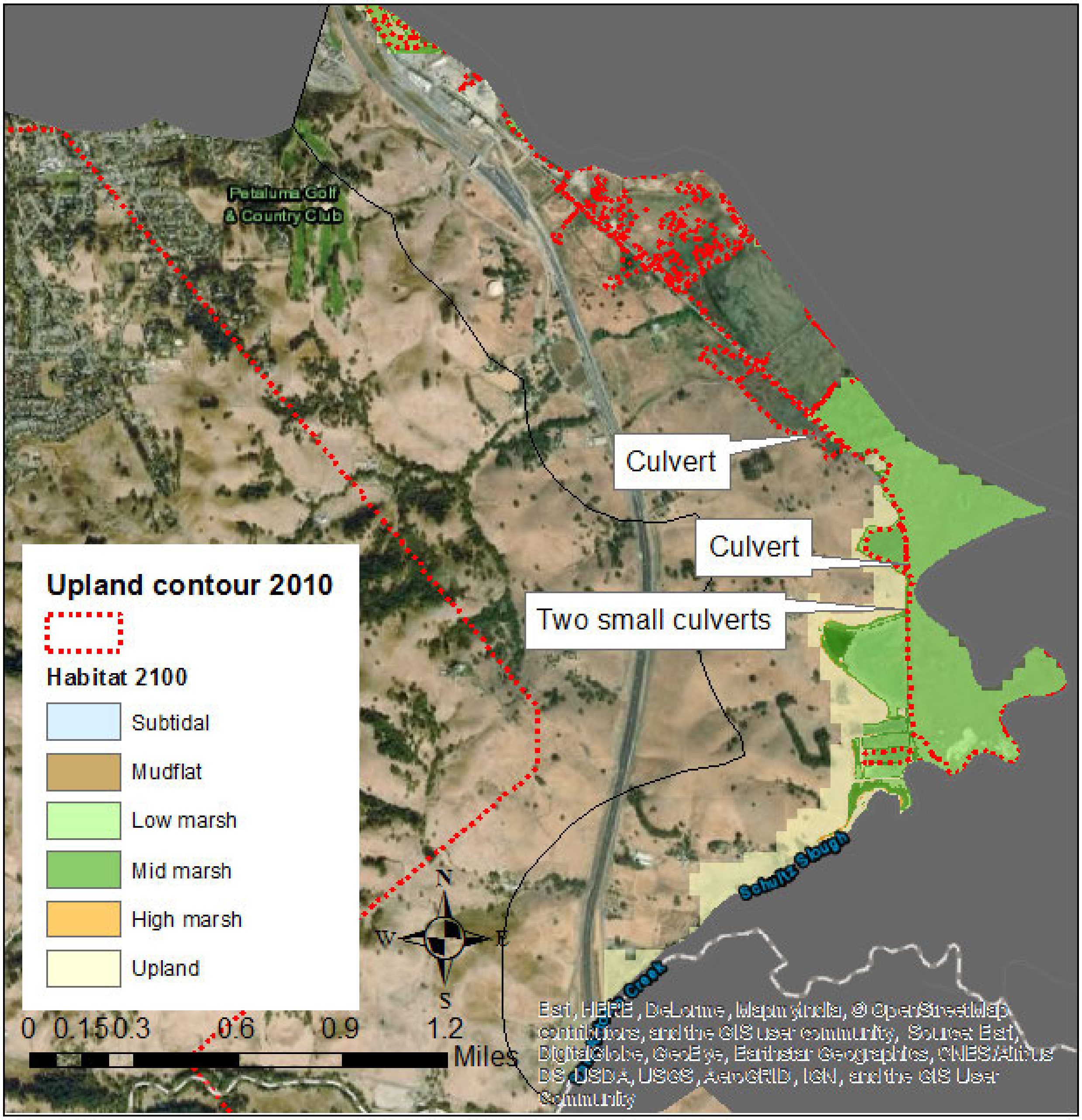


Figure D-11: Projected bayland habitats in 2100 in the Haystack subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

San Pablo Bay

The San Pablo Bay unit has the highest areas of subtidal and mudflat habitat in the study area.We project that these areas will largely accrete to marsh habitat elevations by 2060. However, the model projects that marshes will convert to mostly low marsh elevations between 2060 and the end of the century. Still, the model projects the highest area of marsh by 2100 than any other subunit in the study other than Ancient marsh highlighting the importance of recently restored areas.

There is limited space for marsh migration within the subunit without further restoration. The only available space is along existing levees or the levee that was breached as part of the Sears Point Restoration Project (note that the new levee is not accurately represented in Figure D-12).

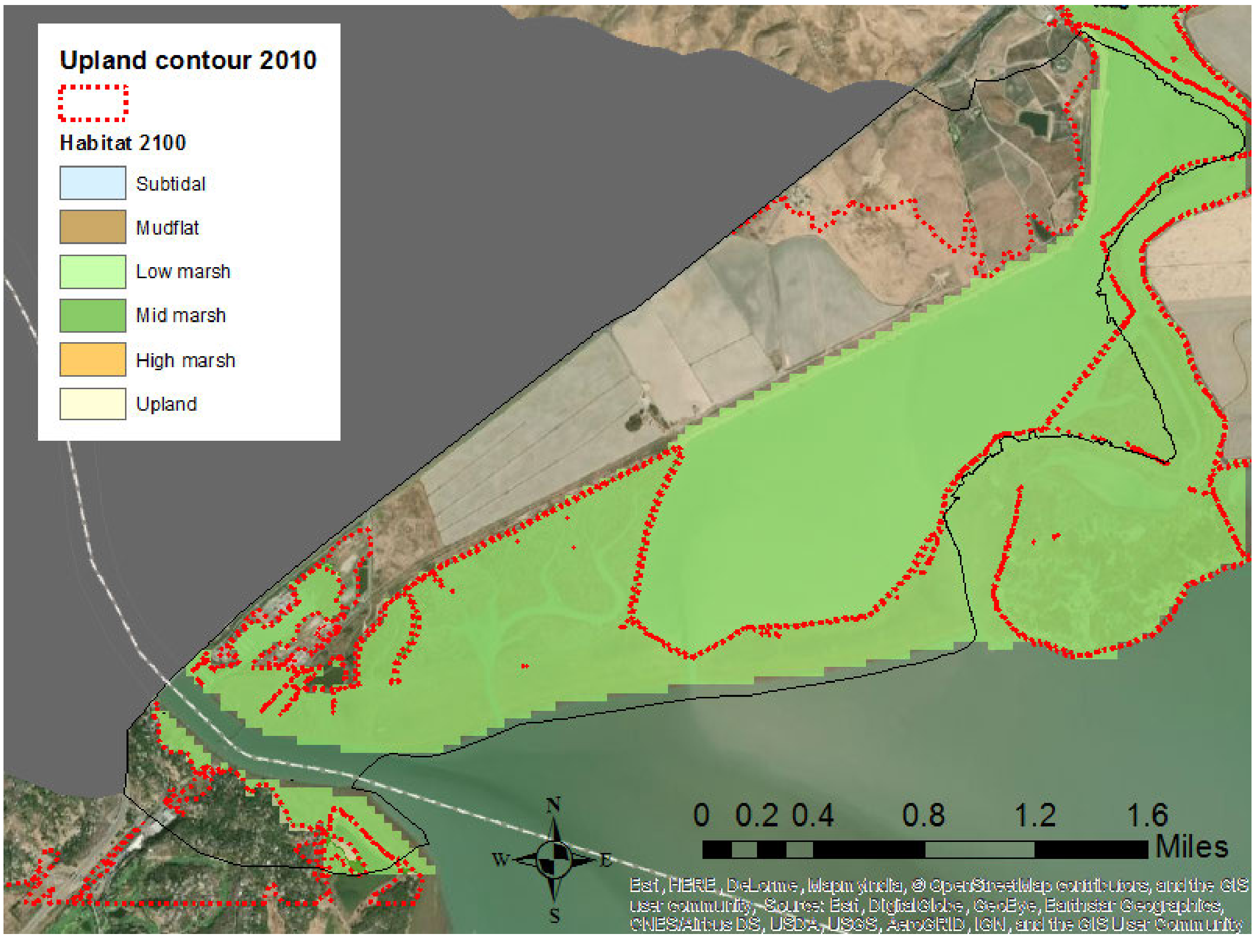


Figure D-12: Projected bayland habitats in 2100 in the San Pablo Bay subunit. The dashed red line marks the upland boundary in 2010 but does not reflect the new levee constructed as part of the Sears Point restoration project. Areas landward of the red line indicate unimpeded marsh migration space.

False Bay

In False Bay there is very limited extant marsh habitat and most occurs in relatively thin strips on the edge of the Petaluma River. This landscape unit has the least amount of marsh habitat than any other subunit both under current conditions and as sea levels rise. Carl's marsh has the most marsh habitat available within the subunit, and the marsh is a mix of mostly mid-marsh with some low marsh habitat. However, we project that this marsh will almost entirely convert to low marsh by 2100 (Figure 6 & 13). We found few opportunities for marsh migration in areas open to tidal exchange as much of the area in the subunit is protected by steep levees that won't support marsh migration (Figure 6 & 13). However, there is a small area available for marsh migration in the northern boundary of the subunit at the apex of the bend in the Petaluma River (Figure D-13).

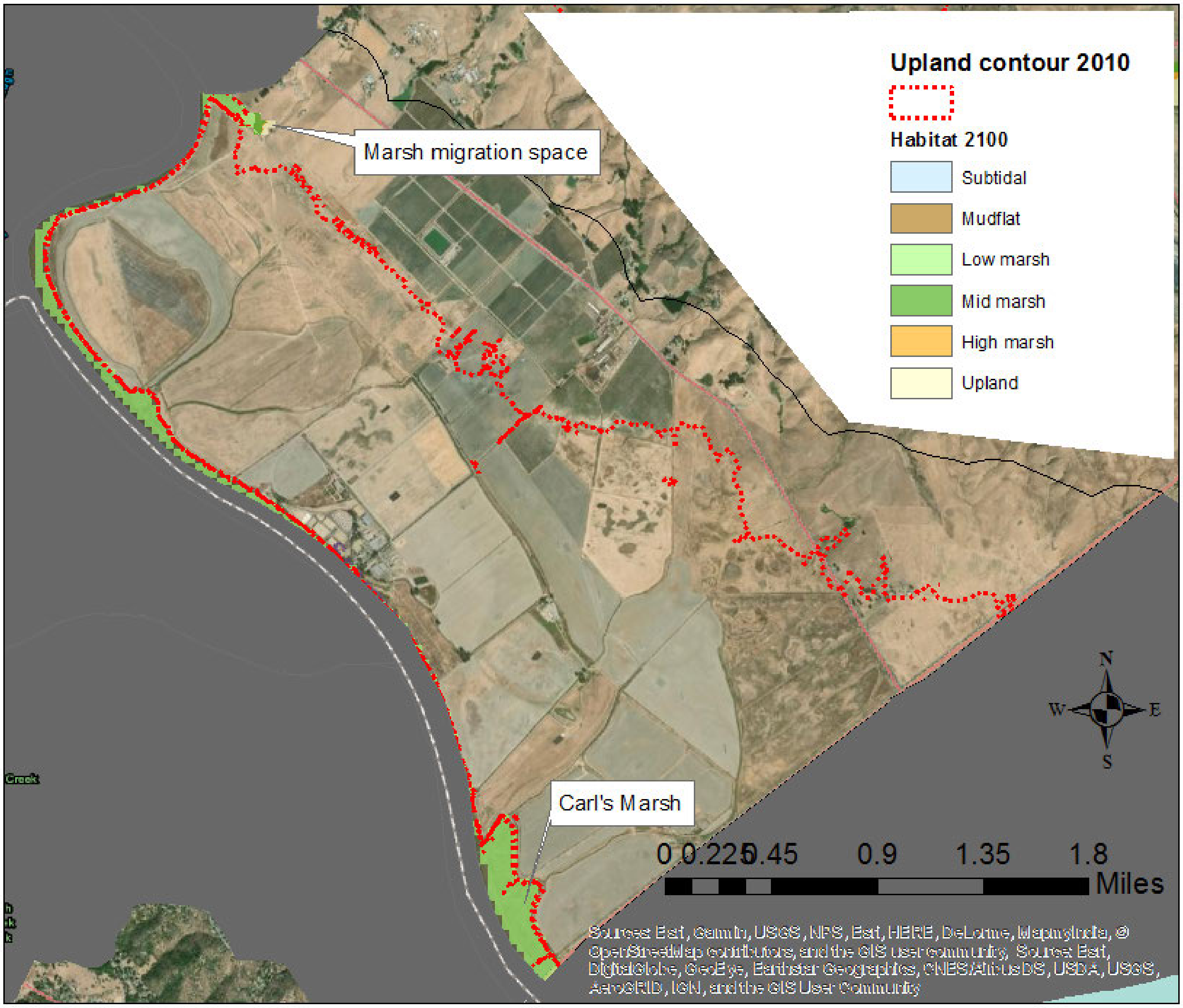


Figure D-13. Projected bayland habitats in 2100 in the False Bay subunit. The dashed red line marks the upland boundary in 2010. Areas landward of the red line indicate unimpeded marsh migration space.

Restoration Scenarios

The timing of restoration does affect the amount of tidal habitats that result from those actions at the end of the century. In particular, the amount of low marsh habitat resulting from restoration is very sensitive to the timing of restoration. For example, if all areas had been restored in 2010 we would have over four times the amount of low marsh habitat at 2100 than we would have if all marshes were restored in 2050 (Figure D-14). In contrast, we find that the amount of restored mid marsh and high marsh habitat at 2100 does not vary substantially depending on when restoration is initiated but it does vary substantially at earlier in the simulation, with much more mid and high-marsh habitat available the earlier restoration begins (Figure D-14). Rapid increases in the area of restored high marsh occur as sea levels increase and expose formally upland areas to tidal influence (Figure D-14).

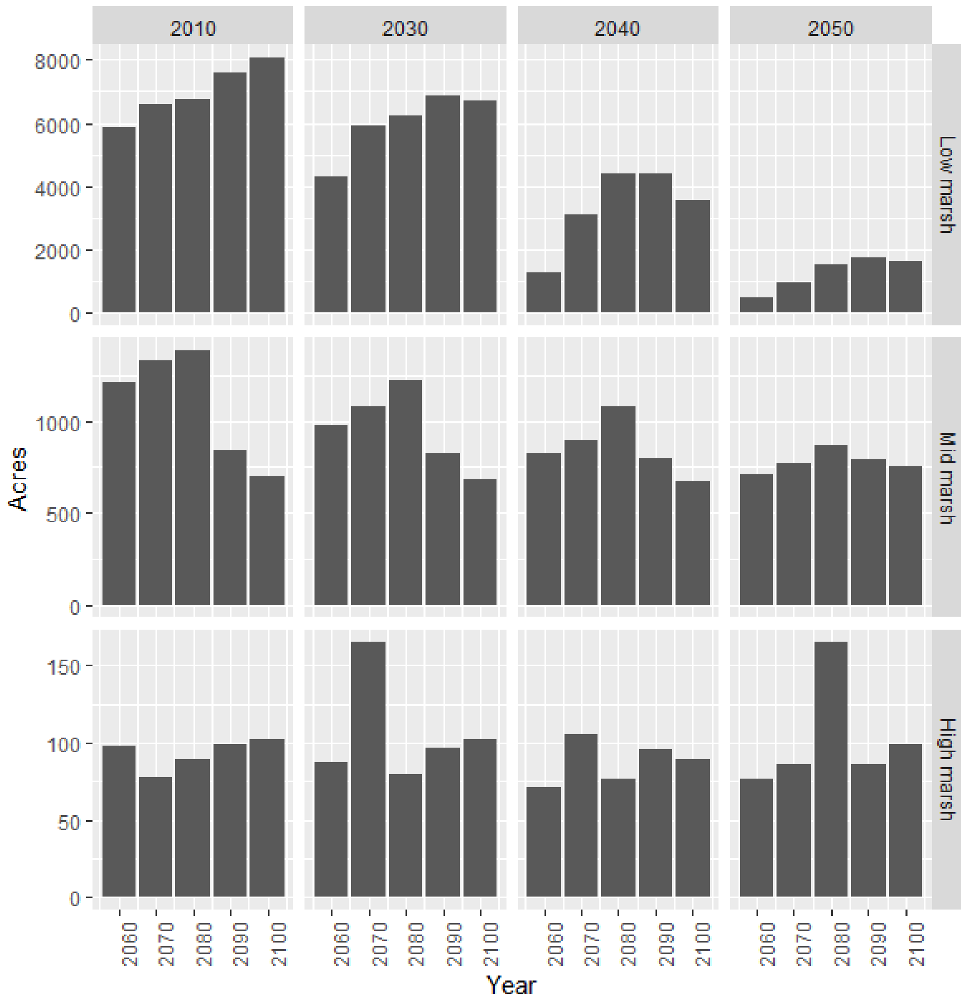


Figure D-14. Area of restored tidal marsh habitat predicted by Marsh98 models. The horizontal axis in each plot indicates the model year of the simulation. The vertical axis indicates the predicted acres of habitat. Each vertical panel presents the results when restoration is initiated in the year indicated in the panel title. Each horizontal pane shows the results for each habitat type.

The later that restoration is initiated, the less overall marsh habitat is available and the greater amount of mudflat habitat will occur in the study area. If restoration is initiated in 2050, we find that most currently subsided baylands will be at mudflat elevation by 2100 (Figure D-15).

However, if restoration is initiated by 2040, even relatively subsided areas such as Burdell could still maintain low marsh elevation by 2100 (Figure D-14).

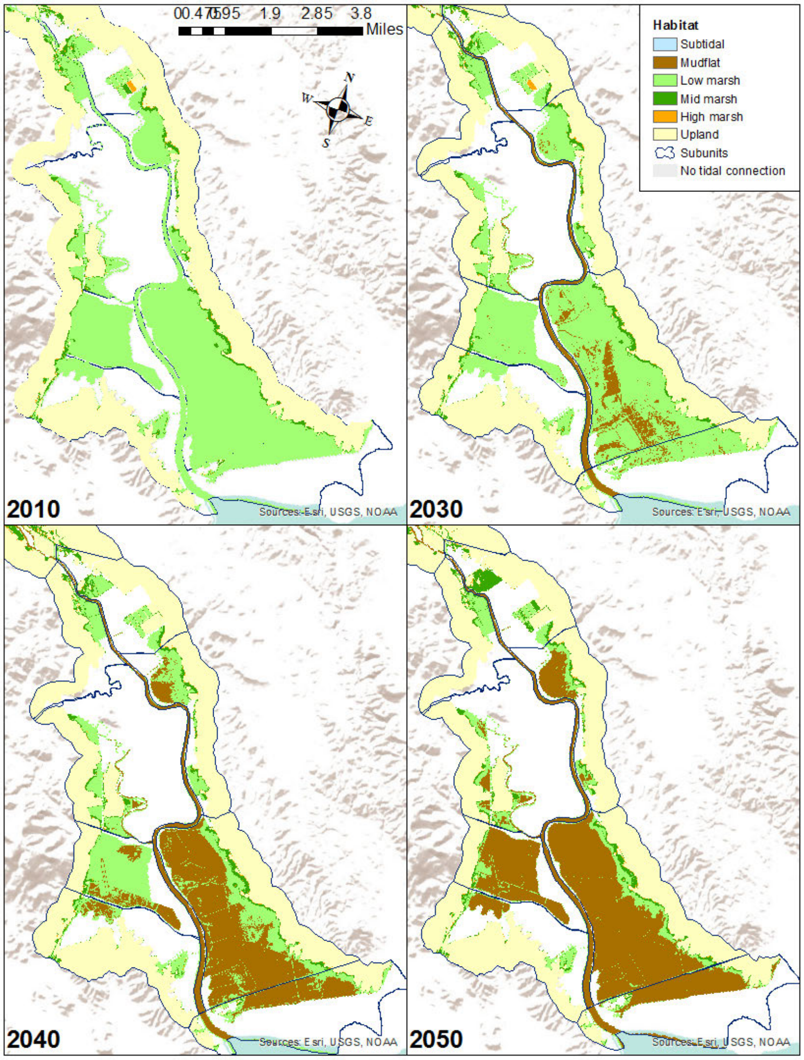


Figure D-15. Maps of modeled intertidal habitats in the Petaluma River watershed at 2100. The year in the lower left hand corner of each map indicates the year in which restoration is initiated.

Bird Models

Introduction

While acres of habitat protected and restored is a frequent and relatively easy metric to track with respect to restoration progress, one of the primary objectives of restoring tidal marsh is to support the growth of populations of native bayland species. Tidal marsh birds are useful indicators of the quality of habitat for wildlife and here we use observations across the entire estuary and from multiple decades to examine how the abundance of five tidal marsh bird species respond to evolving habitat conditions.

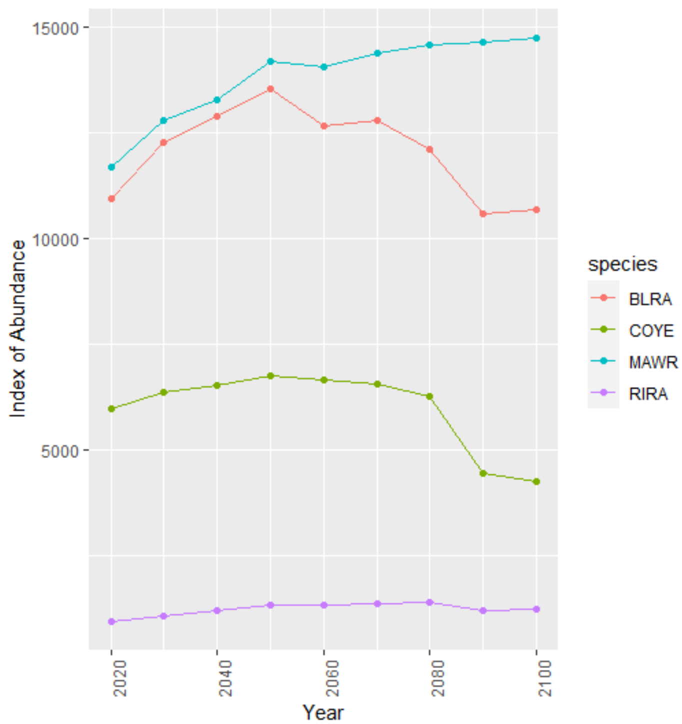
Methods

We used existing models of tidal marsh bird abundance (Veloz et al. 2013) to assess whether the habitat provided in each alternative could provide functional habitat for wildlife species. Observations of four species of tidal marsh birds were made from the entire San Francisco Estuary between 2000 and 2009; California black rail (*Laterallus jamaicensis coturniculus,* CA state threatened), California Ridgway's rail (*Rallus obsoletus obsoletus*, federally endangered), saltmarsh common yellowthroat (*Geothlypis trichas sinuosa*, state species of special concern) and marsh wren (*Cistothorus palustris*). These species were selected as they represent a range of conservation concern from endangered to common and each species utilizes different aspects of marsh habitat thus serving as indicators for a range of marsh species. California Ridgway's Rails are tidal marsh obligates that are associated with tidal channels where they focus their foraging efforts. They are most abundant in mature marshes but can also use restored and low-marsh areas making them somewhat resilient to sea-level rise provided sufficient high tide cover remains nearby. The seldom-seen California Black Rail is a tidal marsh-obligate in San Pablo Bay and favors mature marshes characterized by tall dense vegetation. They are more abundant in areas with lower salinity that contain extensive patches of bulrush (*Bolboschoenus maritimus*). Because they favor lower-saline high marsh areas, require ample cover, and do not often fly or travel far to seek cover, Black Rails may be more sensitive to sea-level rise and increases in salinity than other tidal marsh obligates. Saltmarsh Common Yellowthroats are a species of warbler and breed in low numbers in San Pablo tidal marshes. They are typically found near levees, marsh edges, and areas within the marsh that support tall dense vegetation such as gumplant (*Grindelia stricta*) and bulrush (*Bolboschoenus maritimus*). Because they place their nests relatively close to the ground they are at risk from sea-level rise and increased storm events that threaten to inundate their nests. Marsh wren are associated with bulrush (*Bolboschoenus maritimus*) and *Spartina*, both relatively low marsh elevation species and thus may be able to persist as the majority of the tidal baylands convert to low marsh towards the end of the century

We used a statistical machine learning approach to correlate the abundance of individuals of each species of tidal marsh birds to a suite of environmental variables such as elevation-based habitat metrics, salinity, channel density and distance to the bay and levees. Additional details on modeling are provided in Veloz et al. (2013). We used these existing models to project an index of abundance of individuals of each species to the evolved landscape at 10 year time intervals (2020 – 2100) from the Marsh98 model results. We summarized this index for each species within each subunit in the study area to assess the response to the management alternatives.

Results

No-action scenario



We project that all four tidal marsh bird species will increase in abundance between 2020 and 2050 (Figure D-16). We project that the abundance of marsh wren will continue to increase to 2100. Marsh wren are associated low marsh elevation species and thus may be able to persist as the majority of the tidal baylands convert to low marsh towards the end of the century. Conversely, we project that black rail will decline during the same period (Figure D-16). We project that California Ridgway's rail abundance will remain relatively stable throughout the study period while common yellowthroat abundance will remain stable until 2080 and then decline below 2020 levels by 2090.

Figure D-16. The index of abundance of four species of tidal marsh birds across the Petaluma River Baylands study region: black rail (BLRA), common yellowthroat (COYE), marsh wren (MAWR) and California Ridgway's rail (RIRA).

Sub-unit summary

We project that the abundance of the four species of tidal marsh birds will remain relatively stable within most of the subunits in the study area. With the exception of Ancient Marsh, Bahia and San Pablo Bay, changes in tidal marsh bird abundance are relatively small in other subunits, primarily due to the small areas of suitable habitat during any period of time (Figure D-17). There are some small declines in the abundance of black rail and common yellowthroat towards the end of the century at Burdell, City of Petaluma South and Haystack, likely due to the projected conversion of mid-marsh habitat to low marsh after 2070 (Figure D-17).

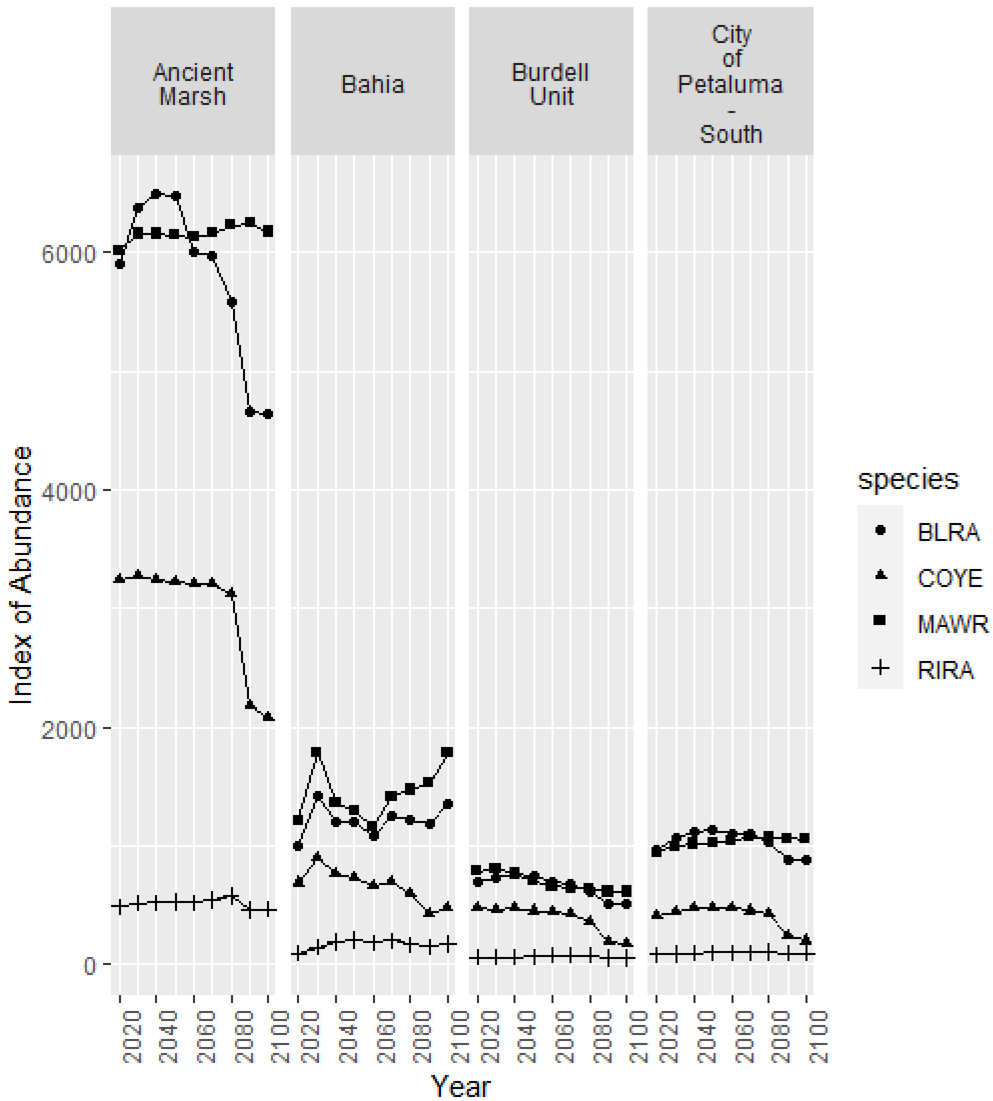

Ancient Marsh
Bahia
Burdell Unit
City of Petaluma - South
Index of Abundance
0
2000
4000
6000
2020
2040
2060
2080
2100
Year
species
BLRA
COYE
MAWR
RIRA

Figure D-17a

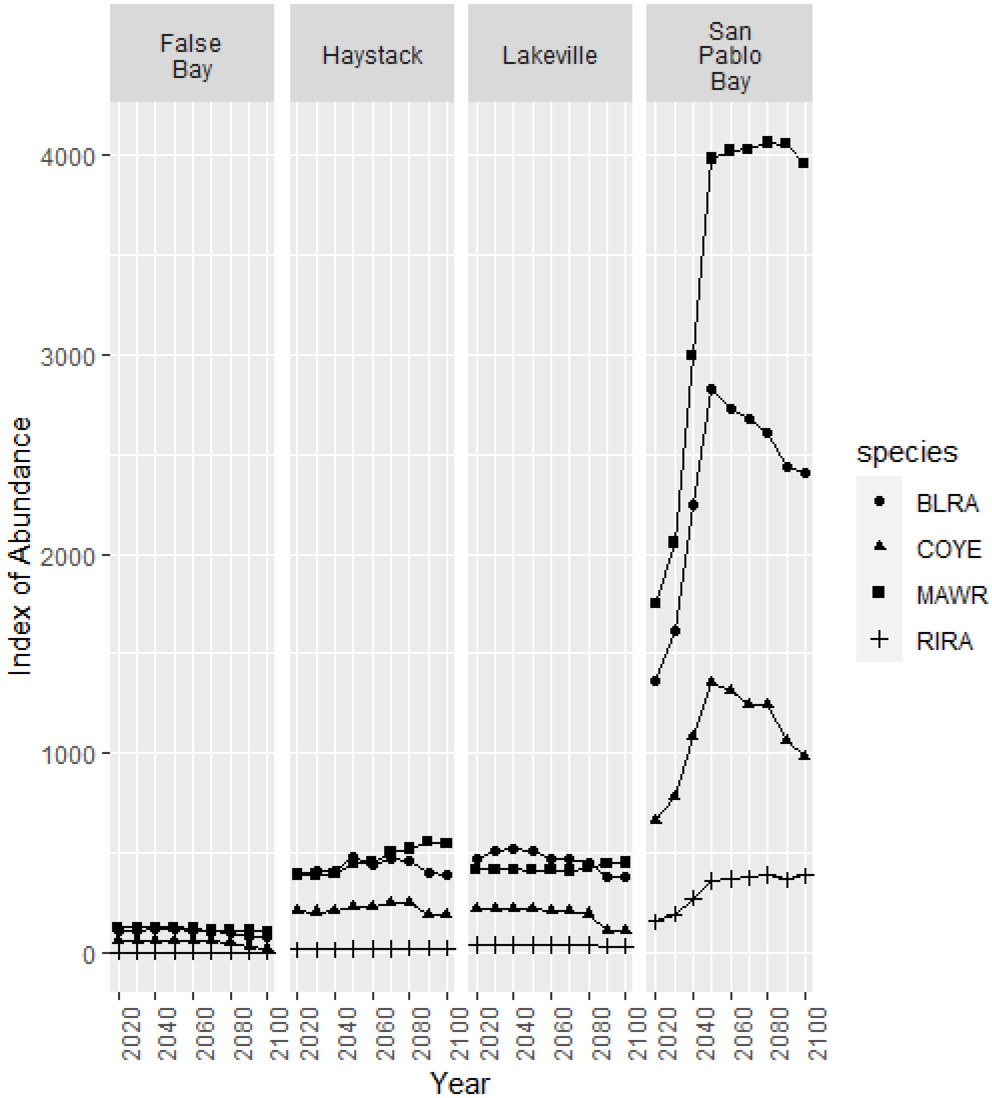


Figure D-17 b.

Figure D-17. Index of abundance of four species of tidal marsh birds: Black rail (BLRA), Common yellowthroat (COYE), Marsh wren (MAWR) and California Ridgway's rail (RIRA). Each panel represents the results from individual subunits, Ancient Marsh, Bahia, Burdell, City of Petaluma South (a) and False Bay, Haystack, Lakeville and San Pablo Bay (b). The horizontal axis is the year from the model.

We find that black rail and common yellowthroat are both sensitive to changes in the types of marsh habitat available in the different subunits. As the amount of marsh habitat increases in the Ancient marsh and San Pablo Bay subunits, we project a corresponding increase of abundance of both species (Figure D-17). However, as mid-marsh and high marsh convert to low marsh towards the end of the century, we find that the abundance of both species declines below projected 2020 levels (Figures D-17 & D-18).

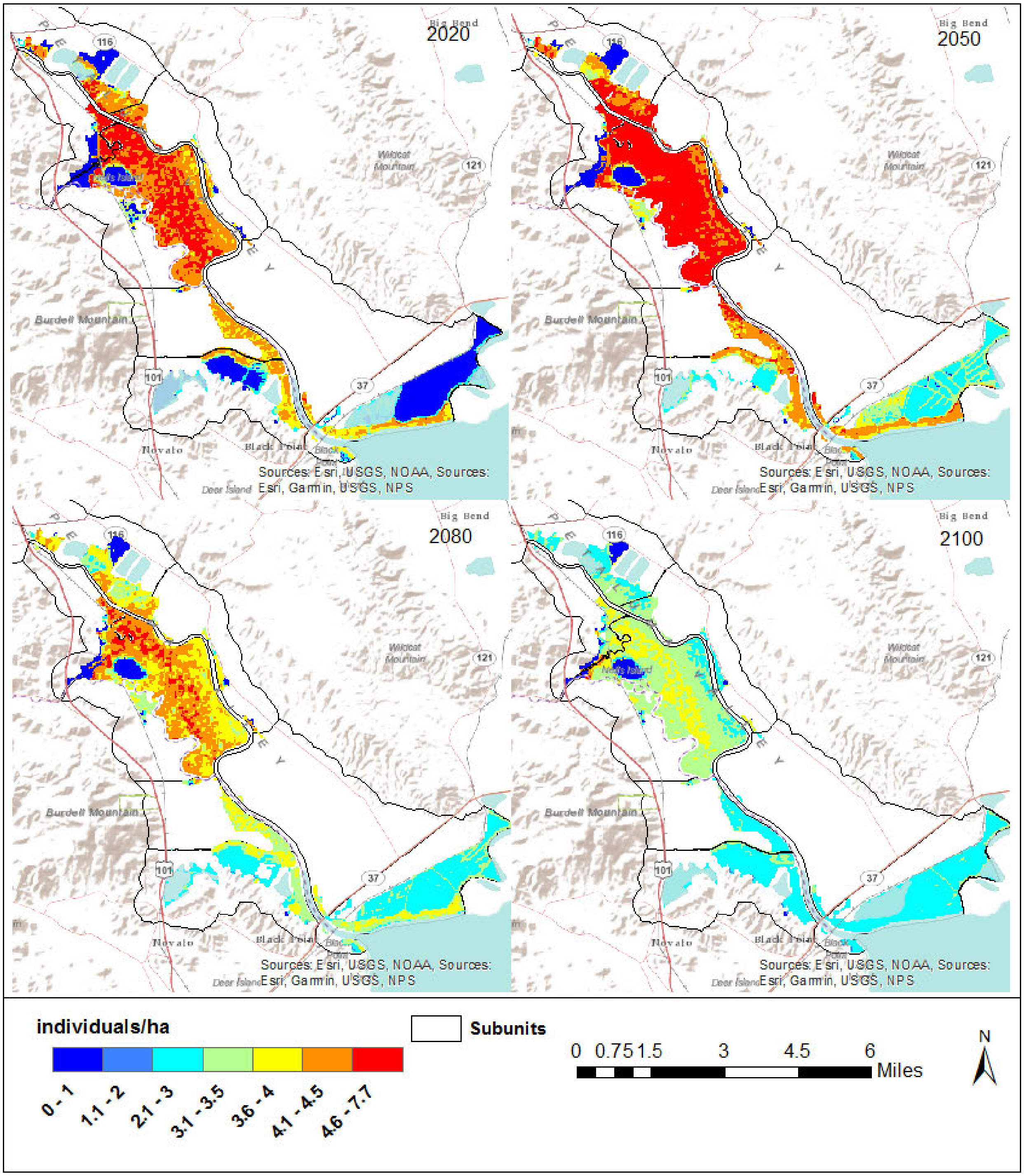


Figure D-18. Projected black rail per hectare within the study region for 2020, 2050, 2080 and 2100.

In contrast, California Ridgway's rail and marsh wren are less sensitive to the changes in the composition of marsh habitats across the subunits than the other two bird species we consider.

While we project that both species will increase in abundance as sub-tidal and mudflat habitats reach marsh elevations within the San Pablo Bay subunit, we find that abundance of both species will remain stable throughout the rest of the century even as we project substantial changes in the composition of marsh habitats (Figure D-17). Within the Ancient marsh, we project only small changes in the abundance of California Ridgway's rail throughout the century with the projected abundance in 2100 only slightly lower than what we project in 2020. We project little change in marsh wren abundance between 2020 and 2100 within the Ancient marsh subunit.

Discussion

Our model results show that current tidal bayland habitats within the study area are somewhat resilient to projected changes resulting from sea-level rise. Despite a substantial loss of tidal marsh habitat in the study area over the previous 150 years, primarily from human development, we project that the remaining habitat will continue to support tidal marsh species, including California Ridgway's rail and marsh wren, for which we project increases in abundance at the scale of the entire study area. These two species utilize low marsh habitat and are thus projected to sustain or increase populations based on the changes in habitat from the models. At the same time, we find that black rail and marsh wren will initially increase in population size as the area of mid-marsh habitat increases but then the populations are expected to decline below 2010 levels as mid-marsh is converted to low marsh towards the end of the century. In summary, we project that the marshes in the study area should continue to provide important habitat for the tidal marsh species analyzed throughout the century without further human intervention but we also should expect that the composition of tidal marsh communities will change as the conditions evolve to favor those species that better tolerate lower elevations. These changes will have effects on other plant and animal species that are not analyzed here.

Our models indicate that the relatively high availability of sediment within the Petaluma River could enable tidal marsh restorations to evolve to marsh habitat soon enough to support bird populations even with increasing rates of sea-level rise. Despite relatively low initial elevations within the San Pablo Bay subunit, we project that by 2040 the subunit will support more individuals of each of the four tidal marsh bird species than any other subunit except for the Ancient marsh.

There are some important caveats of the results to consider. The marsh evolution models we use do not account for processes such as erosion. The large areas of low marsh that we project do not actually have analogs anywhere within the estuary and it is uncertain whether marshes will drown in such a uniform way as sea levels rise. It is possible that erosion could result in increased loss of marsh habitats as accretion within marshes fails to keep pace with sea-level rise. At the same time, it may be that greater heterogeneity in marsh elevations could result from erosion and the resuspension of sediment from marsh edges to marsh interior areas.

Appendix E. Regulatory Considerations

Several key state and federal regulatory requirements will apply to restoration projects within the study area. These regulatory requirements will also provide guidance and standards for project planning, implementation, and post-project monitoring.

Federal, State, and Regional regulations

Some of the laws governing these programs include the:

- California Environmental Quality Act,
- National Environmental Policy Act
- Federal Clean Water Act (Sections 401, 402 and 404),
- Federal Rivers and Harbors Act (Section 10),
- Federal and California Endangered Species Acts,
- Magnuson-Stevens Act,
- State Fish and Game Code,
- California Title 23 and United States Code Section 408 for flood protection,
- Porter-Cologne Water Quality Control Act,
- McAteer-Petris Act
- Coastal Zone Management Act (Section 307)
- Williamson Act, and
- National Historic Preservation Act.

Agencies governing these laws include the:

- U.S. Army Corps of Engineers,
- U.S. Fish and Wildlife Service,
- National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service
- California Department of Fish and Wildlife,
- State Water Resources Control Board,
- San Francisco Bay Conservation and Development Commission (BCDC),
- California State Lands Commission
- Sonoma County Board of Supervisors, and
- Native American Heritage Commission.

Jurisdictional seasonal wetlands may exist in the diked baylands, potentially placing a constraint on tidal restoration in these areas, though deference has been given to restoring the historic habitat type, such as in the Sears Point Tidal Wetlands Restoration Project, which was considered a net beneficial project and mitigation was not required.

Recent regulatory changes

Some recent regulatory developments may provide an integrated streamlined permitting approach for large tidal wetland restoration projects in San Francisco Bay. The Bay Restoration Regulatory Integration Team (BRRIT) was recently developed to collaboratively process permit applications for multi-benefit wetland restoration projects. The BRRIT consists of six state and federal regulatory agencies and is designed to work closely together, identify challenges that can cause permitting delays between and among regulatory and resource agencies, and to resolve those delays.

BCDC has been making a number of amendments to its San Francisco Bay Plan policies, perhaps most pertinent is the 2020 Fill for Habitat update that modified the language for a "minor amount of fill" for habitat restoration projects. Habitat restoration projects will now be allowed to use larger amounts of Bay fill for the "minimum amount necessary for the project purpose" to restore and enhance habitat in light of sea-level rise impacts on Bay habitats. BCDC has several types of jurisdiction that would potentially apply within the strategy boundary, including Bay, Shoreline Band, Managed Wetlands, and Certain Waterways, each of which are defined in the McAteer-Petris Act. The extent of BCDC's jurisdiction could be mapped according to the definition of each of these jurisdictions and how they pertain to the strategy boundaries. BCDC's Certain Waterways jurisdiction occurs in the southern portion of the Petaluma River Baylands along Petaluma River to its confluence with Adobe Creek and San Antonio Creek to the easterly line of the Northwestern Pacific Railroad right-of-way (BCDC 2008).

Under the banner of "Cutting the Green Tape," the California Department of Fish and Wildlife issued its Statutory Exemption for Restoration Projects (SERP). Restoration projects meeting specific criteria can be awarded a statutory exception resulting in considerable savings in time and cost. A recent example within the Petaluma River in which the SERP was used effectively was Sonoma Land Trust's Lakeville Creek Restoration Project. The project includes restoration of a seasonal tributary to the Petaluma River with projected benefits for wildlife, habitat, groundwater, and range management. Lakeville Creek terminates in seasonal wetlands along the historic bay margin above False Bay. If tidal wetlands can be restored in False Bay, a complete ecosystem linking subtidal, tidal, transition zone, and upland habitats will be established.

Similarly, the State Water Board has adopted a new General Order for Clean Water Act Section 401 Water Quality Certification and Waste Discharge Requirements for Restoration Projects Statewide (General Order) and has certified the supporting California Environmental Quality Act consolidated final Program Environmental Impact Report (PEIR). This could substantially expedite restoration project timelines, and use of the General Order is at the discretion of the Regional Water Boards. Restoration Projects with elements beyond those covered in the PEIR would tier from that document with additional analyses in the event of additional significant impacts or substantial deviations from the PEIR.

The State Water Board also recently issued a new policy for water quality control with its new State wetland definition and procedures for discharges of dredged or fill material to Waters of the State in 2019. These State Water Board Wetland Procedures, which became effective May 2020, create a State process by defining wetlands (potentially separately) from the federal Clean Water Action Section 404 definition. This can result in waters and wetlands that are not considered to fall within federal jurisdiction being deemed jurisdictional by the State.

Appendix F: Supplemental Figures and Tables

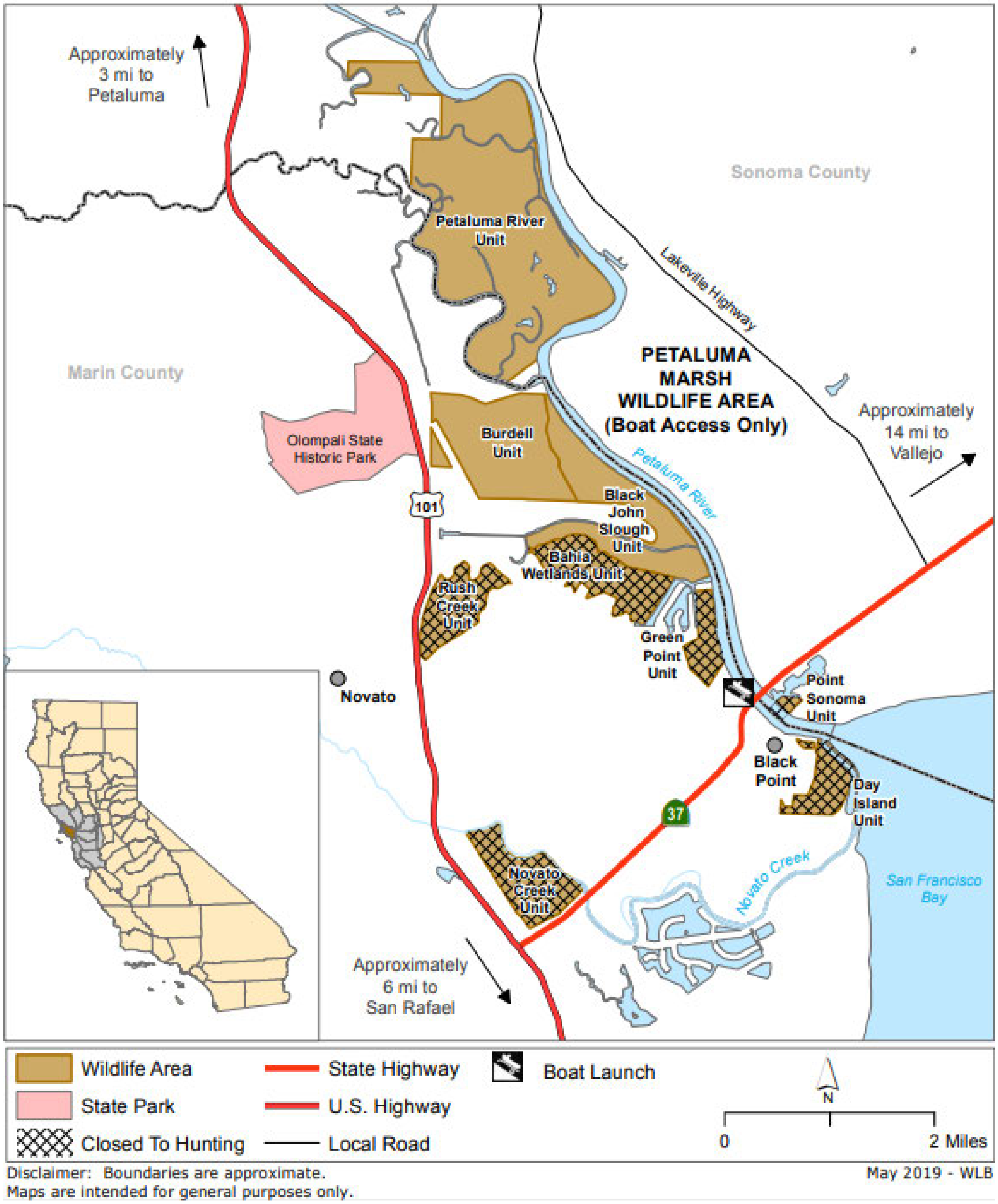


Figure F-1. Petaluma Marsh Wildlife Area (courtesy of CDFW). CDFW's Petaluma River Unit falls within the Ancient Marsh subunit; the Burdell and Black John Slough Units fall within the Burdell subunit; the Green Point, Bahia Wetlands and Rush Creek Units fall within the Bahia subunit; the Day Island and Point Sonoma Units fall within the San Pablo Bay subunit. The Novato Creek Unit is outside the Strategy study area.

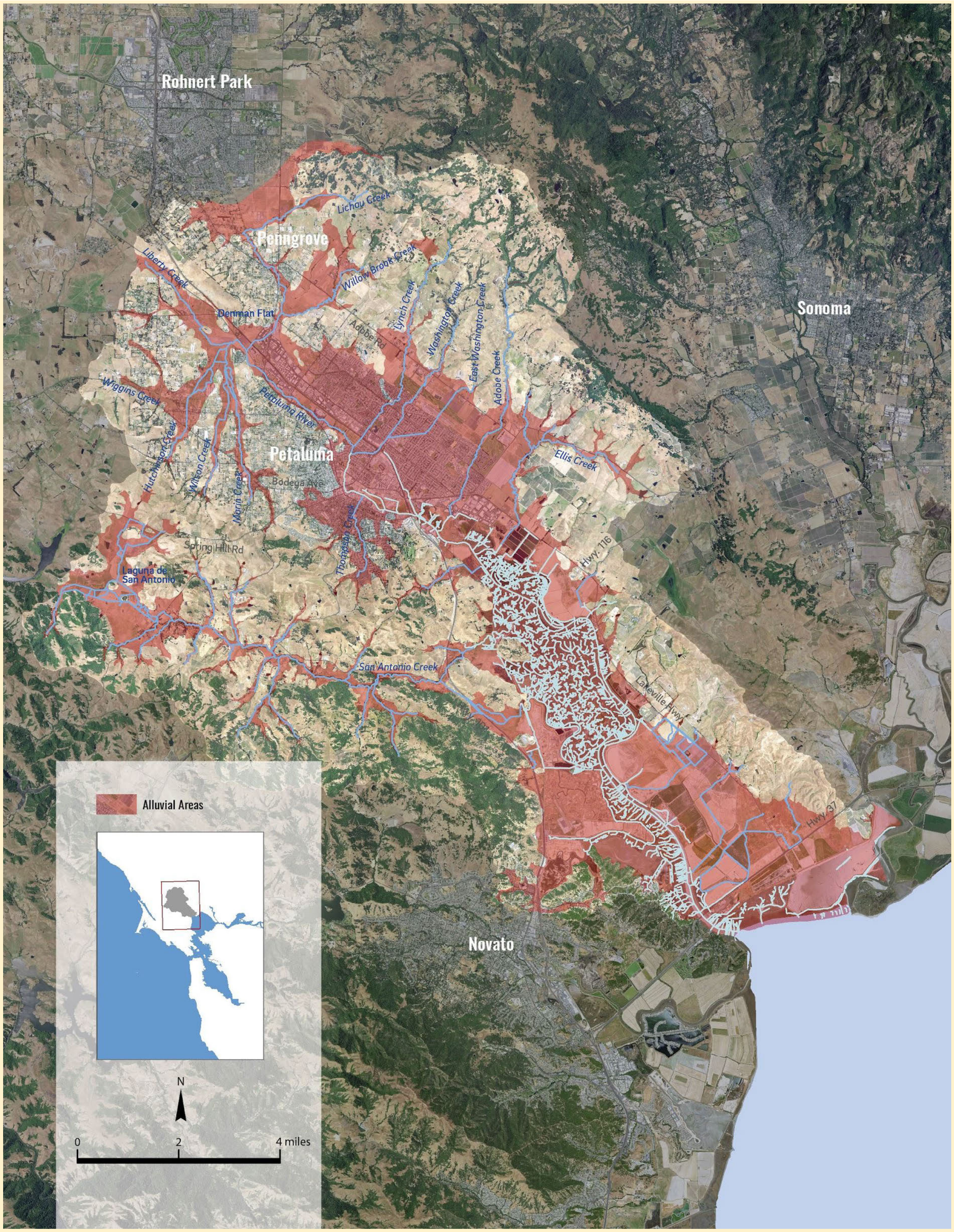


Figure F-2. Extent of the Petaluma River watershed. The watershed is highlighted and the alluvial areas shown in red. From the Petaluma Valley Historical Hydrology and Ecology Study (Baumgarten et al. 2018).

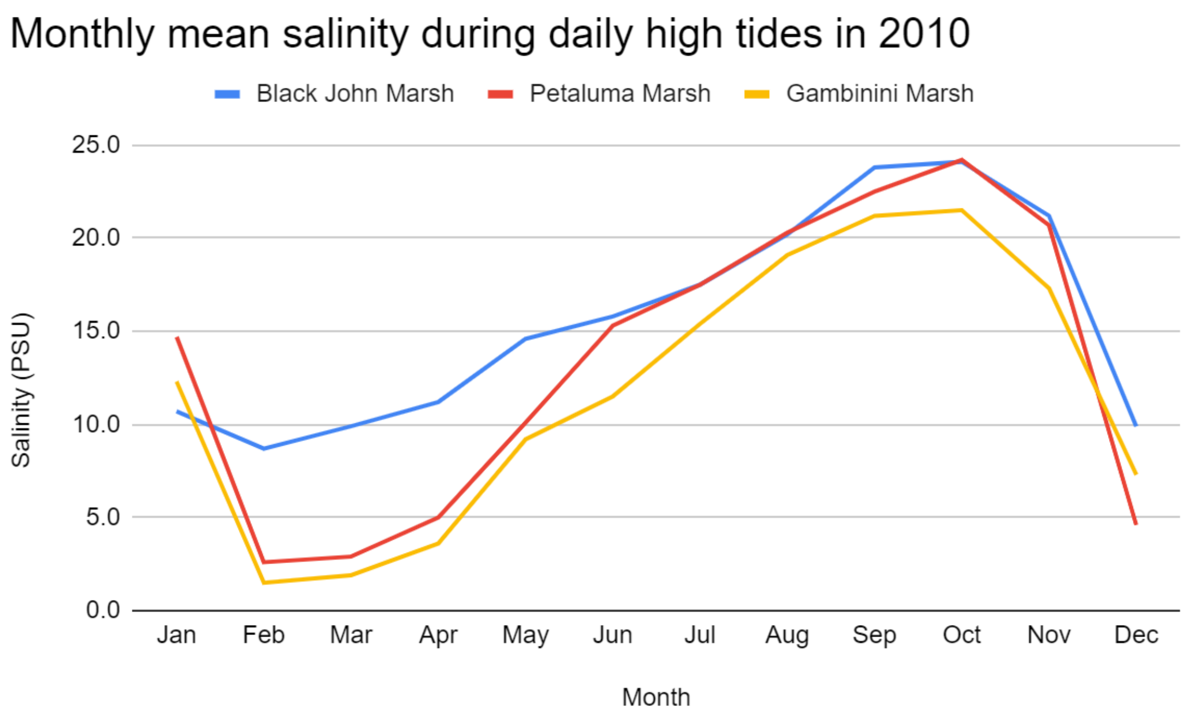


Figure F-3. Salinity, in Practical Salinity Scale (PSU) during 2010 calculated by taking the monthly mean of salinity from daily high tides. Seawater has a PSU of 35. Black John Marsh is relatively more saline than the Petaluma Marsh and Gambinini Marsh (Figure 2.5; see Figure 2.1 for locations). All three marshes are more saline in the dry season (May-October) and during periods of drought, and less saline in the wet season (November-April) and during wet years. Data from Takekawa *et al* (2013).

Table F-1. Tidal datums relative to MSL for the Petaluma River Entrance, Lakeville, and Upper Drawbridge gauges (NOAA 9415252, 9415423, 9415584). See Figure 2.1 for locations.

	River Entrance (Railroad Swing Bridge)		Lakeville (Marina)		Upper Drawbridge	
	ft MSL	m MSL	ft MSL	m MSL	ft MSL	m MSL
MHHW	2.78	0.85	2.93	0.89	2.93	0.89
MHW	2.25	0.68	2.44	0.74	2.46	0.75
MSL	0.00	0.00	0.00	0.00	0.00	0.00
MLW	-2.29	-0.70	-2.55	-0.77	-2.75	-0.84
MLLW	-3.23	-0.98	-3.44	-1.05	-3.73	-1.14

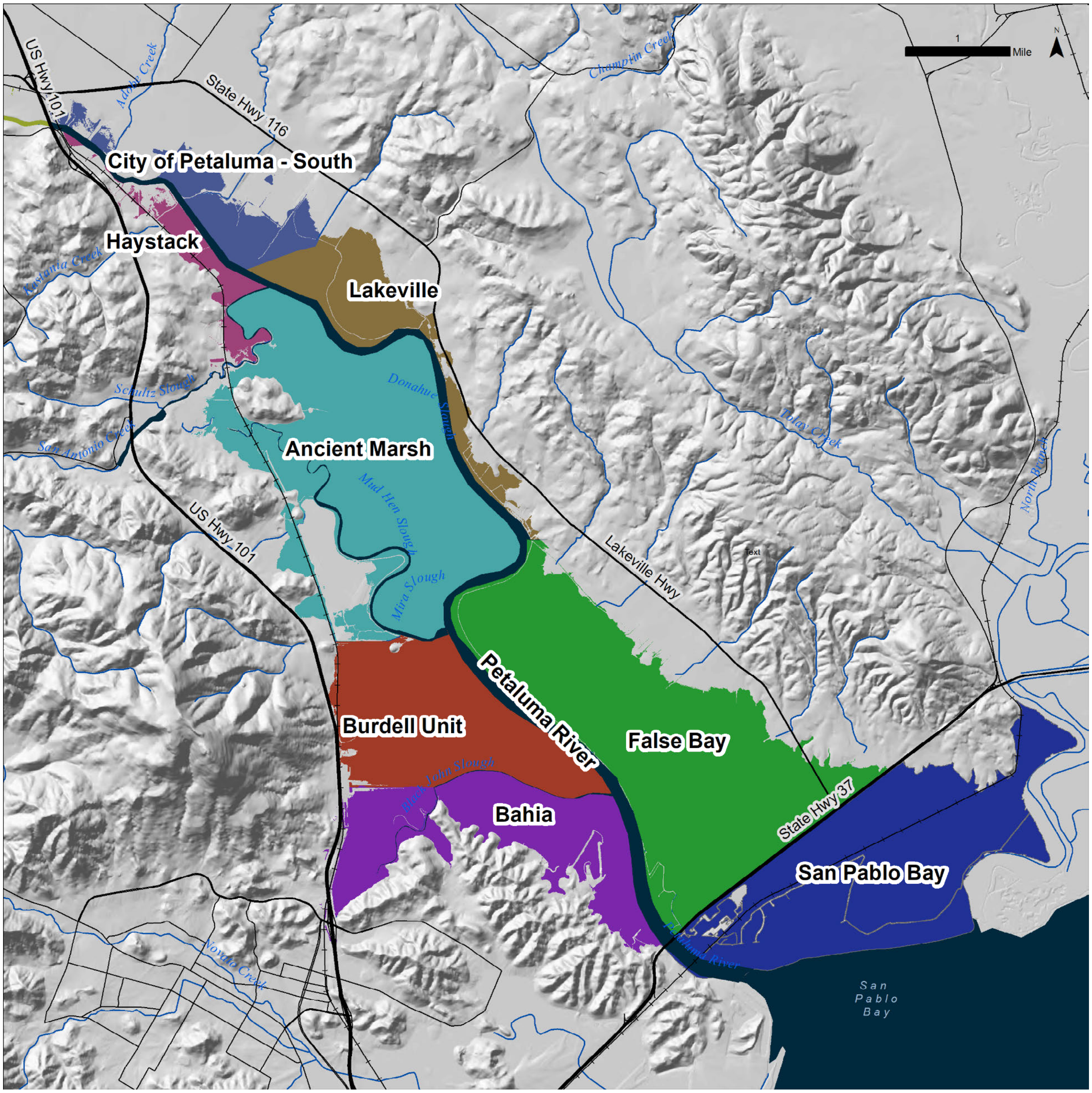


Figure F-4. The baylands area of each subunit used to calculate the mean elevations shown in Figure 2.4. These areas exclude elevations above the highest astronomical tide (MHHW + 1 ft).

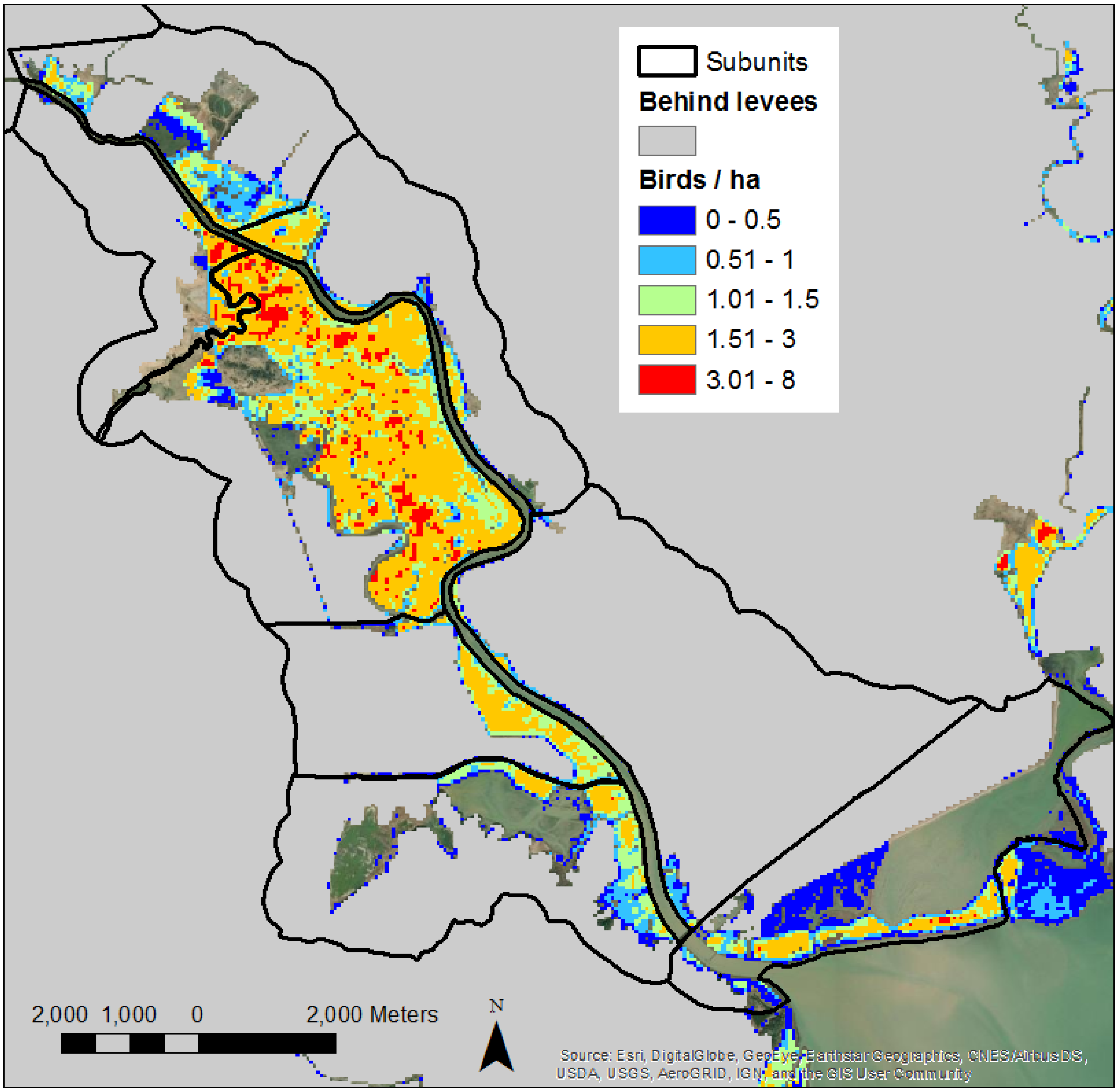


Figure F-5. Current predicted density (birds/ hectare) of Black rail within the study area. Areas not currently open to tidal exchange are colored grey. Areas that are above or below marsh elevations do not have predicted values.

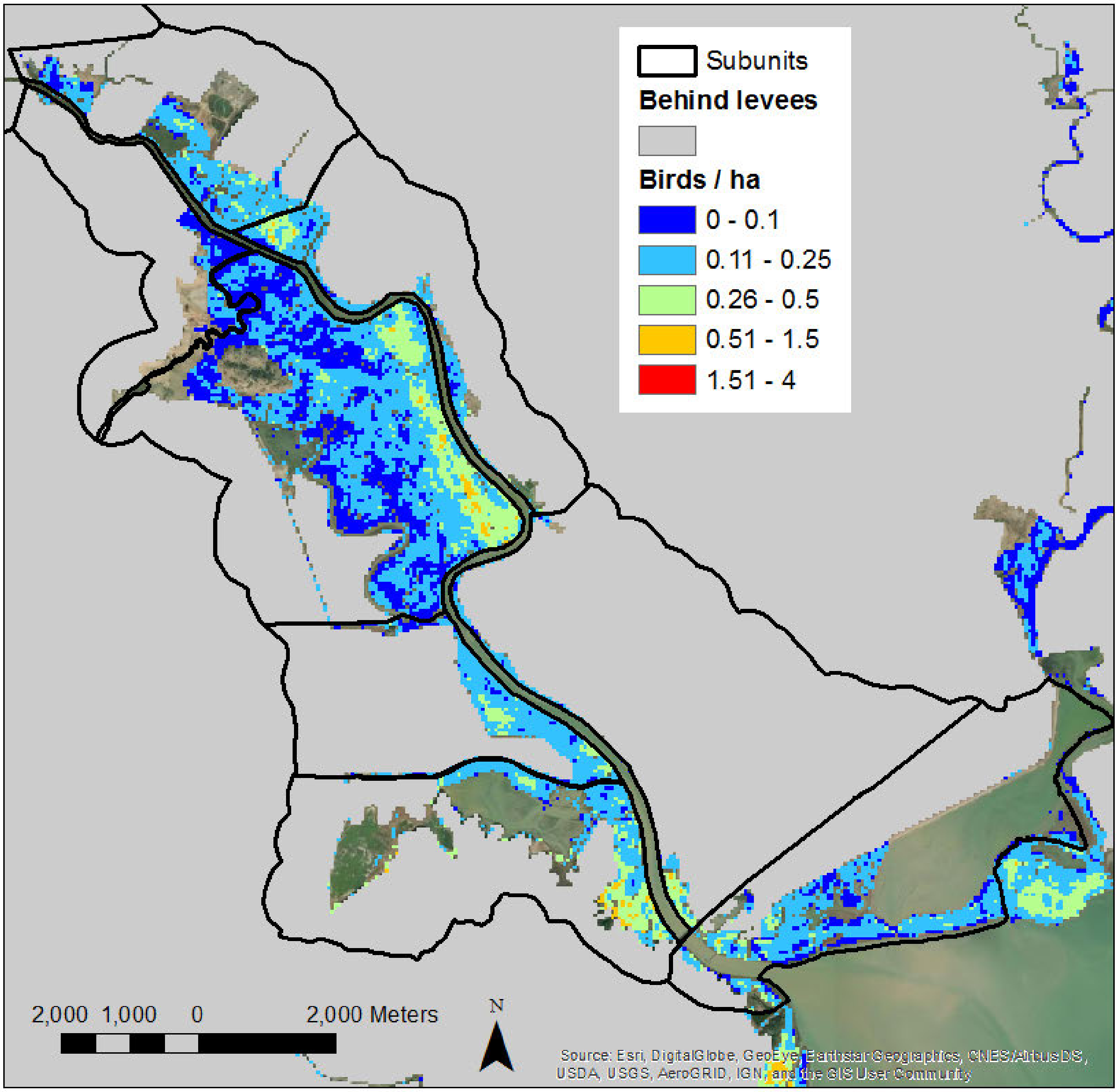


Figure F-6. Current predicted density (birds/ hectare) of California Ridgway's rail within the study area. Areas not currently open to tidal exchange are colored grey. Areas that are above or below marsh elevations do not have predicted values.

Table F-2. Petaluma River tidal and non-tidal wetland restoration and protection projects underway or completed as of 2021.

Name	Acres	Status	Description
Shollenberger Park Wetland Enhancement	62 wetland, 7 upland	Completed (2014)	Replaced flash board risers and culverts
Petaluma Marsh Acquisition, Enhancement, and Access - Hill Property	74 acres	Completed (2004)	Acquisition, enhancement, and restoration of tidal and non-tidal wetlands, riparian, and upland habitat.
Gray's Ranch	120 tidal marsh, 140 upland	Completed (2004)	Acquisition of tidal marsh and upland habitat
Petaluma Marsh Expansion and Restoration	284	In construction	Mitigation project - includes monitoring of existing wetland and enhancement of transition zone habitat
Petaluma River Wildlife Area, Burdell Unit	650	In planning	Assessing feasibility of tidal connectivity to the unit from the north and east
Rush Creek/Cemetery Marsh	300	Completed (1999)	Enhanced muted tidal wetland along Rush Creek
Bahia Restoration Phase I	200 tidal marsh, 286 upland	Completed (2008)	Restored 200 acres of tidal marsh
Petaluma River Marsh (Carl's Marsh)	45	Completed (1994)	Levees breached and tidal action restored
Green Point/Toy Marsh	57	Completed (1986)	
Sonoma Baylands Restoration Project	305	Completed (2007)	Restoration of diked baylands to tidal marsh
North Parcel Restoration (Leonard Ranch Wetlands Restoration Project)	279	Completed (2003)	Seasonal wetland creation and enhancement
Sears Point Wetland and Watershed Restoration Project	970 tidal marsh, 40 seasonal wetlands, 900 upland	Completed (2015)	Restore tidal marsh, enhance seasonal wetlands, red legged frog habitat, and upland habitat

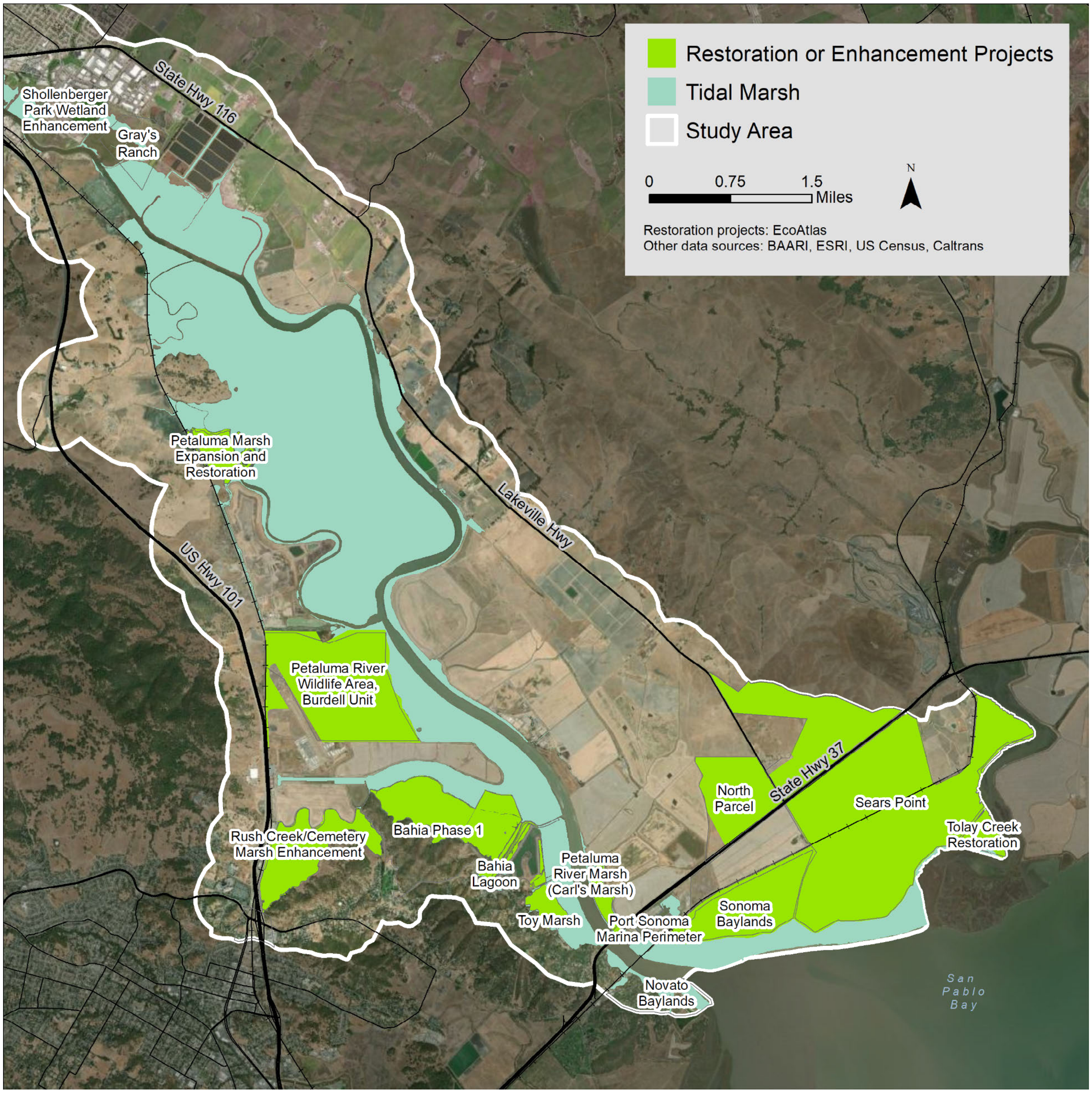


Figure F-7. Restoration and enhancement projects within the study area