San Pablo Bay National Wildlife Refuge Climate Adaptation Plan

Photo by Meg Marriott, USFWS

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Executive Summary

Future climate change is expected to cause dramatic changes in the physical and biological environment of the San Pablo Bay National Wildlife Refuge (Refuge). To effectively plan for an uncertain future, managers and decision makers must consider a range of future scenarios using tools and decision support frameworks that can incorporate uncertainty. Successful strategies will be those that are robust to uncertainty and are likely to provide benefits across a range of scenarios. Uncertain future conditions may also require managers to re-assess traditional conservation goals as they may no longer be feasible under novel conditions.

The purpose of this climate adaptation project is to use the best available information to (1) identify a suite of actions with the highest likelihood of achieving Refuge goals that are feasible and contribute to larger landscape conservation (e.g., *USFWS Tidal marsh Recovery Plan 2013*); (2) gain a better understanding of the projected impacts of climate change on refuge conservation targets; and (3) identify the suite of measures needed to assess conservation progress and support an adaptive decision-making framework.

A working group comprising the San Francisco Bay Joint Venture, Refuge staff, and local scientific experts used the Open Standards for the Practice of Conservation (2013) and structured decision making tools to identify strategies aimed at achieving the Refuge's natural resource conservation vision in light of climate change uncertainty and other environmental threats. The working group first identified Refuge conservation targets and associated key ecological attributes and indicators. We then used conceptual models, expert opinion, and the best available scientific information to identify the most critical threats to Refuge conservation targets from climate change (such as drought, extreme storms, sea level rise) and other threats in two time periods, near term (2016 – 2030) and long term (2030 – 2100). The highest ranked threats in the near- and long-term were climate change, land conversion, and invasive plants. We then brainstormed and ranked strategies (N = 39) aimed at reducing the stress caused by the most critical threats.

The following strategies were ranked as the highest priority in the *near term*:

- Invasive plant management
- Land acquisition
- Raise Hwy 37 from Petaluma River to Mare Island
- Improve Tolay Creek tidal connection across Hwy 37

The following strategies were ranked as the highest priority in the *long term*:

- Land acquisition
- Invasive plant management
- Move refuge boundaries upland
- Raise Hwy 37 from the Petaluma River to Mare Island
- Tidal marsh restoration at Skaggs Island

Refuge staff will ensure that near term activities do not prevent long term strategies from being implemented and will look for opportunities to begin implementing long term strategies.

The decision making process was collaborative and transparent enabling the working group to develop agreed upon priority management strategies. The process enabled scientific experts and refuge staff to coproduce the strategies ensuing collective support as strategies move forward towards implementation. This climate adaptation plan can be used to focus scientific inquiry and direct external decision making and natural resource management to help achieve refuge goals.

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Abbreviations

CADS	Climate Adaptation Decision Support
CCP	Comprehensive Conservation Plan of U.S. Fish and Wildlife Service
KEA	Key Ecological Attribute
NWR	National Wildlife Refuge
ROC	Refuge priority Resources of Concern
SDM	Structured Decision Making
SLR	Sea-level Rise
SPBNWR	San Pablo Bay National Wildlife Refuge
TMRP	Northern California Tidal Marsh Ecosystem Recovery Plan
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WRDA	Water Resources Development Act

1. Introduction

1.1 Background

The San Francisco Bay Estuary (Estuary) is the largest estuary on the West Coast of North America and provides habitat for diverse wildlife including threatened and endangered species. Over a million shorebirds use the Estuary each year to overwinter or to refuel during their migration along the Pacific Flyway. The Estuary also provides people with many benefits, including flood control to protect homes and businesses, filtration of runoff from storm drains, prevention of erosion of waterfront properties, outstanding recreational opportunities and a hatchery for the fish we eat.

But the Estuary is constantly changing, as natural and human-caused pressures increase. Anticipated impacts to natural resources from climate change may include species range shifts, species extinctions or extirpations, phenological changes and changes in primary productivity. Sea-level rise poses a severe threat to the tidal wetlands as there is considerable uncertainty about whether they will be able to maintain elevations relative to future sea level (Stralberg et al. 2011, Swanson et al. 2013, Kirwan et al. 2016). Moreover, human actions are inherently unpredictable, have had and will continue to have significant impacts on the resilience of natural communities. For example, the amount of suspended sediment within estuary waters can influence whether or not marshes can keep pace with high rates of sea level rise (Stralberg et al. 2011) but it is unclear how land use and water flow management upstream or directly in the estuary will affect future sediment supply. To effectively plan for an uncertain future, managers and decision makers must consider a range of future scenarios using tools and decision support frameworks that can incorporate uncertainty. Successful strategies will be those that are robust to uncertainty and are likely to provide benefits across a range of scenarios. Uncertain future conditions may also require managers to re-assess traditional conservation goals as they may no longer be feasible under novel conditions. For example, the need to anticipate and manage for change (in contrast to managing for stable or static systems) is a key concept in the Climate Smart Conservation Guide (Stein 2014). As new information becomes available on strategy effectiveness and future scenarios, the goals, objectives, and strategies in this plan should be revisited and revised to maximize multi-benefits.

With billions of dollars slated for investment in the restoration, acquisition and management of wetland habitat in the Estuary, a decision process was needed to help direct managers and planners towards the most effective strategies such that conservation actions would continue to provide benefits under a range of plausible climate scenarios. In 2015, the San Francisco Bay Joint Venture led a multi-stakeholder project to identify optimal management alternatives that could be coordinated among partners to achieve fundamental objectives for conservation in the face of climate change. This project, "Supporting Climate Adaptation Decisions for Estuarine Ecosystems of the San Francisco Bay" (CADS Phase I; Mattsson et al. 2015), brought together natural resource managers, conservation coordinators and planners, and scientists working within the San Francisco Bay to augment the efforts in the Baylands Goals Update (Goals 2015) by evaluating and prioritizing the Update's suite of management recommendations for each subregion. The strategies were evaluated and prioritized by considering their focus and effectiveness in achieving goals, feasibility in light of available resources, and potential impact within and among subregions over time. This Climate Adaptation Plan represents Phase II of the CADS project and demonstrates how the Phase I subregional recommendations inform local scale and site-specific climate adaptation strategies.

The San Pablo Bay National Wildlife Refuge (SPBNWR), located in the northern part of the Estuary, is a critical area for implementing adaptive tidal wetland conservation strategies. Despite the loss of over 80% of historic tidal marshes in the Estuary since the 19th century (U.S. Fish & Wildlife Service 2013), the lands surrounding the Refuge are predominantly conserved open space. With 19,200 acres of land, the Refuge contains extensive tidal habitats (11,200 acres) and has many opportunities for tidal restoration owing to reduced urban development relative to other areas of the Estuary. The tidal habitats within and adjacent the Refuge support shorebirds, federal and state-listed species, and other wildlife as well as many of the above-mentioned ecosystem services. The large expanses of tidal flats provide essential migrating and wintering habitat for hundreds of thousands of shorebirds and waterfowl. Large contiguous expanses of pickleweed (*Sarcocornia pacifica*)-dominated tidal marsh support the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*), endangered California Ridgway's rail (*Rallus obsoletus obsoletus*), and other tidal marsh-dependent species of concern.

1.2 Project Purpose, Scope and Objectives

The purpose of this project is to (1) identify a suite of actions with the highest likelihood of achieving Refuge conservation goals that are feasible and contribute to larger landscape conservation (such as outlined in the *USFWS Tidal marsh Recovery Plan*); (2) gain a better understanding of the projected impacts of climate change on Refuge conservation targets; and (3) identify what suite of measures are needed to assess conservation progress and support an adaptive decision-making framework.

1.2.1 Objectives

- Identify optimal set of strategies to reduce stress on SPBNWR conservation targets from climate change and other threats in the near (current to 2030) and long-term (2030-2100). This will be accomplished by
  - Identifying priority conservation targets and associated conservation goals for San Pablo Bay NWR
  - Identifying priority threats to conservation targets, including climate change
  - Identify optimal set of strategies to reduce stress on conservation targets from climate change and other threats
  - Summarize abiotic factors of climate change and other threats for SPB and how they stress ecological attributes of their conservation targets
- Use information from the near- and long-term objectives to develop a climate change adaption plan for San Pablo Bay NWR

1.2.3 Spatial and temporal scope

A clear spatial scope set the boundaries for climate analysis and development of management strategies. The scope encompassed the area where strategies will be implemented by the Refuge (and its partners) in order to meet its conservation goals as well as contribute to larger landscape conservation goals. We also identified the temporal scope of the plan to help evaluate threats and strategies.

The spatial scope encompasses natural resources within the approved boundary of the Refuge and surrounding uplands that could be inundated by rising sea levels by 2100 (Figure 1; Ballard et al. 2016).

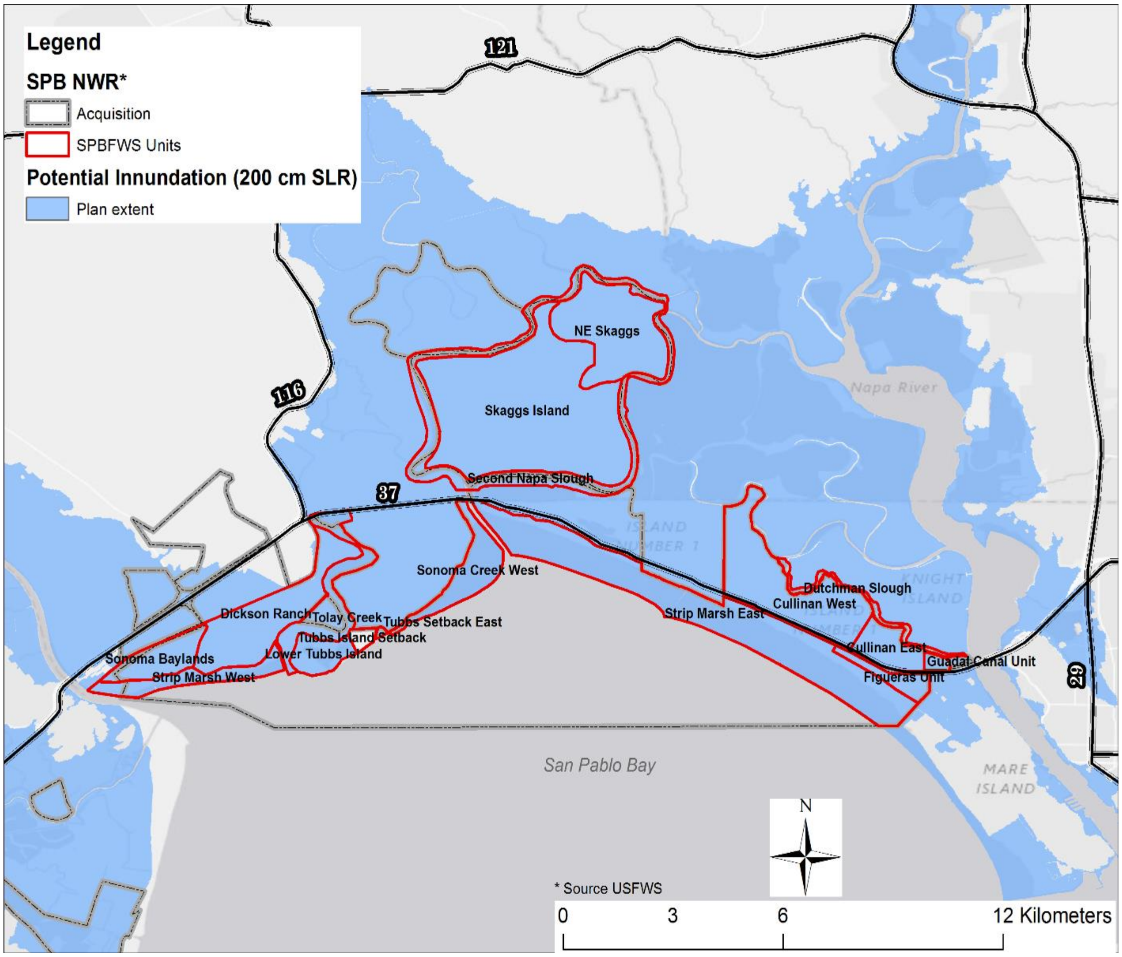


Figure 1. Study extent defined by the flooding extent of 200 cm of sea level rise surrounding the San Pablo Bay National Wildlife Refuge.

2. Methods

We drew upon previous climate change modeling efforts, maps, and decision support tools to guide development of this climate adaptation plan: 1) Open Standards for the Practice of Conservation (2013), 2) Structured Decision Making (SDM), and 3) scenario planning (Foundations of Success 2009, Conservation Measures Partnership 2013, Moore et al. 2013). Documents that were key to informing development of this climate adaptation plan included *San Pablo Bay National Wildlife Refuge Final Comprehensive Conservation Plan* (CCP) *(USFWS 2011)*, *Climate-SMART Conservation* (Stein et al., 2014), *Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California* (TMRP; USFWS 2013), *The Baylands and Climate Change: What Can We Do* (Baylands Goals; 2015), and *Climate Adaptation for Decision Support: CADS Phase I* (Mattsson et. Al. 2015; Thorne et al. 2012). From October 2015 to February 2016, the project team used several in-person workshops and web-based meetings to complete each phase of the project:

I. Develop project structure, team, and spatial scope
II. Define project goals and objectives (expected results)
III. Identify priority Refuge conservation targets and associated key ecological attributes, indicators, and goals

IV. Identify, describe, and prioritize threats to conservation targets (including climate change)
V. Assess future projected climatic conditions and associated environmental vulnerabilities
VI. Develop conceptual models describing the relationship between targets and threats
VII. Use information from previous phases to identify optimal set of management strategies that have the highest likelihood of conservation success in light of climate change and other critical threats

2.1 Project Structure and Team

Many individuals worked together to develop the San Pablo Bay National Wildlife Refuge Climate Adaptation Plan (hereafter referred to as the 'climate adaptation plan'; Table 1). These individuals, groups, and institutions have a vested interest in the natural resources of the project area and/or potentially will be affected by project activities and have something to gain or lose if conditions change or stay the same.

Table 1. Individuals who contributed to the development of the San Pablo Bay Climate Adaptation Plan.

Univ.	Organization	Position	Role in Project
Meg Marriott	USFWS, National Wildlife Refuge System, Region 8	Wildlife Biologist, San Pablo Bay National Wildlife Refuge	Advisor, stakeholder
Don Brubaker	USFWS, National Wildlife Refuge System, Region 8	Wildlife refuge manager, San Pablo Bay National Wildlife Refuge	Advisor, stakeholder
Joy Albertson	USFWS, National Wildlife Refuge System, Region 8	Supervisory Biologist, San Francisco Bay National Wildlife Refuge Complex	Advisor, stakeholder
Giselle Block	USFWS, National Wildlife Refuge System, Region 8	Coastal zone biologist, Inventory and Monitoring Program	Core team
Sam Veloz	Point Blue Conservation Science	Climate adaptation group director	Core team
Julian Wood	Point Blue Conservation Science	San Francisco Bay program leader	Core team
Anne Morkill	USFWS, National Wildlife Refuge System, Region 8	Project leader, San Francisco Bay National Wildlife Refuge Complex	Advisor, stakeholder
Melissa Amato	USFWS, National Wildlife Refuge System, Region 8	Wildlife Refuge Specialist, San Pablo Bay National Wildlife Refuge	Advisor, stakeholder
Karen Thorne	USGS, Western Ecological Research Center	Landscape ecologist	Advisor (climate change)
Nadav Nur	Point Blue Conservation Science	Quantitative ecologist	Advisor (biometrics)
Julian Meisler	Sonoma Land Trust	Baylands program manager	Advisor (wetland restoration)

Beth Huning	San Francisco Bay Joint Venture	Coordinator	Project manager
Tessa Turner	USFWS, National Wildlife Refuge System, Region 8	Biological science technician, Inventory and Monitoring Program	Core team
Renee Spenst	Ducks Unlimited	Regional biologist	Advisor (wetland ecology and restoration)
Courtney Gutman	Richardson Bay Audubon Center and Sanctuary	Restoration program manager	Advisor (wetland ecology)
Kelly Robinson	Michigan State Univ., Dept. of Fish and Wildlife	Assistant Professor	Core team

Notes: project manager = individual who ensured the project was carried out as planned, core team = individuals who planned and facilitated creation of the climate adaptation plan, advisors and stakeholders = Refuge staff, partners, and other individuals who have topical expertise or have a vested interested in conservation of Refuge natural resources.

2.2 Priority Conservation Targets, Key Ecological Attributes, Indicators, and Goals

We identified a limited set of Refuge species, communities, or ecosystem conservation targets (and associated nested targets[1]) that best represent biodiversity within the project scope. **The targets provided the foundation for assessing the impact of climate change and other threats. Over the long-term, they also provide a framework for assessing health of natural resources over time, learning, and adapting our conservation actions.** When trying to conserve the full expression of biodiversity of an area, there is a tendency to include too many conservation targets to realistically measure. Since most conservation managers lack the resources to measure so many indicators, it is important to keep the overall number of targets to a manageable level.

The project team first identified major ecosystems (targets) of the project scope and then brainstormed species or communities that are representative of each ecosystem (nested targets). We considered all species, communities, and ecosystems identified in the CCP, TMRP, and Baylands Goals Update that are known to occur in the project scope. We then identified Key Ecological Attributes (KEAs) and indicators of each ecosystem target (hereafter referred to as *target* or *conservation target*). KEAs are aspects of a conservation target's biology or ecology that best define a healthy conservation target. We assume missing or significantly altered KEAs could ultimately lead to the outright loss or extreme degradation of a conservation target over time. Indicators are units of information measured over time that document change in a KEA. For example:

- Target: tidal marsh ecosystem
- Key ecological attribute: native plant composition
- Indicator: % cover native plants

[1] A nested target is a species, community or ecological process that is also conserved if the broader ecosystem target within which it is found is conserved. We want to limit this list to species or communities that are a high conservation priority or are representative of the overall biodiversity or integrity of the ecosystem rather than list every species that occurs.

Because the set of KEAs and indicators identified by the project team was too large to feasibly measure over time, we ranked the indicators based on how well they indicate target health and feasibility of measuring. We then used scientific literature, reports, and conservation plans to describe each target (ecology, status and trends, management goals). Target indicators provided a basis for evaluating threats (including climate change) and management strategies. We identified existing Refuge conservation goals by reviewing the Refuge CCP and discussion with Refuge staff.

2.3 Identify Priority Threats and Develop Conceptual Models

We evaluated all threats[2] within the project scope to allow a more comprehensive picture of the conservation situation and to provide a framework for deciding what actions are most needed to address the impacts of climate change and other threats, and ultimately reach conservation goals. We assume climate change will likely exacerbate current threats as well as cause direct stress to conservation targets.

We used a ranking process to identify which threats are expected to put the most stress (altered KEA) on conservation targets in the near-term (current to 2030) and long-term (2030-2100). The process involved defining and applying a set of criteria (and associated scores) to each threat. Ideally, conservation actions are then directed towards the most critical threats given limited resources. The process used for ranking threats is described in more detail in "Conceptualizing and Planning Conservation Projects and Programs: A Training Manual" (Foundations of Success 2009).

The steps for identifying and ranking threats to conservation targets within the study area were as follows:

1. Identify and describe threats to conservation targets within the project scope. The list of threats was compiled from the refuge CCP and expert knowledge (project team, expert advisors).
2. Identify and describe the stress each threat has on targets within the study area. A stress is an attribute(s) of a target's ecology that is impaired directly or indirectly by a threat. For example, reduced target population size caused by the threat of predation.
3. Rank threats to each target, in the near-term (current to 2030) and long-term (2030-2100), using the following criteria:
    - Scope – Proportion of the target within the project scope that can reasonably be expected to be affected by the threat given the continuation of current circumstances and trends. For ecosystems and ecological communities, measured as the proportion of the target's occurrence. For species, measured as the proportion of the target's population.
    - Severity – The level of damage to the target (within the scope) from a threat that can reasonably be expected given the continuation of current circumstances and trends. For ecosystems and ecological communities, typically measured as the degree of destruction or degradation of the target within the scope. For species, usually measured as the degree of

[2] A threat is a human-induced action that stresses—or has the potential to stress—one or more conservation targets. Examples include logging, contaminants, invasive species introductions, land/habitat conversion, fire suppression, altered hydrology, and human disturbance. A stress is the expression of a threat on a conservation target or how it negatively impacts the target. Examples include reduced population/ecosystem size or extent, reduced reproductive success, habitat loss, reduced habitat connectivity, altered community composition or structure, and altered sediment dynamics.

reduction of the target population within the scope. We considered a range future scenarios when assessing climate change impacts across the study extent. For ranking the threat of sea-level rise on conservation targets, the higher rate of sea-level rise, >1.5 m by 2100 and a low end suspended sediment assumption was assumed for both time periods. In most cases, the recommended actions would also have a beneficial impact on conservation targets in a scenario with low rates of sea level rise and/or higher suspended sediment concentrations.

- Irreversibility – The degree to which the effects of a threat can be reversed and the target restored, if the threat no longer existed.

4. Review threat rankings. Threat criteria scores were entered into and summarized using Miradi Adaptive management software (www.Miradi.org) and reviewed by the project team.

Following the threat analysis, we developed conceptual models (using Miradi Adaptive Management software) to visualize the key factors affecting conservation targets within the study area, including threats (and the stress they cause to targets) and other factors that may contribute to threats (indirect threat) or provide opportunities to reduce threats. Conceptual models helped the project team come to collective understanding about the factors influencing conservation targets and to inform where management action should be focused. Often project team members believe they have a shared understanding of their project's context, main threats, opportunities, and the relationships among factors and conservation targets. However, by working through a formal process to gather information about the site and using it to document underlying assumptions about the project's context, project team members can find they have somewhat different perceptions of the same situation.

Because the threat of climate change to refuge natural resources is not well understood, we used available data, scientific literature, and other relevant information to summarize projected changes in climate and how they may impact our conservation targets (see Chapter 3: *Climate Change and Impacts*).

2.4 Identify Optimal Set of Strategies

We used the tools of Structured Decision Making (Hammond et al. 1999) to identify a set of strategies aimed at reducing stress caused by climate change and other priority threats, and ultimately reach conservation goals. Strategies here refer to a group of actions that work together to reduce one or more threats or to restore natural systems. Major steps were:

1. Brainstormed a potential set of strategies to address priority threats or directly restore conservation targets
2. Evaluate the consequences (expected outcomes or results) of each strategy on conservation targets in the near-term (current to 2030) and long-term (2030-2100)
3. Use the consequences analysis and project team discussion to identify an optimal set of strategies for the near-term (current to 2030) and long-term (2030-2100)

2.4.1 Strategy development

The core team compiled a list of potential strategies to address climate change and other priority threats within the project scope. The strategies were first compiled from the Refuge CCP and larger landscape conservation plans of the San Francisco Estuary or estuarine ecosystems elsewhere (such as the TMRP, Goals Project, CADS Phase I). The larger project team and advisors then met to identify any other potential strategies to reduce the impacts of climate change and other priority threats. We then described each strategy, including when it would likely be implemented and what threat(s) it would address.

2.4.2 Strategy ranking

After creating a set of strategies, the team then needed evaluate the consequences of each of these strategies on the conservation targets (objectives) in each time frame. These consequences are simply predictions of how each of the strategies would specifically affect each of the conservation targets. The core team, with input from the larger project team, created a strategy rating rubric to rate the strategies in terms of spatial extent, impact, and feasibility. Spatial extent and impact were rated by refuge and complex staff for each ecosystem target (and associated nested target) within the bounds of the refuge. In addition to strategy impact, we created a series of measures to assess feasibility of each strategy. Refuge and complex staff were then asked to rate each strategy (see below) and take notes about their individual responses. The team was also asked to make these predictions in light of the projected climate impacts described in Chapter 3: *Climate Change and Impacts.*

The criteria and scores used to rank strategies were:

- **Spatial Extent**: Describes the spatial extent of the ecosystem, within the bounds of the Refuge that would be affected by a given strategy.
    - 5 = 80-100% of ecosystem would benefit,
    - 4 = <80% of ecosystem would benefit,
    - 3 = <50% of ecosystem would benefit,
    - 2 = <25% of ecosystem would benefit,
    - 1 = <5% of ecosystem scope would benefit,
    - 0 = no effect
- **Impact**: Describes the impact that a strategy would have on each of the biological targets (measurable attributes) within each ecosystem (fundamental objectives). Composed of two sub-categories: likelihood and magnitude.
    - **Likelihood**: Describes the likelihood that a strategy, acting alone, would increase an ecosystem measure/indicator (biological target). In other words, if you do it, where you plan to do it, how well will it work?
        - 5 = 80-100% chance indicator will increase,
        - 4 = <80% chance indicator will increase,
        - 3 = <50% chance indicator will increase,
        - 2 = <25% chance indicator will increase,
        - 1 = <5 % chance indicator will increase,
        - 0 = No chance indicator will increase or indicator will decrease
    - **Magnitude**: Predicted magnitude of change in the indicator/measure, if the strategy were implemented.
        - 6 = large magnitude of increase (>50%)
        - 5 = moderate magnitude of increase (10 – 49%),
        - 4 = small magnitude of increase (5 – 9%),
        - 3 = no detectable change (-4 – 5 %),
        - 2 = small magnitude of decrease (-9 – -5%),

    - 1 = moderate magnitude of decrease (-49 – -10%),
    - 0 = large magnitude of decrease (< -50%)
- **Feasibility**: Comprised of four sub-categories:
  - **Technical capacity, political or leadership support, and Refuge staff capacity**: Technical capacity describes the state of the science. Refuge staff capacity is comprised of time and effort for Refuge staff and ability.
    - 3 = all three factors are met,
    - 2 = two of the three factors are met,
    - 1 = one of the three factors is met,
    - 0 = none of the three factors is met
  - **Initial cost**: Cost necessary to implement the strategy, but not necessarily funded by the Refuge.
    - 5 = <$100,000,
    - 4 = <$250,000,
    - 3 = <$1 million,
    - 2 = $1-$4 million,
    - 1 = >$4 million
  - **Fundability**: Likelihood of getting the project funded.
    - 2 = > 60% chance of getting funded
    - 1 = 30 – 60% chance of getting funded
    - 0 = < 30% chance of getting funded
  - **Continuing costs**: Annual costs to the Refuge to maintain or monitor after the initial project is complete.
    - 2 = < $20,000 per year
    - 1 = $20 – 100,000 per year
    - 0 = > $100,000 per year

2.4.3 Analysis of expert rating data

Data from the expert elicitation process were summarized to determine a ranking for each strategy. First, for all ecosystems in which there was more than one biological indicator (key ecological attribute), the ratings for all indicators (n = 2 – 6) were averaged across experts for the Likelihood and Magnitude sub-categories of the Impact category. In this way, there was one composite rating of Likelihood and one composite rating of Magnitude for each ecosystem.

Second, for each elicited category or sub-category, the ratings from all experts were averaged (e.g., $Fundability_j = (\sum_{i=1}^{n} Fundability_{i,j})/n$, where n is the number of experts, and $Fundability_{i,j}$ is the fundability rating of the j^{th} strategy by the i^{th} expert).

To ensure that all measures were compared on the same scale, the resulting average ratings for each of the categories was normalized across all strategies on a 0 – 1 scale. For example, the most highly rated strategy for Fundability received a score of 1, and the least highly rated strategy for Fundability received a 0.

The composite rating for each strategy was calculated as the average rating across all scoring categories and ecosystems (n = 19 total ratings per strategy), resulting in a 0 – 1 score for each strategy. Because we assumed that each category and ecosystem should receive an equal weighting, the average was an appropriate measure.

Each strategy was ranked (near term = 1 – 36; long term = 1 – 40) based on the composite rating for the strategy. These calculations were also performed for each expert individually to evaluate the variation about the average rankings.

After the ratings data were analyzed and the ranked lists were created, we used the modified Delphi approach in which the results were presented to all workshop participants for discussion and experts were allowed to make changes as necessary (Kuhnert et al. 2010). Participants were asked to discuss the overall rankings of each of the strategies (both the average and the individual rankings), as well as the components of those rankings. Through this discussion, participants gained more insight into how to prioritize each strategy and the impact that each strategy would have on the refuge in both the near and long term. Through these discussions, the participants placed the strategies into hierarchical tiers of action (see below). In addition, participants determined that some strategies could be merged, such that the final list of strategies was condensed. After the discussions, all results and notes were compiled and strategies were placed into final tiers according to priority, impact, and feasibility. Impact and priority were determined based on discussions, and feasibility was determined from the results of the initial expert elicitation.

Priority was separated into four tiers: very high, high, medium, and low. Very high tiers were those strategies that were ranked highest by all experts in the initial elicitation and considered to be of the greatest importance. Impact was separated into three tiers: high, medium, and low. Strategies were placed into these categories for both priority and impact based on the discussions about the initial results of the expert elicitation work. Feasibility was separated into three tiers: high, medium, and low. Total feasibility was the average of each of the individual normalized scores for the four sub-categories of feasibility (technical capacity, political or leadership support, and Refuge staff capacity; initial cost; fundability; and continuing costs). For strategies that were merged after discussions, the ratings of each of the strategies that comprised the newly-merged strategy were averaged for each feasibility sub-category. Strategies that had a total feasibility score >0.66 were considered high, medium strategies had a feasibility score between 0.33 and 0.66, and low strategies had a total feasibility score of <0.33.

3. Climate Change and Impacts

3.1 Climate Change Scenario Approach

Future climate change projections include a considerable range of uncertainty because of a lack of scientific understanding of climatic and other physical processes as well as uncertainty about how human behavior will change in the future. Given this uncertainty, climate-smart conservation planning requires an evaluation of a plausible range of future projections to ensure that we consider all possible impacts and that are adaptation strategies are robust to future uncertainty. We drew upon existing studies to identify and describe a plausible set of climate change scenarios for the study regions that includes projections of temperature, precipitation and sea level rise. We selected the most recent projections for the region and, where multiple future models were available, selected a subset of models that characterize the range of future projections (Table 2). We summarized temperature and precipitation projections for the study region using recently downscaled climate projections provided by the Terrestrial Biodiversity Climate Change Collaborative (TBC3, http://geo.pointblue.org/watershed-analyst/). Sea level rise and related tidal marsh projections were summarized from the Our Coast Our Future Tool (www.ourcoastourfuture.org), the San Francisco Bay Future Marshes Tool (www.pointblue.org/sfbayslr) and numerous other published studies from around the estuary.

3.2 Overview of Changes

3.2.1 Warmer seasons

Climate change projections based on global circulation models downscaled for the North Bay indicate that temperatures will increase. By the last 30 years of this century, North Bay scenarios project average minimum temperatures to increase by 0.5 °C to 5.8 °C and average maximum temperatures to increase by 0.9°C to 5.5 °C relative to conditions over the last 30 years.

3.2.2 Shifts in rainfall and storm events

Most projections point to longer and drier summers and shorter winters characterized by more frequent and more intense storm events (Micheli et al. 2012). Rainfall projections for the North Bay vary among models with some showing strong declines and some showing moderate increases in annual rainfall through the end of the century. However, most scenarios show an increase in the frequency and intensity of droughts and floods meaning that the rainfall will be increasingly sporadic and less available to plants and wildlife. Groundwater recharge will likely be reduced at the same time that groundwater pumping will likely increase in response to the lack of surface water available. The projected increase in storm intensity and frequency underscores the need for a resilient transition zone in providing refuge for wildlife.

3.2.3 Accelerating sea-level rise

Sea-level rise projections for the region range from 42 to 167 cm (1.38 to 5.48 ft) by 2100 (NRC 2012, CO-CAT 2013). An increase in sea level will cause the tidal marsh-upland transition zone to shift to adjacent upland areas where such accommodation space is available. In many areas in the North Bay accommodation space for marsh and transition zone migration is hindered by narrow levees, urban development, and steep topography. The transition zone in these areas will likely disappear or be greatly reduced. Baywide, about 2,000 to 3,000 hectares of uplands may transition to tidal marsh depending on the amount of suspended sediment available to marshes and the rate of sea-level rise (Stralberg et al. 2012). To keep pace with sea-level rise, marshes need sediment to maintain their elevation relative to mean sea level. Higher suspended sediment concentrations in the water column lead to more rapid marsh accretion. Much of the area available for marsh and transition zone migration baywide occurs in the North Bay because of the gradual topography and low-intensity development relative to the Central and South bays (Veloz et al. 2012).

3.2.4 Higher salinity

An increase in water salinity levels is expected as a result of sea-level rise, decreasing precipitation, runoff, and snowmelt contribution to runoff that feed tributaries entering the Bay (Cloern et al. 2011). Salinity levels are projected to increase by 0.33 to 0.46 psu per decade in Northern San Francisco Bay. These salinity increases will in turn affect soil salinity in the transition zone resulting in habitat changes for plants and wildlife.

3.3 Climate Projections

Historic climate and 14 future climate models were summarized for the two watersheds encompassing the San Pablo Bay NWR (Figure 2). The first area surrounds the Napa River from the mouth and runs north to Lake Hennessey and west to Skaggs Island. The second area surrounds Sonoma Creek and its mouth and Skaggs Island, and runs north just past the town of Sonoma and west along Highway 121. Minimum and maximum values for a set of hydro-climate variables are provided in Table 2.

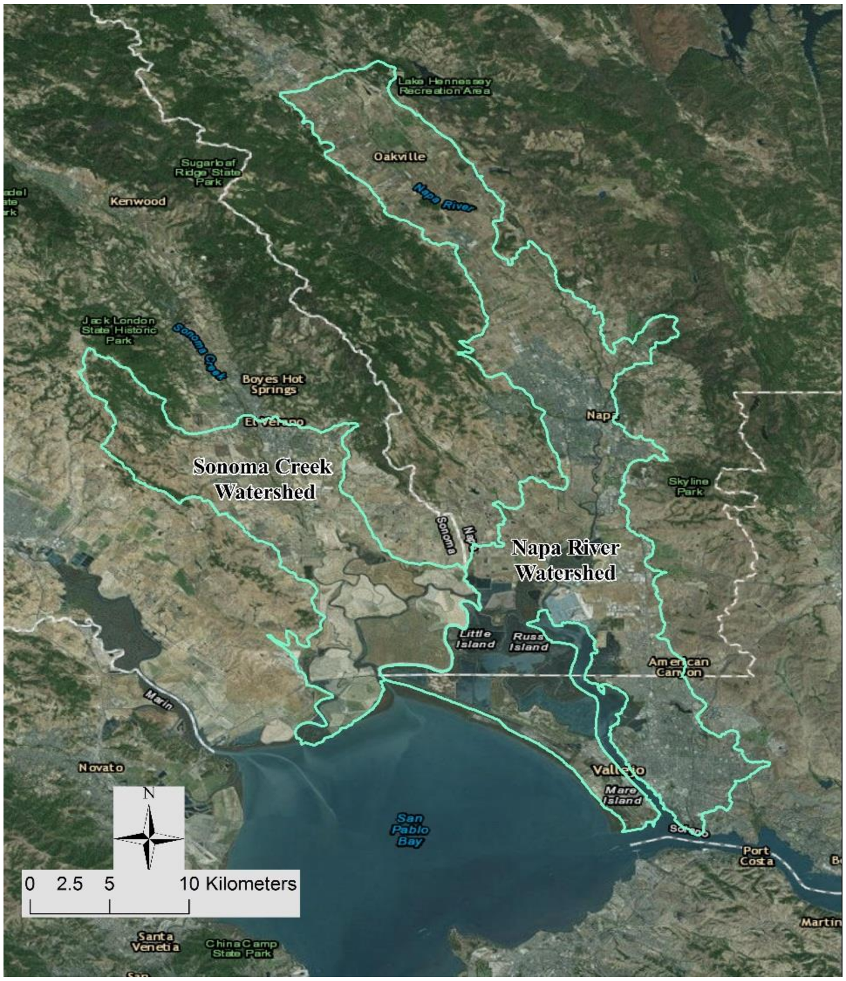


Figure 2. Study area watersheds where future climate projections were summarized.

3.3.1 Temperature

Historic monthly high and low temperature values were averaged across each year and compared to projected future values. Between 1921 and 2009 the highest monthly mean maximum temperature was 23.01 degrees Celsius in 1981. The historic high mean minimum temperature was 9.33 degrees Celsius in 1997. Out of 14 climate models, MIROC RCP85 surpasses the historic maximum the most at

Table 2. Summary of observed historic (1950 – 1980) and modeled future (2011-2040 and 2070 – 2099) climate and hydrological variables. Reported future values represent the lowest an upper values for each variable selected from 14 models that include a range of general circulation models and greenhouse gas emission scenarios. We use 2011-2040 for the new term as future climate projections are typically reported as a 30 year average.

Napa River Watershed

Average Annual Data	Observed: 1951-1980	Lower: 2011-2040	Upper: 2011-2040	Lower: 2070-2099	Upper: 2070-2099
Daily Max Temperature	21.7 °C	22.6 °C	23.1 °C	22.4 °C	27.5 °C
Daily Min Temperature	7.4 °C	8.4 °C	9.2 °C	8.3 °C	12.9 °C
Precipitation	623 mm	611 mm	841 mm	492 mm	883 mm
Runoff	19 mm	15 mm	59 mm	8 mm	86 mm
Recharge	146 mm	117 mm	265 mm	76 mm	301 mm
Potential Evapotranspiration	1206 mm	1252 mm	1258 mm	1326 mm	1312 mm
Actual Evapotranspiration	453 mm	469 mm	508 mm	411 mm	497 mm
Climatic Water Deficit	747 mm	743 mm	784 mm	818 mm	937 mm

Sonoma Creek Watershed

Average Annual Data	Observed: 1951-1980	Lower: 2011-2040	Upper: 2011-2040	Lower: 2070-2099	Upper: 2070-2099
Daily Max Temperature	21.9 °C	22.3 °C	22.9 °C	22.4 °C	27.2 °C
Daily Min Temperature	6.4 °C	8.1 °C	8.9 °C	7.3 °C	11.8 °C
Precipitation	877 mm	681 mm	1141 mm	690 mm	1095 mm
Runoff	42 mm	25 mm	131 mm	16 mm	73
Recharge	241 mm	203 mm	374 mm	134 mm	366
Potential Evapotranspiration	1199 mm	1238 mm	1242 mm	1221 mm	1309 mm
Actual Evapotranspiration	578 mm	607 mm	629 mm	540 mm	647 mm
Climatic Water Deficit	611 mm	608 mm	632 mm	570 mm	790 mm

73 times for Sonoma Creek watershed (Table 3) and 75 times for the Napa River watershed (Table 4). The historic high mean minimum temperature is surpassed 67 times by this same model for the Sonoma Creek watershed (Table 2) and 68 times for the Napa River watershed (Table 4). In contrast, the GISS RCP26 model surpasses the historic high maximum temperature only 10 times for Sonoma Creek and Napa Creek while surpassing historic high minimum temperature 1 time for each watershed.

Table 3. Count of Sonoma Creek projected mean maximum and minimum temperature values compared to the historic maximum and historic minimum. Models with the highest or lowest counts are shown in red.

Climate Model	Years over historic max temp	Years over historic min temp
CCSM4_rcp85	58	49
CNRM_rcp85	64	58
CSIRO_A1B	62	52
GFDL_A2	66	62
GFDL_B1	69	53
GISS_AOM_A1B	56	41
GISS_rcp26	10	1
MIROC_rcp45	62	32
MIROC_rcp60	56	26
MIROC_rcp85	73	67
MIROC5_rcp26	45	12
MPI_rcp45	61	45
MRI_rcp26	15	1
PCM_A2	65	41

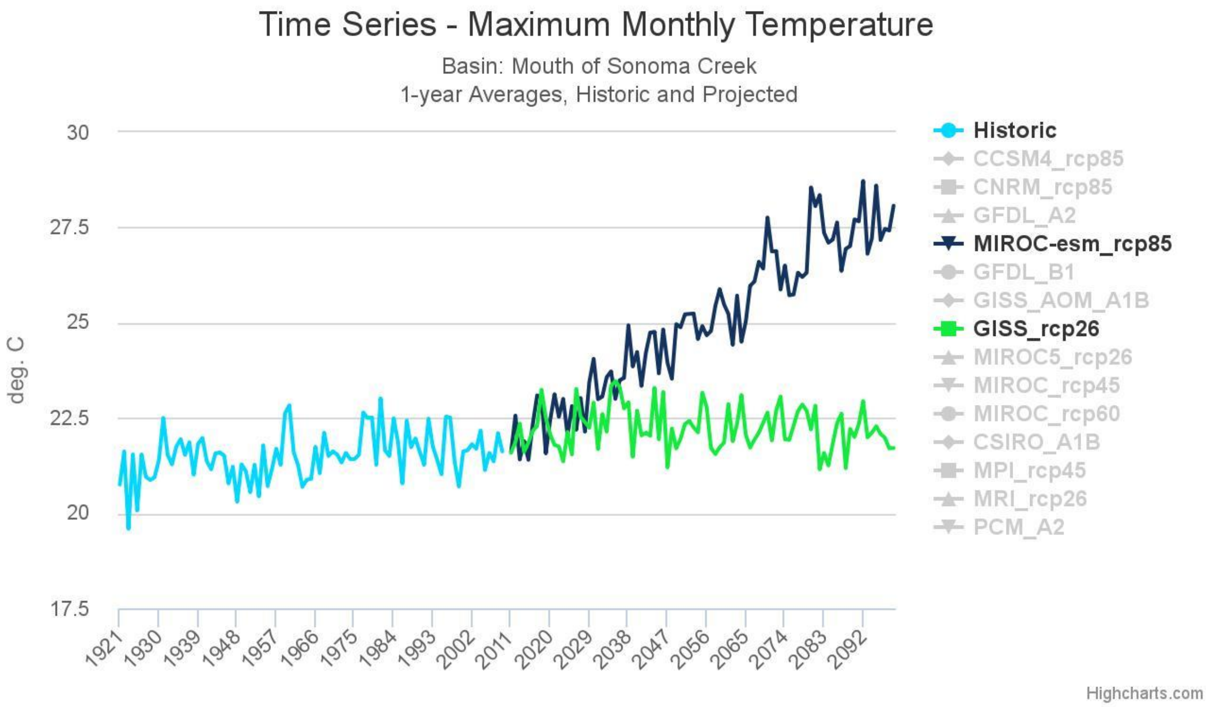


Figure 3. Historic and projected monthly mean maximum temperature for Sonoma Creek watershed. The MIROC RCP85 climate model has the most years over the historic maximum, The GISS RCP26 model has the fewest years over the historic maximum.

Table 4. Count of Napa River watershed projected mean maximum temperature values compared to the historic maximum and highest historic minimum.

Climate Model	Years over historic max temp	Years over historic min temp
CCSM4_rcp85	59	50
CNRM_rcp85	64	61
CSIRO_A1B	62	54
GFDL_A2	66	62
GFDL_B1	67	50
GISS_AOM_A1B	57	42
GISS_rcp26	10	1
MIROC_rcp45	63	33
MIROC_rcp60	60	29
MIROC_rcp85	75	68
MIROC5_rcp26	46	18
MPI_rcp45	61	48
MRI_rcp26	15	2
PCM_A2	64	41

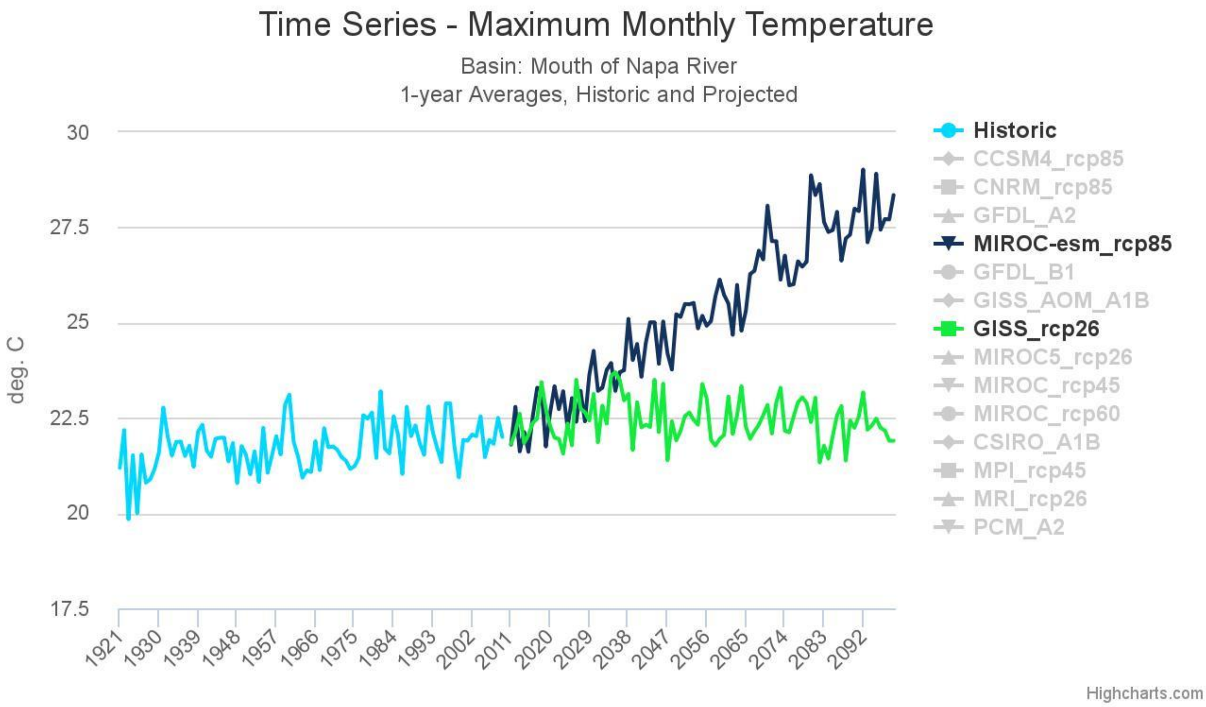


Figure 4. Historic and projected monthly mean maximum temperature for Napa River watershed. The MIROC RCP85 climate model has the most years over the historic maximum, The GISS RCP26 model has the fewest years over the historic maximum.

3.3.2 Precipitation

Annual precipitation totals were calculated for each water year from 1921 through 2099 (with historic values up until 2009). We then summed the number of times future precipitation exceeded historic extremes for both Sonoma Creek and the Napa River (Table 5) watersheds. A time series graph for the climate models showing the most extremes was also produced (Figure 3 and 4).

Table 5. Count of Sonoma Creek projected extreme precipitation values for 14 climate models compared to historic. Models with the highest counts are shown in red.

Climate Model	Years over historic 90 percentile	Years over max historic	Years below historic 10 percentile	Years below min historic
CCSM4_rcp85	10	2	9	1
CNRM_rcp85	33	6	2	0
CSIRO_A1B	22	1	1	0
GFDL_A2	11	2	24	5
GFDL_B1	10	2	11	1
GISS_AOM_A1B	7	0	13	2
GISS_rcp26	18	0	3	0
MIROC_rcp45	9	0	14	0
MIROC_rcp60	4	0	17	1
MIROC_rcp85	1	0	21	3
MIROC5_rcp26	8	1	13	0
MPI_rcp45	8	2	3	0
MRI_rcp26	17	0	3	0
PCM_A2	16	1	10	3

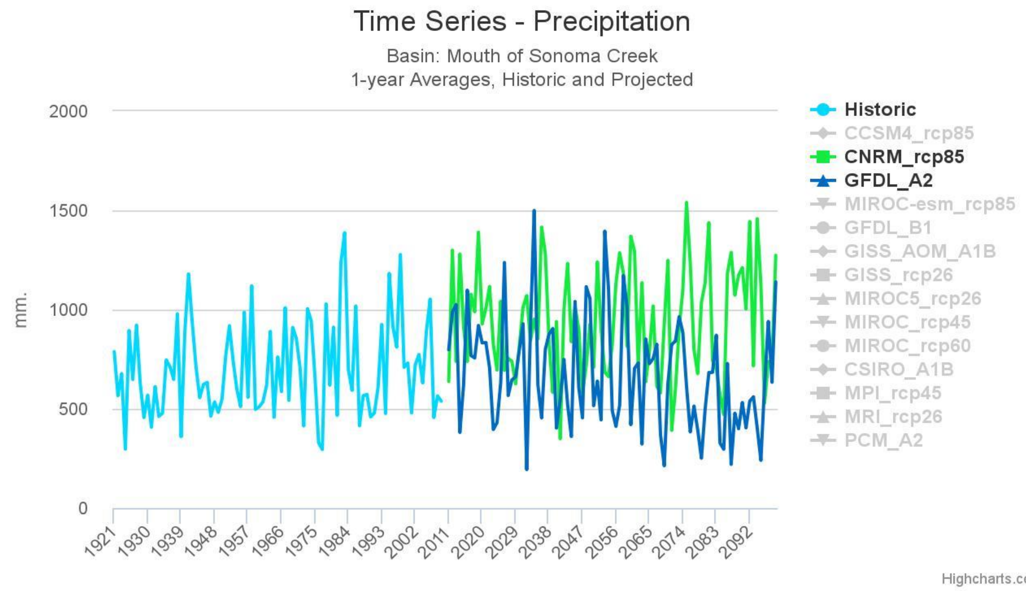


Figure 5. Graph of yearly Sonoma Creek precipitation values for historic and two future climate model projections (CNRM RCP85 and GFDL A2).

3.4 Sea-level Rise and Tidal Marsh Habitat

The impacts of future sea-level rise to marsh habitat were summarized within different study sites. For this report we looked at Tolay Creek, Lower Tubbs Island, Petaluma River Mouth, and Strip Marsh East. Four scenarios were considered for each including site-specific low and high sedimentation rates and a low (0.5 m/century) and high (1.65 m/century) rate of SLR. For each site we looked at potential changes in the area of upland, high marsh, mid marsh, low marsh, mudflat, and subtidal habitat across 5 time periods (2030, 2070, 2090, and 2110) with 2010 serving as the baseline current conditions. These scenarios assume full tidal action occurs across each site. Marsh accretion was modeled using the Marsh98 model (Orr et al. 2003) which assumes that marsh plain elevation change rate depends on the availability of suspended sediment and organic material, water depth, and the duration of inundation. Sediment concentrations across the Bay ranged from 25 to 300 mg/L. Note that the results for these sites are consistent with results from Takekawa et al. (2013).

3.4.1 Tolay Creek

Suspended sediment concentrations for this site were 150 mg/L for low and 300 mg/L for high. Most of the site under current conditions is modeled as low-marsh with some mid-marsh. Given these assumptions, marsh habitat at this site is relatively resilient given a low rate of sea-level rise. Under this SLR scenario and low sediment, low and mid-marsh increases over time and is almost completely converted to mid-marsh by 2090, while under a high sediment assumption the site is completely converted to mid-marsh by 2030 and remains so through 2110.

Given a high rate of SLR, mid marsh at this site increases rapidly under the high sediment assumption becoming almost completely mid-marsh by 2030 and remaining so through 2110. However, by 2110 most mid-marsh is replaced by low-marsh or mudflat under the low sediment assumption.

Figure 6. Map of the Tolay Creek with the site highlighted in light blue and circled in red.

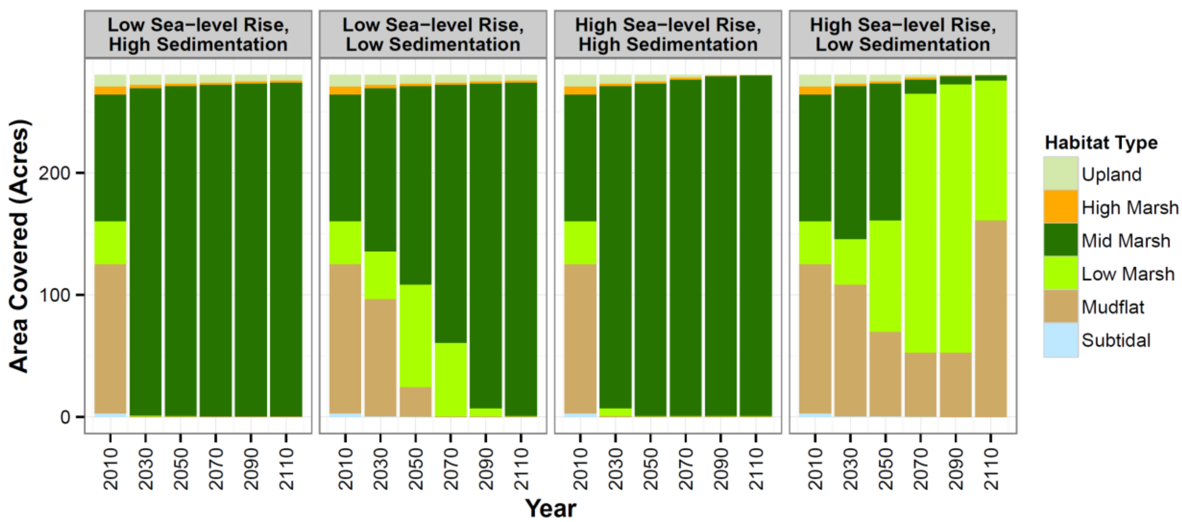


Figure 7. Tolay Creek projected elevation-derived composition of future habitats showing the amount of habitat in acres within the site at five different time periods under four combinations of sea-level rise and sediment scenarios.

3.4.2 Lower Tubbs Island

Suspended sediment concentration estimates for this site were 150 mg/L for the low end and 300 mg/L for the high end. Marsh habitat at this site is relatively resilient given a low rate of sea-level rise. Under this SLR scenario, the entire site is rapidly converted to mid-marsh by 2030 (high sediment) or by 2050 (low sediment) and remains so through 2110.

Given a high rate of SLR, this site becomes completely mid-marsh by 2030 assuming high sediment availability. However, with low sediment availability, the site becomes almost completely low-marsh by 2070 and largely mudflat by 2110.

Figure 8. Map of the Lower Tubbs Island site with the site highlighted in light blue and circled in red.

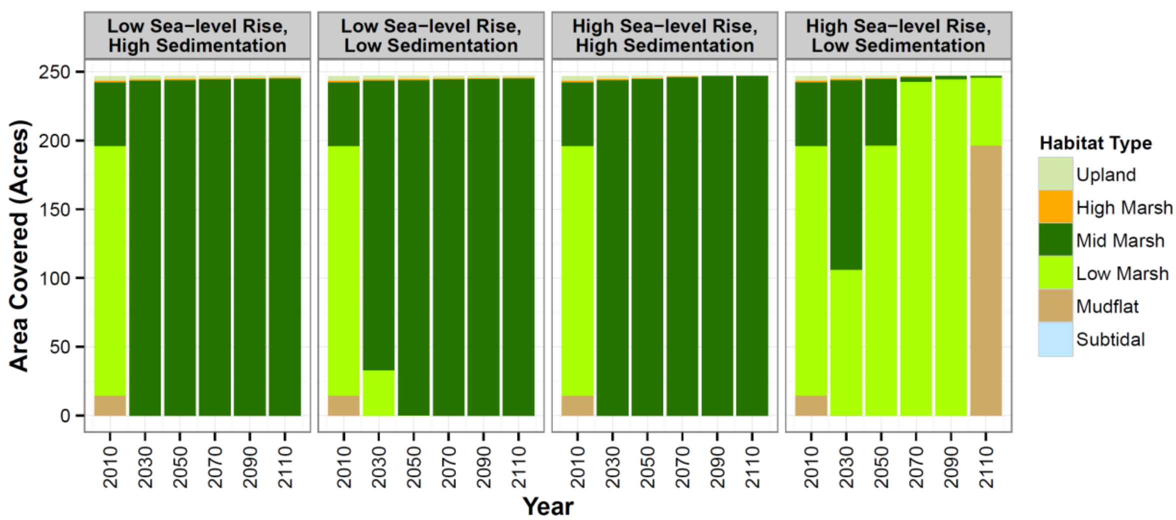


Figure 9. Lower Tubbs projected elevation-derived composition of future habitats showing the amount of habitat in acres within the site at five different time periods under four combinations of sea-level rise and sediment scenarios.

3.4.3 Strip Marsh West (Petaluma River Mouth)

Suspended sediment concentrations for this site were also 150 mg/L for low and 300 mg/L for high. This site was modeled as largely high-marsh. Under a low SLR assumption, most of the area is converted to mid-marsh by 2050 and remains so through 2110.

Under a high SLR scenario, the pattern of conversion to mid-marsh remains the same given high sediment availability, with most of the site becoming mid-marsh by 2030. Assuming low sediment availability, much of the site is converted to mid-marsh through 2070, but then becomes largely low marsh in 2090 and 2110.

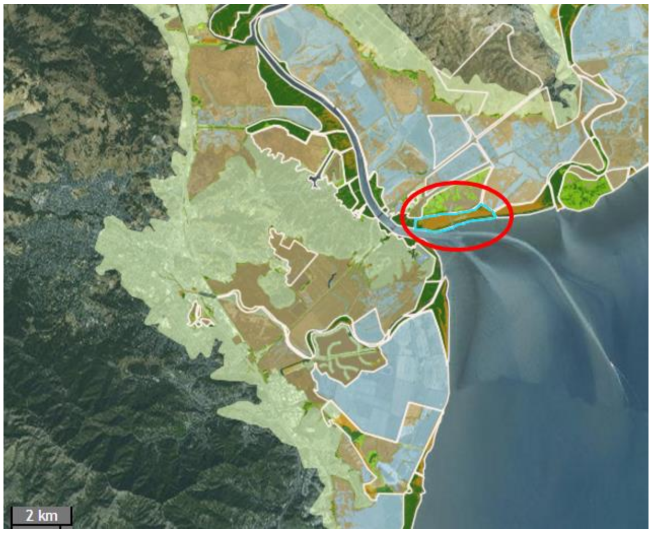


Figure 10. Map of the Strip Marsh West Unit with the site highlighted in light blue and circled in red

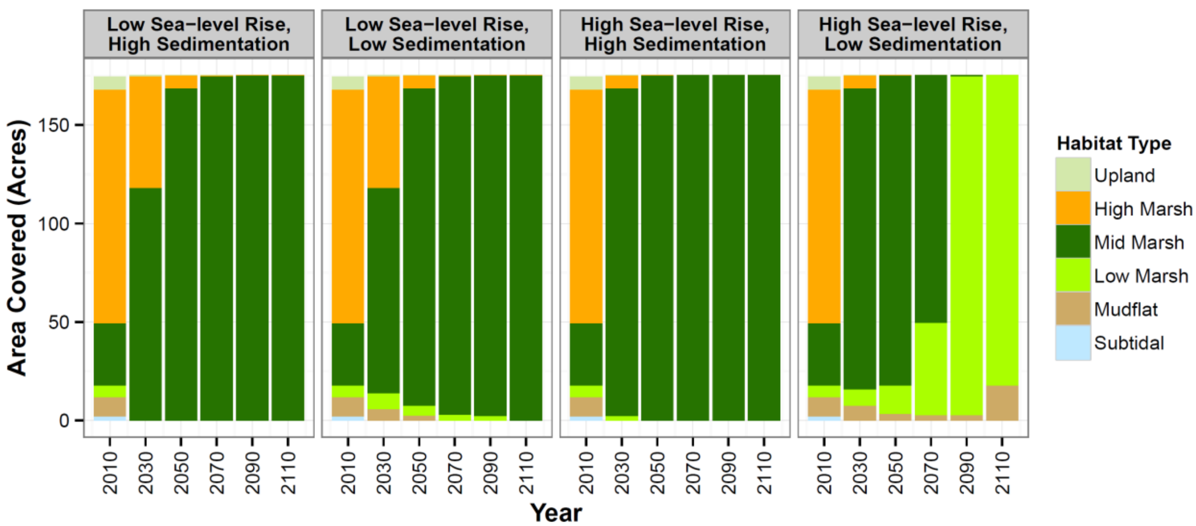


Figure 11. Strip Marsh West (Petaluma River Mouth) projected elevation-derived composition of future habitats showing the amount of habitat in acres within the site at five different time periods under four combinations of sea-level rise and sediment scenarios.

3.4.4 Strip Marsh East

The tidal marsh on the northern edge of San Pablo bay that extends east from Sonoma Creek to Mare Island is the largest in the SPBNWR. This marsh is relatively new having been formed within the last 150 years due to sediment influx during years of peak hydraulic mining in the Sierras. The suspended sediment range used for projecting marsh accretion at this site was 150 to 300 mg/L. Under a low SLR assumption, most of the area remains or is converted to mid-marsh by 2050 and remains so through 2110 regardless of whether the high or low sediment scenario is chosen.

Under the high SLR assumption, most of the area remains or is converted to mid-marsh by 2030 given the high sediment scenario. Under the low sediment scenario, much of the site is converted to mid-marsh through 2050, but then becomes largely low marsh in 2070 through 2110.

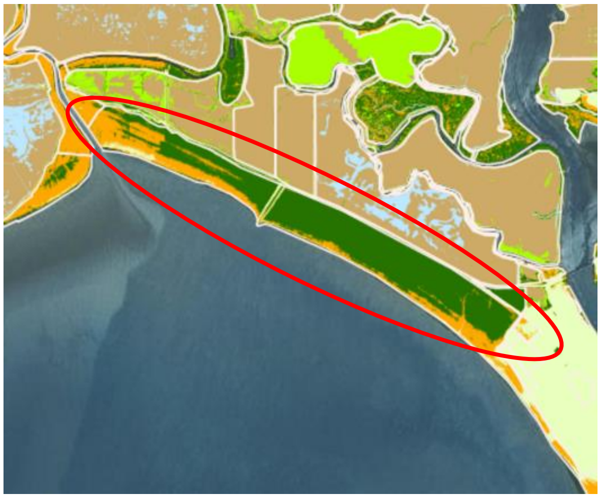


Figure 12. Map of the Strip Marsh East Unit with the site circled in red

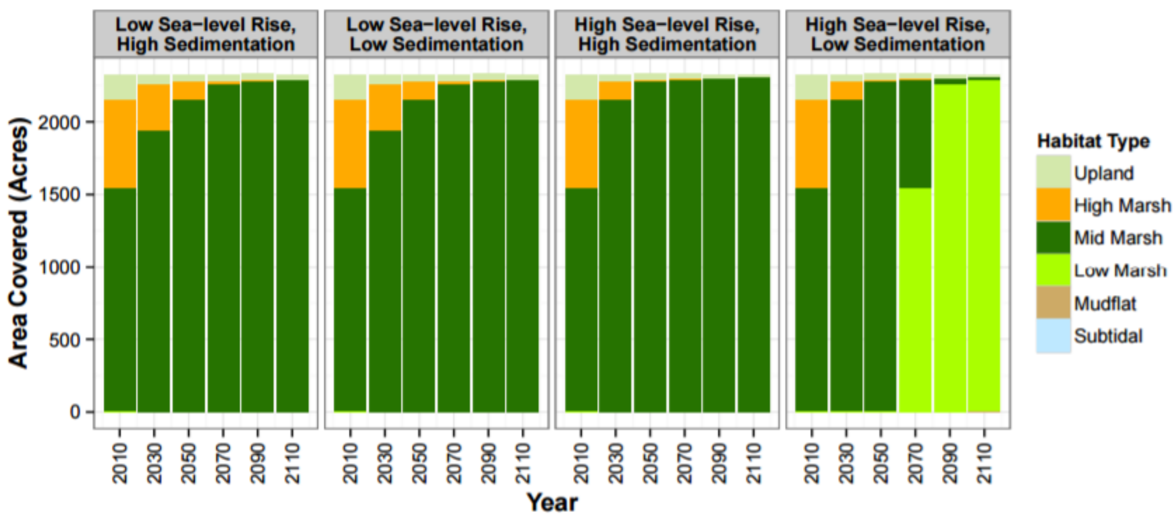


Figure 13. Strip Marsh East Unit projected elevation-derived composition of future habitats showing the amount of habitat in acres within the site at five different time periods under four combinations of sea-level rise and sediment scenarios.

3.5 Flood Risks

The potential flood risks of future sea-level rise and storms and flood depth (mean over mean higher high water) were summarized using the Our Coast Our Future (OCOF) online tool for three sites: Skaggs Island and two additional units to the northeast and northwest. These sites were selected because they are historic marsh sites that are currently protected by levees. The flooding potential of these sites illustrates under what conditions adaptation will be necessary if levees are not breached for restoration. This tool examines an array of sea-level rise scenarios ranging from 25cm to 200cm in increments of 25cm as well as a 5m extreme scenario. Additionally, we evaluate the potential flooding from different storms scenarios (which include, SLR, tide, surge, and waves) on coastal flooding.

3.5.1 Skaggs Island

For analysis, we split the Skaggs Island site into two sections (west and east; Figure 14). The mean elevation for western Skaggs Island is 0.27m with a minimum elevation of -0.42m and a maximum elevation of 3.24m. The mean elevation for eastern Skaggs Island is 0.33m with a minimum elevation of -0.44m and a maximum elevation of 4.34m. The model assumes that existing levees remain in place.

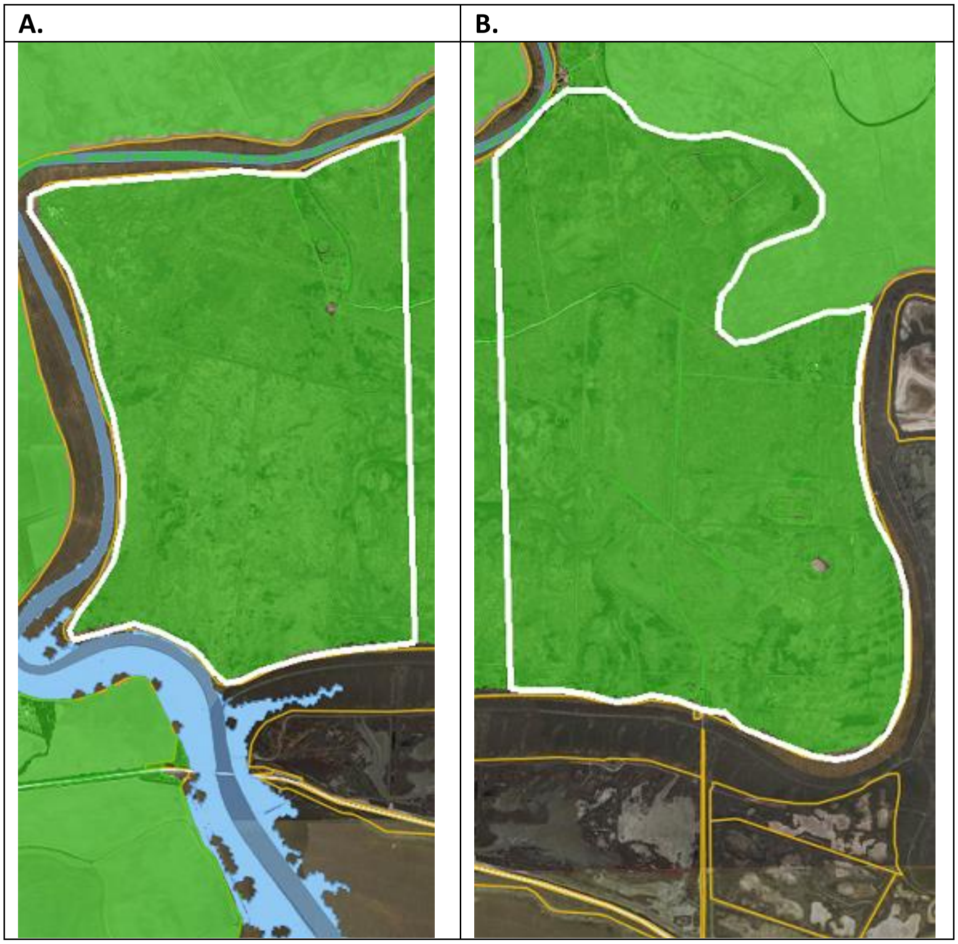


Figure 14. Western (A) and Eastern (B) Skaggs Island areas used to summarize flooding impacts.

Given up to 75cm of SLR, Skaggs Island is resilient to flooding. At 100cm of SLR, the site becomes 100% flooded across any storm scenario.

Table 6. Projected flood extents (% site flooded) for Skaggs Island for a set of sea level rise and storm scenarios.

Storm Scenario	100 yr Storm	0	0	100%	100%	100%	100%
	20 yr Storm	0	0	100%	100%	100%	100%
	Annual Storm	0	0	100%	100%	100%	100%
	No Storm	0	0	100%	100%	100%	100%
		none	50 cm	100 cm	150 cm	200 cm	500 cm
	Sea Level Rise Scenario						

We looked at flooding depth data for the west and east portions of the site. Once Skaggs Island becomes flooded, depth of flooding patterns are similar across the site (Figure 14). Across the entire site, flooding depth reaches over 5 feet of depth given at least 100cm of SLR and any storm scenario.

Table 7. Western (A) and eastern (B) Skaggs Island projected average flood depth for SLR and storm scenario combinations.

A.

Storm Scenario							
	100 yr Storm	none	none	220 - 300 cm 7.2 - 9.8 ft	310 - 390 cm 10.2 - 12.8 ft	385 - 465 cm 12.6 - 15.3 ft	720 - 800 cm 23.6 - 26.2 ft
	20 yr Storm	none	none	220 - 300 cm 7.2 - 9.8 ft	240 - 320 cm 7.9 - 10.5 ft	315 - 395 cm 10.3 - 13 ft	695 - 775 cm 22.8 - 25.4 ft
	Annual Storm	none	none	180 - 260 cm 5.9 - 8.5 ft	300 - 380 cm 9.8 - 12.5 ft	340 - 420 cm 11.2 - 13.8 ft	670 - 750 cm 22 - 24.6 ft
	No Storm	none	none	195 - 275 cm 6.4 - 9 ft	265 - 345 cm 8.7 - 11.3 ft	340 - 420 cm 11.2 - 13.8 ft	635 - 715 cm 20.8 - 23.5 ft
		none	50 cm	100 cm	150 cm	200 cm	500 cm
	Sea Level Rise Scenario						

B.

Storm Scenario							
	100 yr Storm	none	none	210 - 290 cm 6.9 - 9.5 ft	305 - 385 cm 10 - 12.6 ft	380 - 460 cm 12.5 - 15.1 ft	710 - 790 cm 23.3 - 25.9 ft
	20 yr Storm	none	none	215 - 295 cm 7.1 - 9.7 ft	230 - 310 cm 7.5 - 10.2 ft	305 - 385 cm 10 - 12.6 ft	690 - 770 cm 22.6 - 25.3 ft
	Annual Storm	none	none	170 - 250 cm 5.6 - 8.2 ft	295 - 375 cm 9.7 - 12.3 ft	335 - 415 cm 11 - 13.6 ft	665 - 745 cm 21.8 - 24.4 ft
	No Storm	none	none	190 - 270 cm 6.2 - 8.9 ft	260 - 340 cm 8.5 - 11.2 ft	340 - 420 cm 11.2 - 13.8 ft	630 - 710 cm 20.7 - 23.3 ft
		none	50 cm	100 cm	150 cm	200 cm	500 cm
	Sea Level Rise Scenario						

3.5.2 Haire Ranch

Haire Ranch Unit in the northeast section of Skaggs Island is vulnerable to sea level rise at 1.00 m of sea level rise across all storm scenarios. The average flood depth ranges from 1.8 m to 3.05 m with 1 m of sea level rise.

Figure 15. The Haire Ranch site to the Northeast of Skaggs Island used to summarize flooding impacts.

Table 8. Projected flood extent and flood depth for the unit Northeast of Skaggs Island.

Projected Percent Area Flooded for the Selected Area

Values indicate the percentage of the selected area flooded for the Storm and Sea Level Rise Scenario combination.

Storm Scenario		Sea Level Rise Scenario: none	50 cm	100 cm	150 cm	200 cm	500 cm
	100 yr Storm	0	0	100%	100%	100%	100%
	20 yr Storm	0	0	100%	100%	100%	100%
	Annual Storm	0	0	100%	100%	100%	100%
	No Storm	0	0	100%	100%	100%	100%

under 25% flooded | 25-50% flooded | 50-75% flooded | over 75% flooded

Projected Average Flood Depth for the Selected Area

Values indicate the average flood depth (in feet and centimeters) over the Mean Higher High Water (MHHW) within the selected area for each Storm and Sea Level Rise Scenario combination. Values include modeling uncertainty bracket of +/- 40 cm.

Storm Scenario		Sea Level Rise Scenario: none	50 cm	100 cm	150 cm	200 cm	500 cm
	100 yr Storm	none	none	215 - 295 cm 7.1 - 9.7 ft	315 - 395 cm 10.3 - 13 ft	390 - 470 cm 12.8 - 15.4 ft	725 - 805 cm 23.8 - 26.4 ft
	20 yr Storm	none	none	225 - 305 cm 7.4 - 10 ft	230 - 310 cm 7.5 - 10.2 ft	310 - 390 cm 10.2 - 12.8 ft	705 - 785 cm 23.1 - 25.8 ft
	Annual Storm	none	none	180 - 260 cm 5.9 - 8.5 ft	305 - 385 cm 10 - 12.6 ft	350 - 430 cm 11.5 - 14.1 ft	680 - 760 cm 22.3 - 24.9 ft
	No Storm	none	none	200 - 280 cm 6.6 - 9.2 ft	265 - 345 cm 8.7 - 11.3 ft	350 - 430 cm 11.5 - 14.1 ft	640 - 720 cm 21 - 23.6 ft

average less than 1 ft | 1 to 3 ft | 3 to 5 ft | over 5 ft

3.5.3 Northwest Unit

Figure 16. Unit to the Northwest of Skaggs Island used to summarize flooding impacts.

The unit to the northwest of Skaggs Island is vulnerable to flooding at 150 cm of sea level rise under most storm scenarios (Table 9). At 1.5 m of sea level rise, flood depth ranges from 3.7 m to 4.5 m (except the 20 year storm scenario).

Table 9. Projected flood extent and flood depth for the unit Northwest of Skaggs Island.

Projected Percent Area Flooded for the Selected Area

Values indicate the percentage of the selected area flooded for the Storm and Sea Level Rise Scenario combination. Areas of open water are excluded from these percentages.

Storm Scenario		none	25 cm	50 cm	75 cm	100 cm	125 cm	150 cm	175 cm	200 cm	500 cm
	100 yr Storm	0	<1%	<1%	<1%	2%	100%	100%	100%	100%	100%
	20 yr Storm	0	<1%	<1%	<1%	2%	<1%	2%	100%	100%	100%
	Annual Storm	<1%	<1%	<1%	<1%	<1%	2%	100%	100%	100%	100%
	No Storm	<1%	<1%	<1%	<1%	<1%	2%	100%	100%	100%	100%
		Sea Level Rise Scenario									

under 25% flooded | 25-50% flooded | 50-75% flooded | over 75% flooded

Projected Average Flood Depth for the Selected Area

Values indicate the average flood depth (in feet and centimeters) over the Mean Higher High Water (MHHW) within the selected area for each Storm and Sea Level Rise Scenario combination. Values include modeling uncertainty bracket of +/- 40 cm.

Storm Scenario		none	25 cm	50 cm	75 cm	100 cm	125 cm	150 cm	175 cm	200 cm	500 cm
	100 yr Storm	none	0 - 55 cm 0 - 1.8 ft	0 - 80 cm 0 - 2.6 ft	0 - 75 cm 0 - 2.5 ft	20 - 100 cm 0.7 - 3.3 ft	285 - 365 cm 9.4 - 12 ft	330 - 410 cm 10.8 - 13.5 ft	370 - 450 cm 12.1 - 14.8 ft	405 - 485 cm 13.3 - 15.9 ft	745 - 825 cm 24.4 - 27.1 ft
	20 yr Storm	none	0 - 60 cm 0 - 2 ft	0 - 65 cm 0 - 2.1 ft	0 - 75 cm 0 - 2.5 ft	25 - 105 cm 0.8 - 3.4 ft	5 - 85 cm 0.2 - 2.8 ft	30 - 110 cm 1 - 3.6 ft	290 - 370 cm 9.5 - 12.1 ft	325 - 405 cm 10.7 - 13.3 ft	720 - 800 cm 23.6 - 26.2 ft
	Annual Storm	0 - 55 cm 0 - 1.8 ft	0 - 60 cm 0 - 2 ft	0 - 70 cm 0 - 2.3 ft	0 - 80 cm 0 - 2.6 ft	0 - 75 cm 0 - 2.5 ft	20 - 100 cm 0.7 - 3.3 ft	325 - 405 cm 10.7 - 13.3 ft	335 - 415 cm 11 - 13.6 ft	365 - 445 cm 12 - 14.6 ft	695 - 775 cm 22.8 - 25.4 ft
	No Storm	none	0 - 55 cm 0 - 1.8 ft	0 - 75 cm 0 - 2.5 ft	0 - 70 cm 0 - 2.3 ft	5 - 85 cm 0.2 - 2.8 ft	15 - 95 cm 0.5 - 3.1 ft	285 - 365 cm 9.4 - 12 ft	330 - 410 cm 10.8 - 13.5 ft	365 - 445 cm 12 - 14.6 ft	655 - 735 cm 21.5 - 24.1 ft
		Sea Level Rise Scenario									

average less than 1 ft | 1 to 3 ft | 3 to 5 ft | over 5 ft

4. Conservation Targets Overview

This section provides a broad overview of the five ecosystem targets and nested targets (Table 12) we identified, including their key ecological attributes and indicators (Table 3), and abiotic factors that drive these systems (referred to as *ecosystem drivers* in Table 4).

We also provide a brief overview of each target, including status, goals, and potential impacts from climate change. It is important to note the Refuge places higher conservation value on some conservation targets relative to others. Factors that influenced these decisions include Refuge establishing legislation, purposes, and the contribution of Refuge lands to conservation of a particular ecosystem, community, or species. The Refuge also recognizes the target ecosystems are inter-related and therefore must be evaluated as a whole when deciding what actions to take. Relative importance of ecosystem targets was used as a weighting factor when considering the impact of strategies (see *Chapter 5*).

Table 10. Ecosystem targets descriptions and biological nested targets for San Pablo Bay National Wildlife Refuge.

Ecosystem Target	***Description***	***Nested Targets (biological)***
Subtidal and intertidal mudflats	Estuarine subtidal: Those estuarine ecosystems within substrate that is permanently flooded by tidal water. Estuarine intertidal mudflats: sedimentary intertidal habitats created by deposition in low energy coastal environments, particularly estuaries and other sheltered areas. Their sediment consists mostly of silts and clays with a high organic content. Includes rocky intertidal and barrier beaches (i.e. outboard of Lower Tubbs Island, Sonoma Creek West, Sonoma Creek East)	Delta smelt, green sturgeon, longfin smelt, salmonids, tidewater goby, shorebirds, waterfowl, other waterbirds, invertebrates
Tidal marsh	Marsh found in estuaries where the flooding characteristics are determined by the tidal movement of the adjacent estuary, sea or ocean. According to the salinity of the flooding water, freshwater, brackish and saline tidal marshes are distinguished. Respectively, they may be classified into coastal marshes and estuarine marshes. They are also commonly zoned into lower marshes (also called intertidal marshes) and upper or high marshes, based on their elevation with respect to the sea level. They may be classified by salinity, tide range, and geomorphic setting. Includes associated channels and salt pans	Native salt marsh plants, California black rail, Ridgway's rail Salt marsh associated songbirds (common yellowthroat, San Pablo song sparrow), salt marsh harvest mouse, shrew spp.
Marsh-upland transition zone	Estuarine-terrestrial transition zones occupy the boundary between land and sea, from tidal marsh up to the effective limit of tidal influence. These zones harbor unique plant communities, provide critical wildlife support to adjacent ecosystems, and play an important role in linking marine and terrestrial processes. The marsh-upland transition zone within the scope is primarily composed of flood control levees	Native small mammals, native transition zone plants, salt marsh associated songbirds (common yellowthroat, San Pablo song sparrow)
Migration Space/Grasslands	Lands adjacent to estuarine ecosystems within the project scope that are currently not under tidal influence. Consists primarily of grasslands with seasonal wetlands. Lower elevation grasslands are seasonally wet (from precipitation). These grasslands provide upland and wetland habitat for a variety of native wildlife and plants such as grasses and forbs, migratory birds (especially shorebirds), and sensitive species such as burrowing owls. In the future, these areas may transition to estuarine ecosystems as sea level rises (if they have sufficient slope and elevation and the absence of barriers)	Native herpetofauna (incl. RLFRs), shorebirds, native grasses/forbs, seasonal wetland native plants, burrowing owl, grassland associated songbirds (grasshopper sparrow, meadowlark, red-winged blackbird, savannah sparrow)
Riparian	A drainage basin or watershed is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point at a lower elevation, usually the exit of the basin, where the waters join the estuary	Native willow species, native moist soil indicator plants, riparian birds (both nesting and migratory)

Table 11. Key ecological attributes and their indicator/measure for each conservation target.

Target	Ecological Attribute	Indicator/Measure
Subtidal and intertidal mudflats	Waterfowl richness and abundance	Waterfowl species richness and abundance (winter)
	Invertebrate abundance	Invertebrate abundance (index)
	Shorebird richness and abundance	Shorebird species richness and abundance (winter)
Tidal marsh	Marsh connectivity	Index of tidal marsh hydrologic connectivity
	Extent of high tide refuge (interior marsh)	Extent of high tide refuge (marsh interior)
	Native plant composition	Proportion (%) of tidal marsh with no invasive plants
	Secretive marsh bird abundance	Ridgeway's rail and black rail density (index)
	Native small mammal abundance	Salt marsh harvest mouse capture success (index)
Marsh-upland transition zone	Native plant composition	% area vegetated by native MTZ plants
	Extent of marsh-upland transition zone available at king tide (marsh edge+interior marsh)	Extent (acres) marsh-upland transition zone at king tide
	Native plant cover	% MTZ vegetated
Migration space/grasslands	Native grass/forb vigor	Native grass/forb density and height
	Nesting grassland bird species richness	Nesting grassland bird species richness
	Burrowing owl density	Burrowing owl density (birds/ha)
Riparian	Canopy cover	Native riparian plant cover (%)

Table 12. Abiotic drivers of target ecosystems for the San Pablo Bay National Wildlife Refuge.

Ecosystem	***Abiotic Ecosystem Driver***
Subtidal and intertidal mudflats	Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity), water quality (salinity, pH, temperature), sediment regime (supply, accumulation)
Tidal marsh	Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity), channel complexity, water quality (salinity, pH, temperature), sediment regime (supply, accumulation), marsh size and connectivity, water quality (salinity, pH, temperature)
Marsh-upland transition zone	Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity), sediment regime (supply, accumulation), water quality (salinity, pH, temperature)
Migration space/grasslands	Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity)
Riparian	Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity)

4.1. Subtidal and Intertidal Mudflat Ecosystem

Figure 17. Mudflat Ecosystem (photo by Meg Marriott, USFWS)

Description: Those estuarine ecosystems within substrate that is permanently flooded by tidal water (Figure 17). Estuarine intertidal mudflats: sedimentary intertidal habitats created by deposition in low energy coastal environments, particularly estuaries and other sheltered areas. Their sediment consists mostly of silts and clays with a high organic content.

Nested biological targets: Native Fish, Shorebirds, waterfowl, and invertebrates.

Locations: Open Bay, Cullinan Ranch, Dickson Ranch, Figueras Unit, salt pannes below marsh plain in Strip Marsh East, Tubbs Island Setback, Sonoma Baylands.

Key ecological attributes considered:

- Waterfowl richness and abundance*[Δ]
- Shorebird Richness and abundance*[Δ]
- Invertebrate abundance*[Δ]
- Forage for diving duck populations[Δ]
- Native fish diversity and abundance[Δ]
- Salmonid abundance[Δ]

(* = ecological attributes selected as most important, Δ = a key indicator of biological diversity in the SF Estuary [CADS Phase I; Mattsson et al. 2015])

Key ecosystem drivers: Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity), water quality (salinity, pH, temperature), sediment regime (supply, accumulation).

Refuge CCP goals and objectives related to key ecological attributes or ecosystem drivers:

GOAL 2: Protect, enhance, and restore high quality roosting and foraging environments for overwintering and migratory shorebirds and waterfowl.

GOAL 4: Protect and enhance subtidal systems for the benefit of marine and subtidal dependent species.

4.1.1 Climate change impacts to subtidal and intertidal mudflat

Sea-level rise and changes in flooding regimes will likely cause and Increases in salinity (Knowles and Cayan 2002) which will in turn change the composition of plant, invertebrate and fish communities in the subtidal and intertidal habitats indirectly impacting the composition of shorebird and other waterbird communities (Nur and Herbold, 2015). Sea-level rise may result in a decline in subtidal and intertidal habitat availability (Galbraith et al. 2002) unless currently higher elevation habitats convert to mudflats in which case habitat area could remain stable or increase. Increasing air and water temperatures will favor warm water adapted invertebrate and fish species. Dabbling ducks may experience declines in reproductive success with increases in temperature and salinity (Nur and Herbold, 2015). Overall changes in water temperature, salinity, and flooding may also negatively impact spawning habitat for Delta smelt and Longfin smelt (Moyle 2008). These changes may promote the reestablishment of Tidewater Goby and Grunion (Martin 2015). Extreme precipitation events following extended dry periods can increase the exposure of fish and wildlife to contaminants (Moyle 2008).

4.2 Tidal Marsh Ecosystem

Figure 18. Tidal marsh ecosystem (photo by Meg Marriott, USFWS).

Description: Tidal marshes are found in estuaries where the flooding characteristics are determined by the tidal movement of the adjacent estuary, sea or ocean (Figure 18). According to the salinity of the flooding water, freshwater, brackish and saline tidal marshes are distinguished. Respectively, they may be classified into coastal marshes and estuarine marshes. They are also commonly zoned into lower marshes (also called intertidal marshes) and upper or high marshes, based on their elevation with respect to the sea level. They may be classified by salinity, tide range, and geomorphic setting.

Locations: The primary units with tidal marsh are Figueras Unit, Strip Marsh East, Sonoma Creek East, Sonoma Creek West, Tubbs Island Setback, Tubbs Setback East, Lower Tubbs Island, Strip Marsh West, Sonoma Baylands, Tolay Creek, outboard strips of Cullinan Ranch and Skaggs Island/Haire Ranch, Guadalcanal.

Nested biological targets: Secretive marsh birds, native salt marsh plants, marsh-associated songbirds, and tidal marsh-associated small mammals.

Key Ecological Attributes

- Marsh connectivity*$^{\Delta}$
- Extent of high tide refugia (interior marsh)* $^{\Delta}$
- Native plant composition*$^{\Delta}$
- Secretive marsh bird abundance*$^{\Delta}$
- Native small mammal abundance*$^{\Delta}$
- Native fish diversity and abundance$^{\Delta}$
- Vegetation cover

(* = ecological attributes selected as most important, $^{\Delta =}$ a key indicator of biological diversity in the SF Estuary [CADS Phase I; Mattsson et al. 2015])

Key ecological drivers: Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity), channel complexity, water quality (salinity, pH, temperature), sediment regime (supply, accumulation), marsh size and connectivity, water quality (salinity, pH, temperature).

Refuge CCP goals and objectives related to key ecological attributes or ecosystem drivers:

GOAL 1: Support and contribute to the recovery and protection of threatened and endangered species and related ecosystems of the San Francisco Estuary.

GOAL 3: Acquire, protect, enhance, and restore functioning tidal marsh and associated upland systems to benefit all native wildlife and plants that use environments of the Refuge.

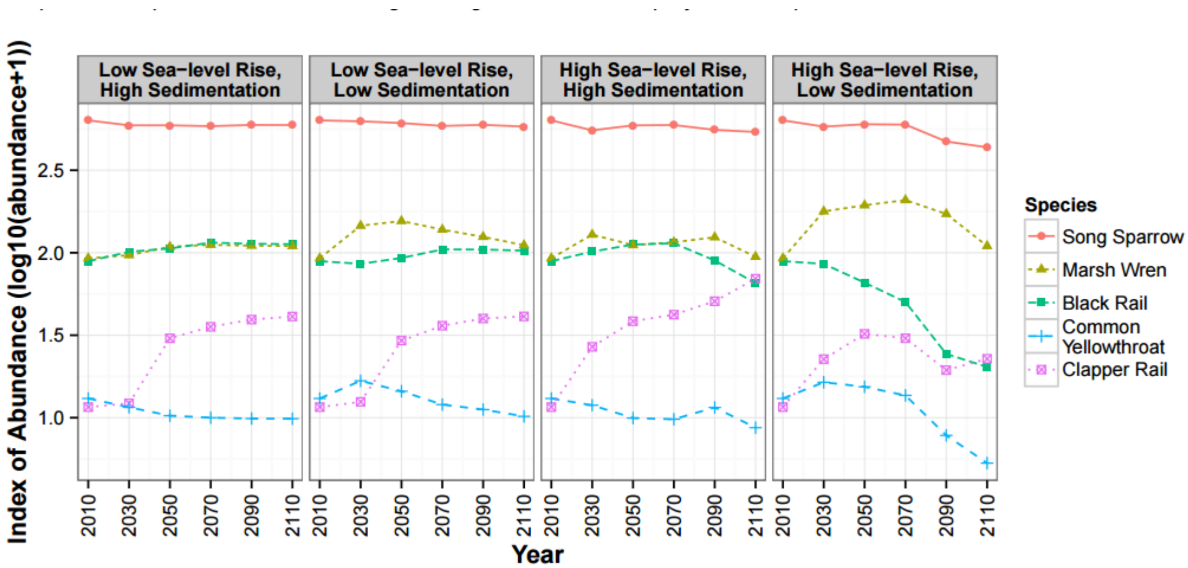
GOAL 5: Identify, assess, and adapt to current and future climate change impacts to Refuge resources.

4.2.1 Climate change impacts to tidal marsh

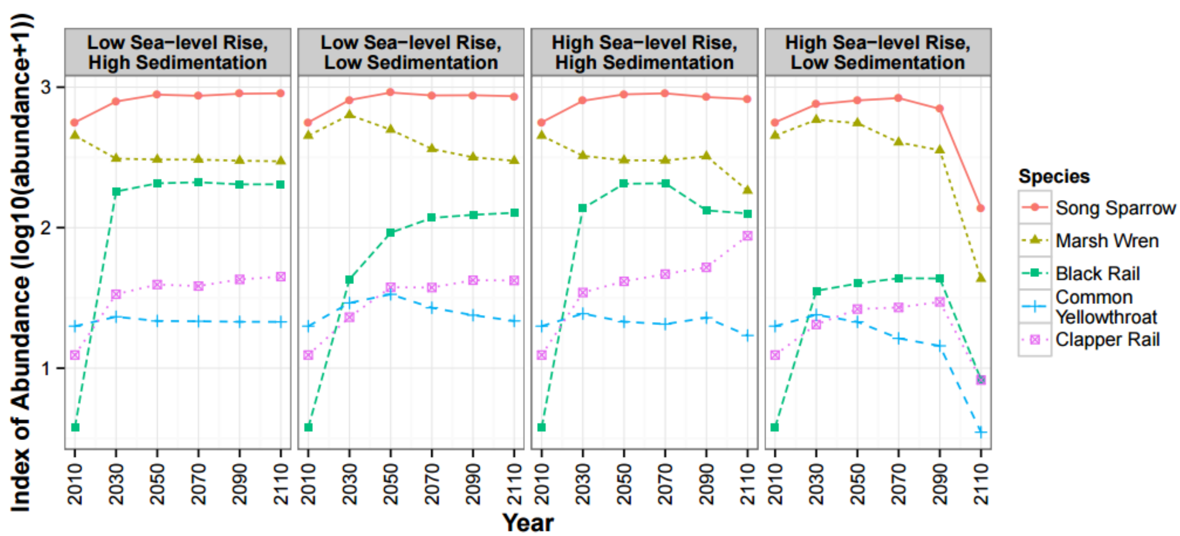
Declines in the amount of tidal marsh habitat in the study area are likely with high rates of sea level rise and low sediment availability increasing the vulnerability of tidal marsh associated populations (Stralberg et al. 2011, Veloz et al. 2013). A decline in habitat available will directly lead to a decline in population sizes that can be supported. Additionally, loss of habitat will increase the exposure of tidal marsh species to predation, particularly during extreme high tide and storm events. Extreme water levels will lead to extended periods where foraging habitat is unavailable (Thorne et al. 2013). However, marshes may be able to maintain elevations relative to changes in sea level if sufficient sediment (concentrations greater than in present day) is available and under this scenario tidal marsh bird populations may increase from present levels (Veloz et al. 2013).

We selected five sites representative of SPBNWR and assessed their trajectories in terms of providing habitat for five tidal marsh bird species under four combinations of sea-level rise and suspended sediment assumption scenarios. The selected species are dependent on tidal marsh habitat during their entire life cycle and are year round residents of San Francisco Bay tidal marshes. Each species occupies a different niche within the tidal marsh and together, they serve as an indicator of the overall health or condition of the tidal marsh ecosystem. The selected sites include mature marsh, young restored marsh, channel fringing marsh, and a low elevation pre-restoration area. For the Skaggs Island site, the model results assume a post-breach condition where the site receives full tidal inundation. Altering the sediment supply or starting elevation at Skaggs Island would result in a different trajectory. In all sites, scenarios involving low sea-level rise resulted in increased numbers of rails and stable or increasing population trajectories. In scenarios with high sea-level rise, those with high suspended sediment assumptions fared better with the exception of Skaggs Island.

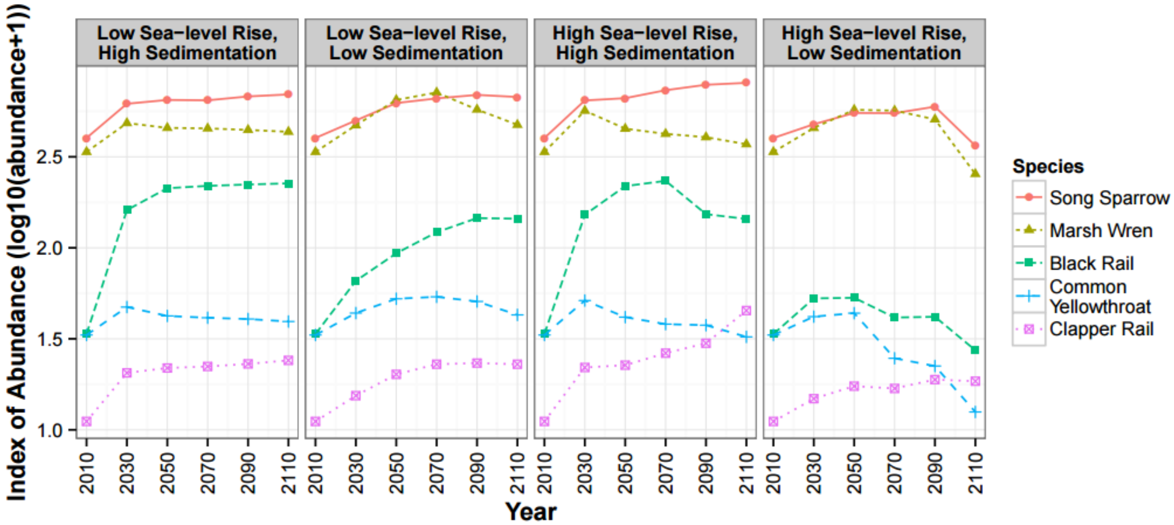
Figure 19 A-F. Marsh bird trends in abundance under four combinations of sea-level rise and suspended sediment assumption scenarios at SPBNWR sites.



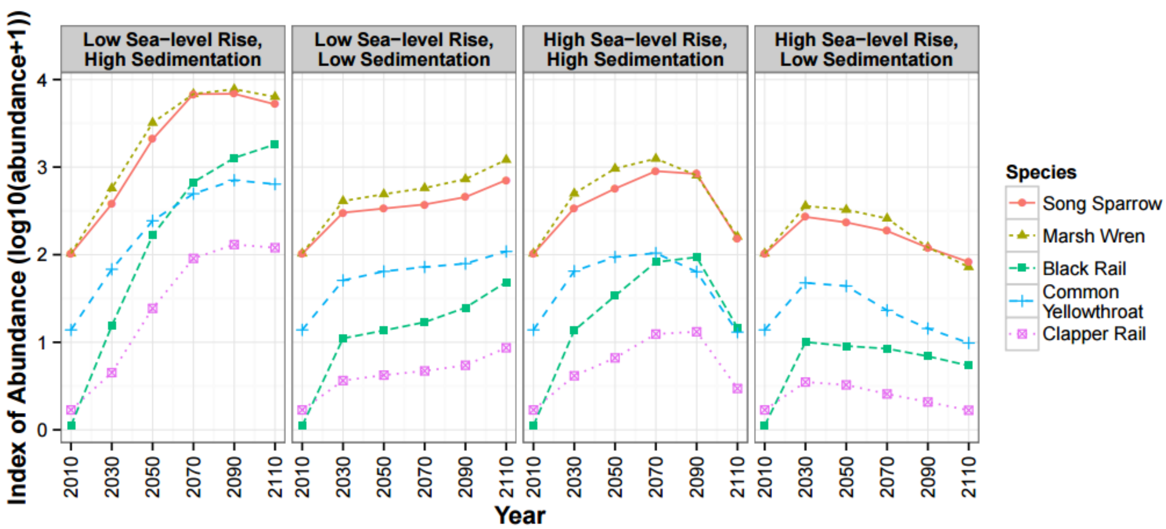
A) Petaluma River Mouth East. All scenarios result in stable or increasing populations.



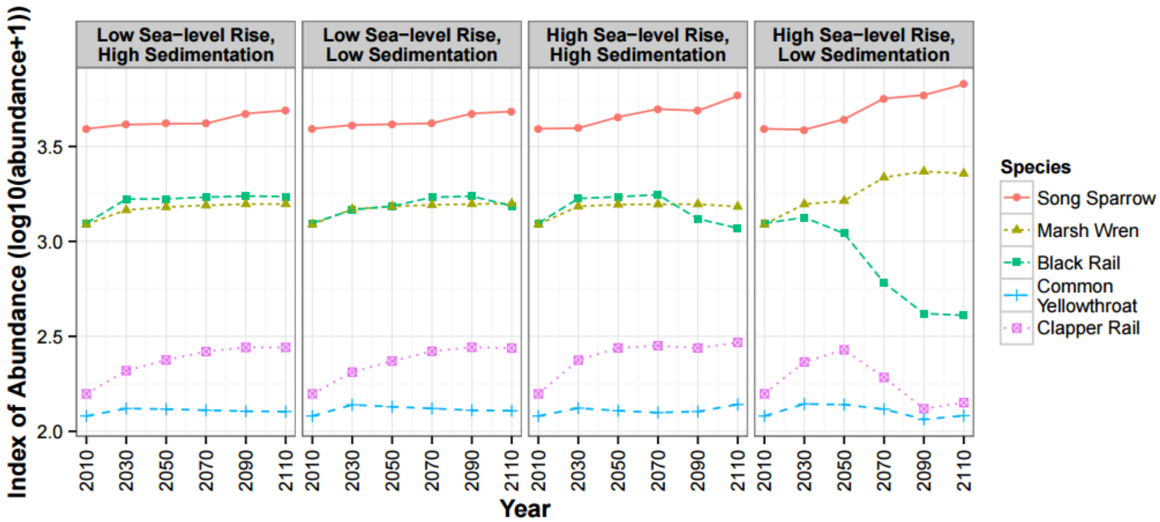
B) Sonoma Baylands Restoration. Only the high sea-level rise/low sedimentation scenario results in population decline.



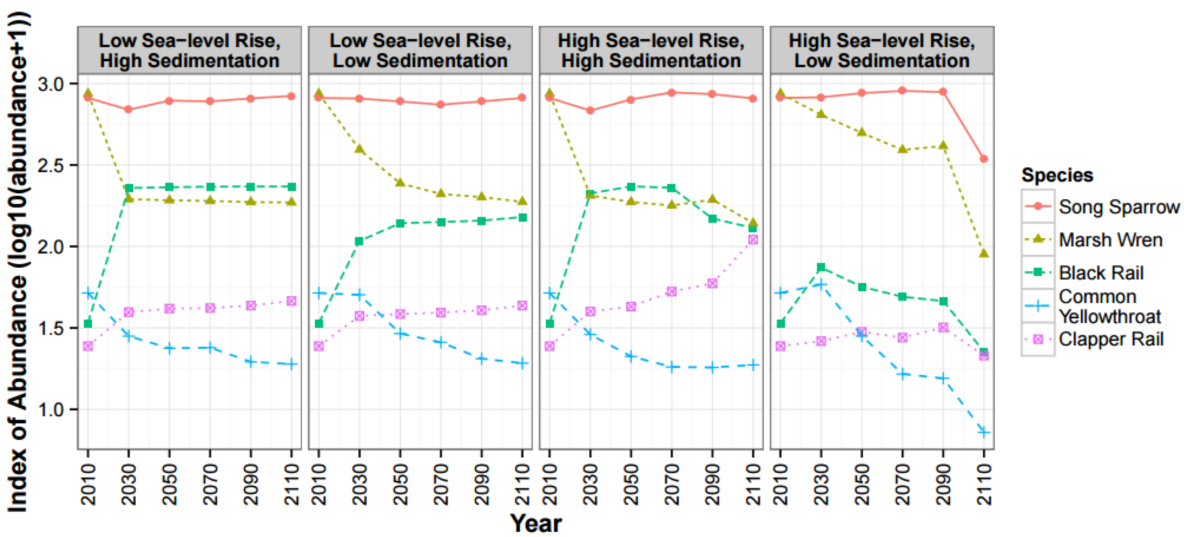
C) Tolay Creek. Three scenarios result in stable population trends and one scenario, high sea-level rise and high sedimentation, results in increasing trends.



D) Skaggs Island. The two high sea-level rise scenarios result in decreasing abundance. The two low sea-level rise scenarios result in stable or increasing populations.



E) Strip Marsh East. Only one scenario, high sea-level rise and low sedimentation, results in decreased abundance.



F) Lower Tubbs. Only one scenario, high sea-level rise and low sedimentation, results in decreased abundance.

4.2.2 Climate change impacts to Ridgway's rail

The California Ridgway's rail (*Rallus obsoletus obsoletus*) is federally endangered and is a high priority species for the Refuge. The majority of conservation actions in the San Pablo Bay region are directed towards the recovery of this species. Therefore, it is important to understand how climate change and other stressors impact this species if we are to identify and pursue strategies to that lead to recovery.

We assessed climate change effects on three main drivers of California Ridgway's rail population change, reproductive success, and juvenile and adult survival (Nur et al. 2012). The main climate change factors affecting these drivers are sea-level rise, increased storm intensity and frequency, and changes in salinity (Nur and Herbold, 2015; Table 13). These factors can affect rail populations directly (e.g., increased mortality due to exposure to high water events) and indirectly (e.g., increased exposure to predation, changes in habitat characteristics or prey communities). Precipitation may be important as well, which can affect vegetation community composition and structure.

Table 13. Key components of reproductive Success for Ridgway's rail and the main threats that impact each component.

Drivers of Population Change	**Direct Threats**
Components of Reproductive Success	
- Number of nesting attempts	Timing of seasons, poor habitat and foraging conditions
- Probability of nest success	Predation, flooding
- Number of young fledged	Predation, flooding, poor foraging conditions
Components of Survival	
- Adult survival	Predation, flooding
- Juvenile survival	Predation, flooding

Adult and juvenile survival is limited by high water events as the amount of vegetation available for cover becomes limited exposing birds to predation and exposure (Overton et al 2014). At SPBNWR, vegetation cover is greatly reduced during higher tides and storm + higher tide combinations (Table 13). Sea-level rise will likely exacerbate these impacts reducing vegetative cover by 96% exposing rails to the elements (hypothermia) and making them more vulnerable to predation (Table 14).

Important components of reproductive success include the probability of adult breeding, the number of nesting attempts, the probability of nest success, and the number of young fledged. Each component can be affected by environmental conditions during the breeding or pre-breeding season (Table 13).

Intense storms can have major effects on the viability of marsh birds, including Ridgway's rail. Thorne et al. (2013) found that during a winter and an early spring storm, as much as 90% of vegetation was inundated (Table 14). Of great concern, these periods of inundation can be long-lasting.

Table 14. Percent marsh vegetation inundated during winter and early-spring storms (from Thorne et al. 2013).

	January 2010		March 2011			
	MHHW Non-Storm	MHHW Storm	Max SLH Storm	MHHW Non-Storm	MHHW Storm	Max SLH Storm
SPBNWR	54.27	65.46	72.23	23.45	90.00	95.85

MHHW= Mean higher high water
SLH = Sea-level height

Recent modeling by D. Cayan et al. (2009) has shown that projected storms, due to climate change influences, combined with astronomical high tides, could result in water levels 20 to 50 cm above the normal levels; such flooding could persist for up to 2 weeks (Nur and Herbold 2015; Figure 20).

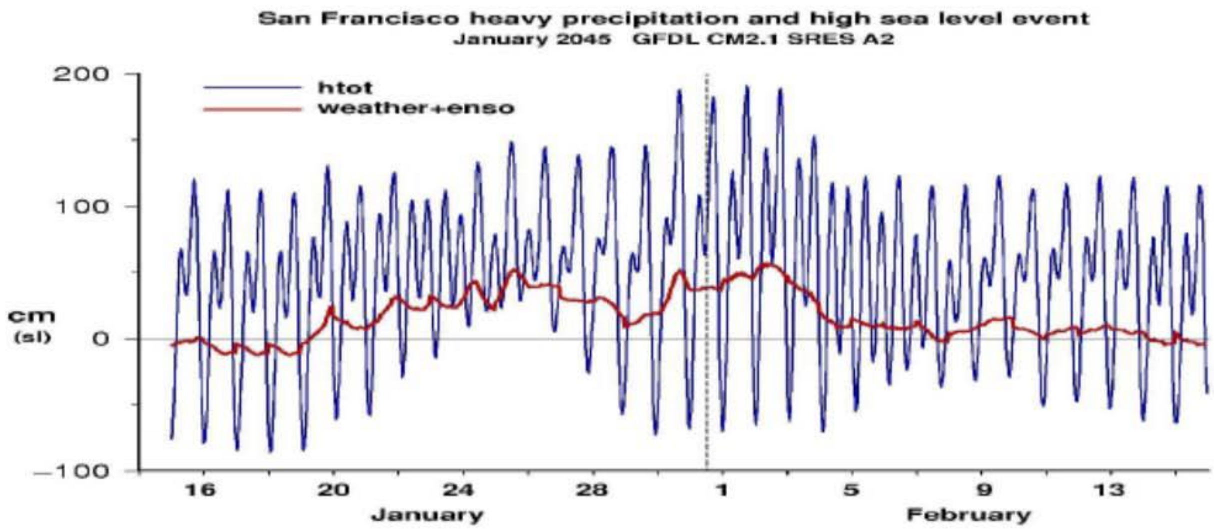


Figure 20. Modeled winter storm event in January 2045, assuming a strong El Nino event that year (Figure provided by D. Cayan 2012). The Y-axis depicts fluctuation in water levels during the simulation (total water level in blue) with the portion.

4.2.3 Climate change impacts to salt marsh harvest mouse

The salt marsh harvest mouse (SMHM; *Reithrodontomys raviventris*) is a federally endangered species and is a high priority species for the Refuge. Many of the conservation actions in the San Pablo Bay region are directed towards the recovery of this species. Therefore, it is important to understand how climate change and other stressors impact this species if we are to identify and pursue strategies that lead to recovery.

The main threats to the SMHM are habitat loss, degradation, and a small and decreasing population (Shellhammer 2000). Fragmentation and degradation of habitat can increase the risk of predation for SMHM and narrow marshes support disproportionately smaller and more vulnerable populations than larger, deeper marshes (Shellhammer and Duke 2010). Many marshes have lost the upper half of the mid-marsh plain and upper marsh areas which are associated with higher elevations and taller vegetation, both of which are important for avoiding predators during higher tides. During high winter tides, mice are particularly susceptible to predation from gulls, herons and other diurnal avian predators (Shellhammer 2000). Tidal marshes in areas of San Pablo Bay influenced by freshwater inputs typically have taller vegetation structure that can shelter mice but the majority of marshes on the Refuge fringe the bay, are more saline, and are dominated by lower growing pickleweed. Although the pickleweed in parts of the Mare Island Strip Marsh along the northern edge of San Pablo Bay grows very tall and provides ample cover for a large SMHM population (USFWS 2013). Some of the conservation actions proposed include increasing channelization and drainage of the Mare Island Strip Marshes and the potential effect of those actions on pickleweed plant heights is uncertain.

Climate change will likely impact SMHM through sea-level rise and increasing storm frequency and severity which may reduce the amount and quality of mid- and high-marsh habitat. These changes can cause increased risks of predation, high adult and juvenile mortality from increased periods of inundation, reduced reproductive success, and reduced population connectivity (USFWS 2013). Of particular concern is storm induced flooding coupled with sea-level rise resulting in elevated water levels and longer periods of inundation. During these periods, SMHM in narrow marshes may move to higher elevation transition zones or levee slopes to find cover above the water level (USFWS 2013). If these areas do not offer abundant dense vegetation, mice will be vulnerable to predators. Mice in the middle of broader marshes are less likely to travel to the marsh's edge and will instead find taller vegetation (usually Grindelia along channel berms or floating debris) to escape high waters (USFWS 2013). SMHM are known to swim even during lower tides but longer periods of flooding can cause widespread mortality.

Salinity in San Pablo Bay is likely to increase and may be exacerbated by extended periods of drought. The SMHM subspecies in San Pablo Bay, (*R. r. halicoetes*) evolved under a greater range of salinities than southern subspecies but their tolerance for prolonged high salinities is not known (Shellhammer 2000). The direct impacts to SMHM from changes in temperature and rainfall patterns are not known (USFWS 2013).

4.3 Marsh-upland transition zone ecosystem

Figure 21. Marsh-upland transition zone ecosystem (photo by Meg Marriott, USFWS).

Description: Estuarine-terrestrial (marsh-upland) transition zones occupy the boundary between land and sea, from tidal marsh up to the effective limit of tidal influence (Figure 21). These zones harbor unique plant communities, provide critical wildlife support to adjacent ecosystems, and play an important role in linking marine and terrestrial processes (Goals 2015). Transition zone habitat and restoration often occurs on the slopes of flood control levees.

Location: Figueras Unit, Strip Marsh East, Sonoma Creek East, Sonoma Creek West, Tubbs Island Setback, Tubbs Setback East, Lower Tubbs Island, Strip Marsh West, Sonoma Baylands, Tolay Creek, outboard strips of Cullinan Ranch and Skaggs Island/Haire Ranch, Cullinan Ranch, Skaggs Island/Haire Ranch, Dickson Unit, and Guadalcanal.

Nested biological targets: Marsh-associated small mammals, secretive marsh birds, native transition zone plants, marsh-associated songbirds.

Key Ecological attributes:

- Native plant composition*$^{\Delta}$
- Refugia available at king tide (at marsh edge and interior)* $^{\Delta}$
- Native plant rigor*
- Herpetofauna abundance
- Song sparrow density$^{\Delta}$
- Common yellowthroat density$^{\Delta}$
- Salt marsh harvest mouse density$^{\Delta}$
- Ridgway's rail density$^{\Delta}$
- Connectivity to uplands

(* = ecological attributes selected as most important, $^{\Delta =}$ a key indicator of biological diversity in the SF Estuary [CADS Phase I; Mattsson et al. 2015])

Key ecological drivers: Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity), sediment regime (supply, accumulation), water quality (salinity, pH, temperature).

Refuge CCP goals related to future desired status of key ecological attributes or ecosystem drivers:

GOAL 1: Support and contribute to the recovery and protection of threatened and endangered species and related ecosystems of the San Francisco Estuary.

GOAL 2: Protect, enhance, and restore high quality roosting and foraging environments for overwintering and migratory shorebirds and waterfowl.

GOAL 3: Acquire, protect, enhance, and restore functioning tidal marsh and associated upland systems to benefit all native wildlife and plants that use environments of the Refuge.

4.3.1 Climate change impacts to marsh-upland transition zone

Where there is insufficient migration space, we expect loss of transition zone habitat as sea-level rise causes a conversion to open water or tidal marsh habitat (Fulfrost and Thomson 2015, Stralberg et al. 2011). Where transition zone habitat remains, warmer and drier climatic conditions will alter plant community composition potentially changing the value of transition zone habitat as high tide cover. Disturbances from climate change will provide opportunities for the establishment of non-native plant species (Dukes and Mooney 1999).

4.4 Migration Space/Grasslands Ecosystem

Figure 22. Migration space/grassland ecosystem (photo by Meg Marriott, USFWS).

Definition: Grasslands adjacent to estuarine ecosystems (Figure 22). These areas provide habitat for a variety of native wildlife and plants such as native grasses and forbs and burrowing owls. Primary management of this ecosystem is accomplished through grazing (cattle, sheep, and goats). In the future, these areas may transition to estuarine ecosystems as sea level rises (if they have sufficient slope and elevation and the absence of barriers; Stralberg et al. 2011). This category includes moist grasslands that are seasonally wet providing shallow open water habitats for migratory birds, especially shorebirds.

Locations: Sears Point (excluding Dickson), North Parcel, and, until breached, Skaggs and Haire.

Nested biological targets: Native herpetofauna, shorebirds, native grasses and forbs, native seasonal wetland plants, grassland-associated birds, burrowing owl, and red-winged blackbird.

Key Ecological attributes:

- Native grass and forb vigor*$^{\Delta}$
- Nesting grassland bird species richness*$^{\Delta}$
- Burrowing owl density*$^{\Delta}$
- Native herptofauna abundance$^{\Delta}$

(* = ecological attributes selected as most important, $^{\Delta\,=}$ a key indicator of biological diversity in the SF Estuary [CADS Phase I; Mattsson et al. 2015])

Key ecological drivers: Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity).

Refuge CCP goals related to future desired status of key ecological attributes or ecosystem drivers:

GOAL 3: Acquire, protect, enhance, and restore functioning tidal marsh and associated upland systems to benefit all native wildlife and plants that use environments of the Refuge.

4.4.1 Climate change impacts to migration space/grasslands

Sea-level rise may result in the transition of grasslands to tidal marsh habitat if hydrological connections to the bay are either intentionally or unintentionally restored (Stralberg et al. 2011). Where grasslands remain, warmer and dryer climatic conditions may decrease plant diversity and productivity reducing the value of the habitat for grazing (De Boceck et al. 2007). Changes in precipitation patterns, particularly a reduction in the length of the rainy season, may reduce the availability of seasonal wetland habitats for migratory birds. An earlier rainy season may also result in a mismatch of timing between seasonal wetland habitat availability and bird migrations.

4.5 Riparian Ecosystem

Figure 23. Riparian ecosystem (photo by Meg Marriott, USFWS).

Definition: A drainage basin or watershed is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point at a lower elevation, usually the exit of the basin, where the waters join the estuary (Figure 23).

Nested biological targets: Native willow species, native moist soil indicator plants, and native riparian birds.

Key Ecological attributes:

- Canopy cover*$^{\Delta}$
- Native moist soil plant density
- Bird density$^{\Delta}$

(* = ecological attributes selected as most important, $^{\Delta=}$ a key indicator of biological diversity in the SF Estuary [CADS Phase I; Mattsson et al. 2015])

Key ecological drivers: Hydrological regime (connectivity; flooding level, frequency, duration, and periodicity).

Refuge CCP goals related to future desired status of key ecological attributes or ecosystem drivers:

GOAL 3: Acquire, protect, enhance, and restore functioning tidal marsh and associated upland systems to benefit all native wildlife and plants that use environments of the Refuge.

4.5.1 Change impacts to riparian ecosystems

Changes precipitation coupled with warming temperatures and changes in runoff and recharge of surrounding habitats will change the overall hydrology of riparian systems (Flint et al. 2013). This may include changes flow rates and timing and duration of peak flows. Additionally, drier climatic conditions will increase demand for water potentially resulting in less water and increased stress to riparian ecosystem conservation targets (Gleick and Chalecki 1999, Meyer et al. 1999). Warmer air temperatures will increase water temperatures, particularly where canopy cover is low. Sea level rise coupled with declining freshwater will increase the salinities of riparian ecosystems and result in salt water intrusion further upstream. Changes in hydrology, temperatures and salinity will likely result in changes in plant and wildlife community composition (Palmer et al. 2008).

5. Results

5.1 Threat Ranking

A total of 28 threats were identified by the project team. Threats and associated rankings are presented in

in

Table 15 and Table 16. Additional details about threat rankings are provided in Appendix B.

Table 15 and Table 16 draw from the same threat ranking data but are summarized in different ways to aid with interpretation. (Figure 24 – 33) depict the relationship between conservation targets and the highest ranked threats (Medium to Very High) in the near and long-term. The highest ranked threats in the near- and long-term were climate change, land conversion, and invasive plants.

Climate change is expected to impact multiple ecosystem targets in both time periods. In the near term climate change and drought will affect water quality for fish while extreme storms will threaten wildlife in tidal marsh habitat. Similarly, climate change and drought induced plant community transitions may facilitate the establishment of invasive plant species in both the upland transition zone and in the migration space grasslands habitat. These changes in plant community will degrade upland transition zone habitat and grassland migrations quality for native plants and wildlife.

Working group participants expect land conversion to have high impacts in both the near and long term timeframe. In the near term, land conversion may have the greatest impact in migration space grassland habitat. Within the project area, much of the migration space grassland is privately owned and could be permanently lost to development. In the long term, working group participants rank threats from land conversion high in every habitat mostly due to the direct loss of habitat but also because of indirect effects that could degrade water quality and impede ecosystem functions such as hydrology and sediment transport.

Table 15. San Pablo Bay near-term and long-term threats when considering all targets within the climate adaptation project scope. Note: these rankings take into account all targets whereas Table 16 hones in on threats to individual targets.

Threat Ranking	***Direct Threats***
Very High - NT	No threats were ranked as very high
Very High - LT	Drought
High - NT	Drought, invasive plants
High - LT	Land conversion, extreme storms, sea level rise, altered air temperatures, altered precipitation patterns, altered water quality, invasive plants
Medium - NT	Roads, railways, altered tidal hydrology, altered sediment dynamics, erosion, land conversion, sea level rise, extreme storms, altered air temperature, altered precipitation patterns, altered water quality, oil spills
Medium - LT	Roads, railways, altered tidal hydrology, altered sediment dynamics, erosion, altered water temperature, oil spills
Low - NT	Human recreation, refuge management activities, illegal human activities, subsidence, botulism, altered water temperature, agricultural effluents, air-borne pollutants, invasive plant control herbicides, mosquito control pesticides, predators, invasive invertebrates, West Nile Virus, algal bloom
Low - LT	Human recreation, refuge management activities, illegal human activities, subsidence, botulism, agricultural effluents, airborne pollutants, invasive plant control herbicides, mosquito control pesticides, predators, invasive invertebrates, West Nile Virus, algal bloom

Table 16. Threats to individual conservation targets within the San Pablo Bay Climate Adaptation Project scope: near-term and long-term.

Target	Very High	High	Medium	Low
Subtidal and intertidal mudflats - NT		Altered sediment dynamics	Altered water quality, oil spills, altered tidal hydrology, invasive invertebrates, altered water temperature, extreme storms	Illegal human activities, land conversion, algal bloom, mosquito control pesticides, invasive plant control herbicides, airborne pollutants, agricultural effluents, erosion, invasive plants, refuge management activities, human recreation, altered precipitation patterns, altered air temperature, drought, sea level rise
Subtidal and intertidal mudflats - LT		Altered water temperature, altered water quality, extreme storms	Altered precipitation patterns, altered air temperatures, oil spills, drought, invasive invertebrates, land conversion, altered sediment dynamics, altered tidal hydrology	Algal bloom, agricultural effluents, airborne pollutants, invasive plant control herbicides, mosquito control pesticides, invasive plants, sea level rise, erosion, illegal human activities, refuge management activities, human recreation
Tidal marsh - NT		Extreme storms	Land conversion, altered water quality, railways, roads, oil spills, subsidence, altered sediment dynamics, altered tidal hydrology, invasive plants, altered precipitation patterns, drought, sea level rise	Illegal human activities, predators, algal bloom, mosquito control pesticides, invasive plant control herbicides, airborne pollutants, agricultural effluents, erosion, invasive invertebrates, refuge management activities, human recreation, West Nile Virus, altered water temperature, altered air temperature
Tidal marsh - LT	Extreme storms, sea level rise	Altered water quality, land conversion, altered sediment dynamics	Altered precipitation patterns, altered air temperature, oil spills, drought, altered water temperature, invasive plants, subsidence, altered tidal hydrology, railways, roads	Algal bloom, agricultural effluents, airborne pollutants, invasive plant control herbicides, mosquito control pesticides, West Nile Virus, invasive invertebrates, predators, erosion, illegal human activities, refuge management activities, human recreation
Marsh-upland transition zone - NT		Invasive plants, drought	Land conversion, railways, roads, erosion, altered precipitation patterns, extreme storms, sea level rise	Illegal human activities, altered water quality, predators, oil spills, invasive plant control herbicides, airborne pollutants, refuge management activities, human recreation, altered air temperature

Target	Very High	High	Medium	Low
Marsh-upland transition zone - LT		Altered precipitation patterns, drought, invasive plants, extreme storms, sea level rise, land conversion, roads	Altered air temperatures, altered water quality, erosion, railways	Airborne pollutants, invasive plant control herbicides, oil spills, predators, illegal human activities, refuge management activities, human recreation
Migration space and grasslands - NT		Land conversion, invasive plants, drought	Railways, roads, altered precipitation patterns, altered air temperatures	Illegal human activities, altered water quality, predators, mosquito control pesticides, invasive plant control herbicides, airborne pollutants, agricultural effluents, erosion, refuge management activities, human recreation, West Nile Virus, botulism, extreme storms
Migration space and grasslands - LT	Drought	Altered precipitation patterns, altered air temperatures, invasive plants, land conversion	Railways, roads	Agricultural effluents, airborne pollutants, invasive plant control herbicides, mosquito control pesticides, West Nile Virus, altered water quality, botulism, predators, extreme storms, erosion, illegal human activities, refuge management activities, human recreation
Riparian - NT			Land conversion, altered water quality, railways, roads, erosion, invasive plants, altered precipitation patterns, altered air temperatures, drought	Illegal human activities, predators, oil spills, mosquito control pesticides, invasive plant control herbicides, agricultural effluents, refuge management activities, human recreation, West Nile Virus
Riparian - LT	Drought	Altered precipitation patterns, altered air temperatures, erosion	Altered water quality, invasive plants, land conversion, railways, roads	Agricultural effluents, invasive plant control herbicides, mosquito control pesticides, oil spills, West Nile Virus, predators, illegal human activities, refuge management activities, human recreation

5.2 Conceptual Models

We developed conceptual models depicting the relationship between environmental threats and each of the Refuge conservation targets (N=5) in the near-term and long-term. The models represent the project teams' collective understanding about how threats interact with (stress) conservation targets and how climate change may exacerbate current threats as well as cause direct stress to conservation targets.

Each model represents medium to very high threats to individual targets in the near-term (current to 2030) or long-term (2030-2100). Threats considered 'low' were not included in these models. Summary threat rankings (across all targets) are presented in the upper left corner of each threat (pink box). Threats are medium (M), high (H), or very high (VH). If a threat rating for a particular target varied from the summary rating (across all targets), we placed a text box below the threat indicating the target-specific threat ranking. For example, the threat of altered sediment dynamics was medium across all targets but high for the subtidal and intertidal mudflat target (Figure 24). Attributes of conservation targets are shown in orange boxes with purple text: '*' indicates ecological attributes selected as a priority indicators of target health, "^" indicates an attribute of interest but. Arrows depict the linkages between threats, attributes/indicators, and the targets.

The models were then used to develop strategies designed to reduce stress from priority threats and ultimately reach conservation target goals.

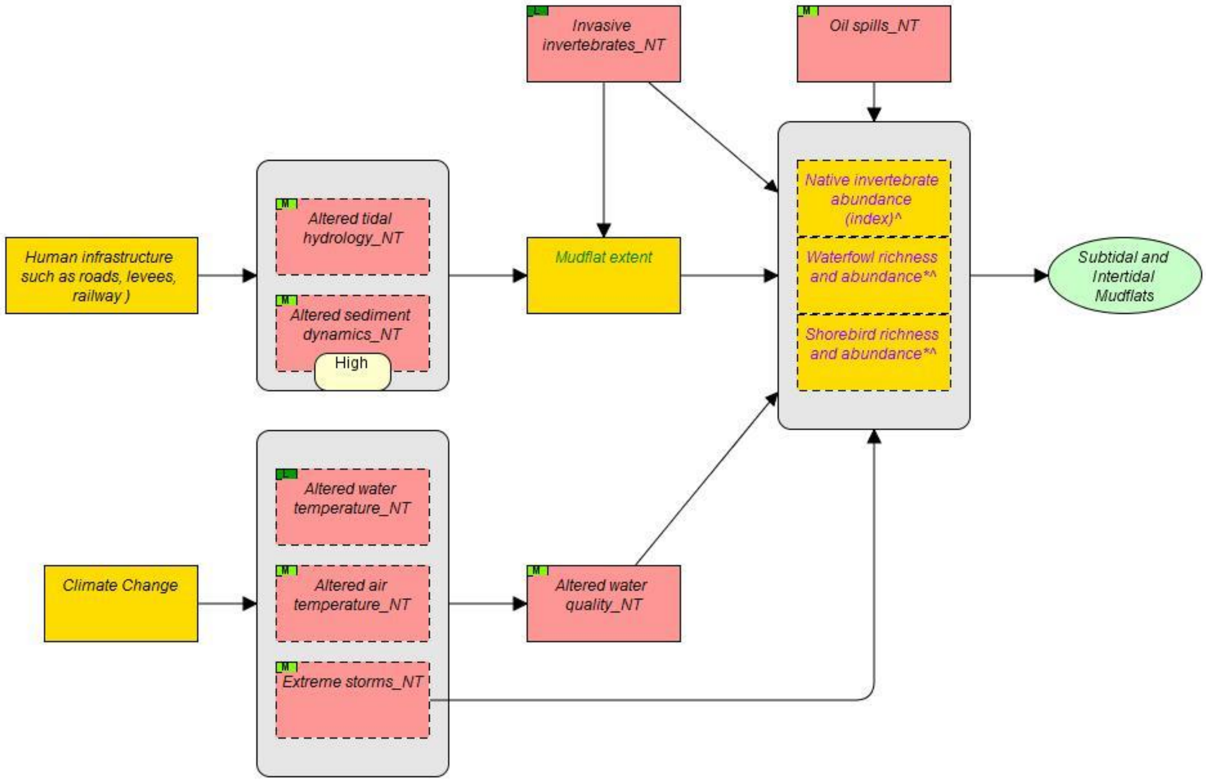


Figure 24. Conceptual model for subtidal and intertidal mudflats in the near-term, current to 2030. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

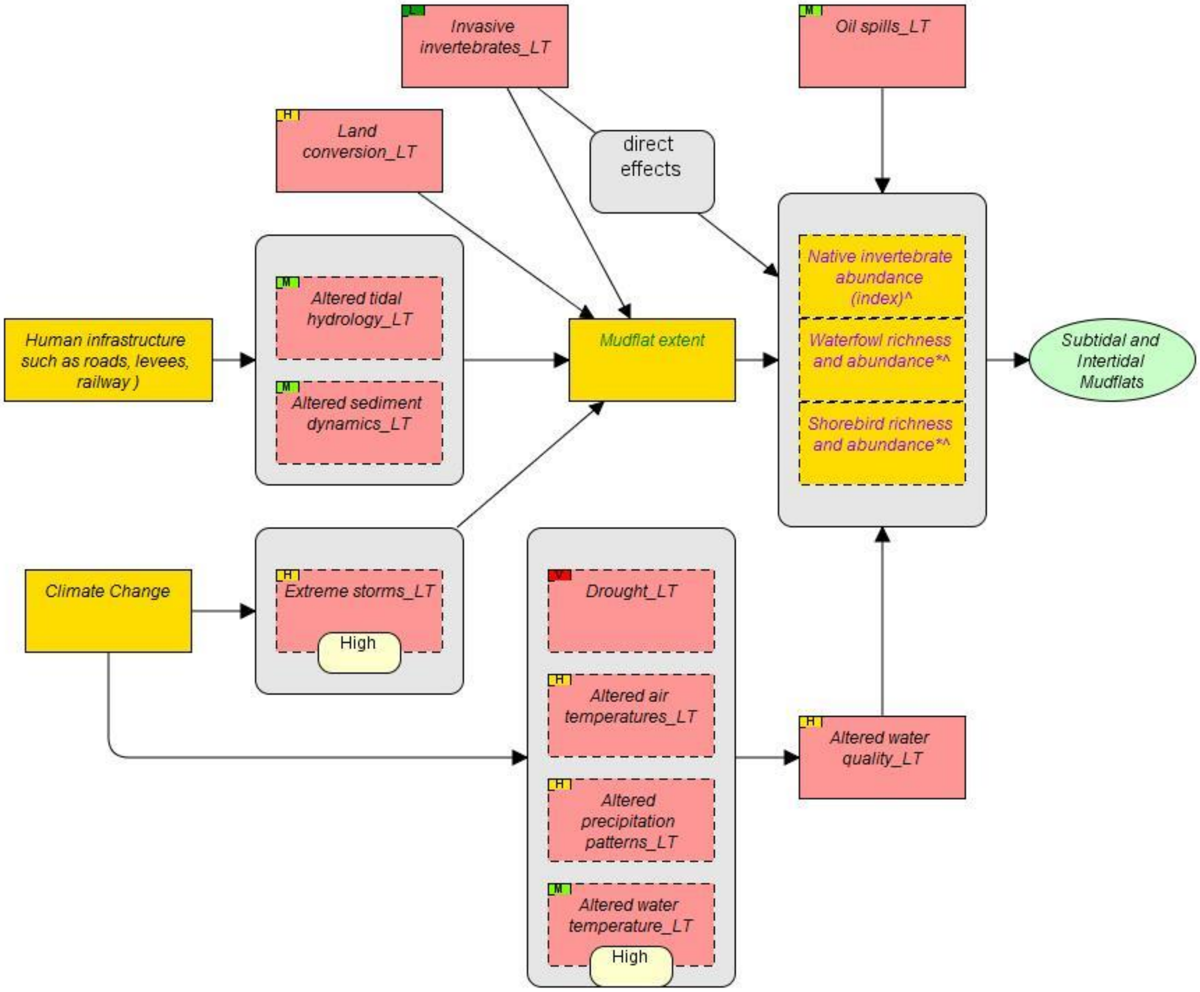


Figure 25. Conceptual model for subtidal and intertidal mudflats in the long-term, 2030-2100. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

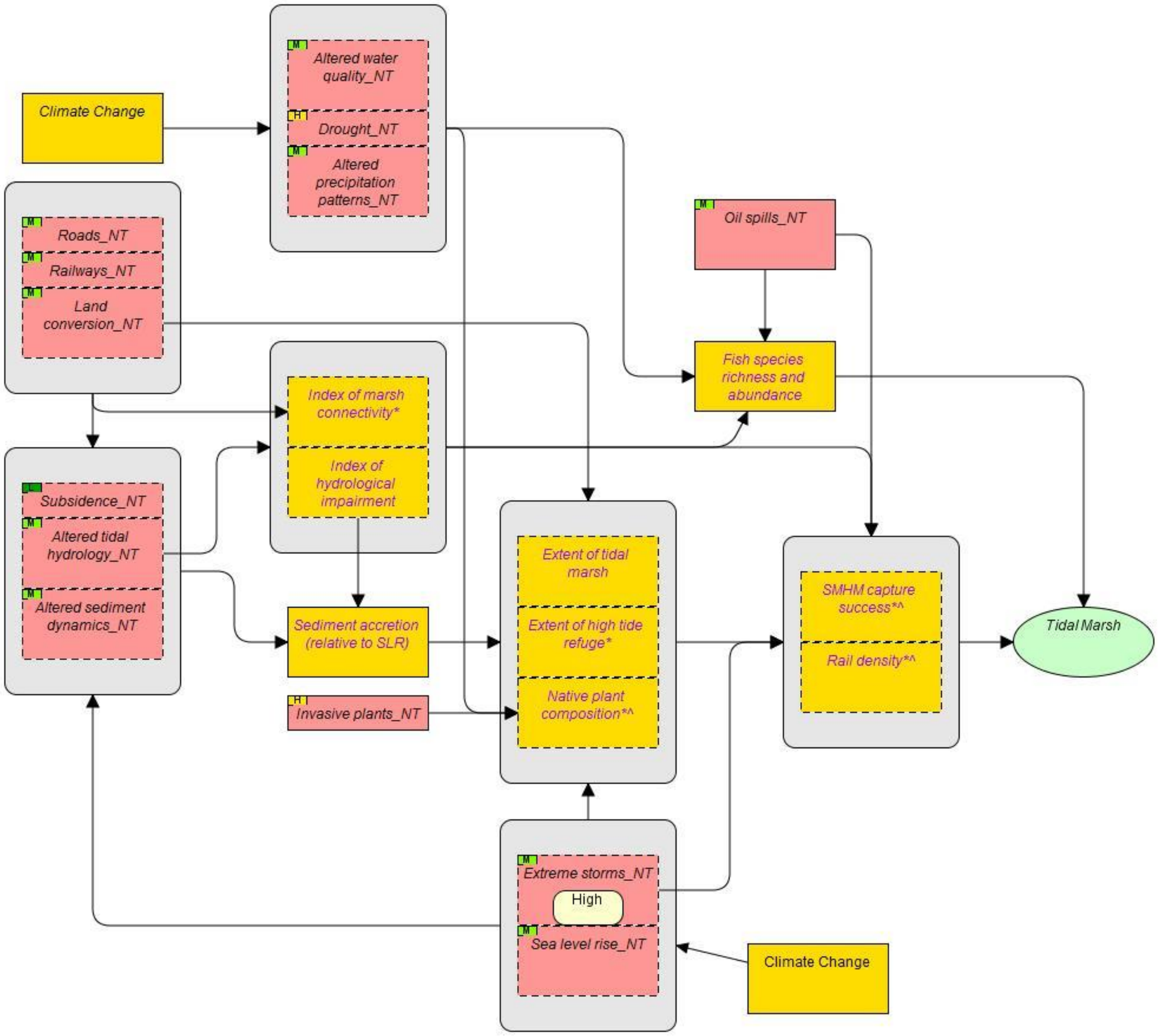


Figure 26. Conceptual model for Tidal Marsh in the near-term, current to 2030. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

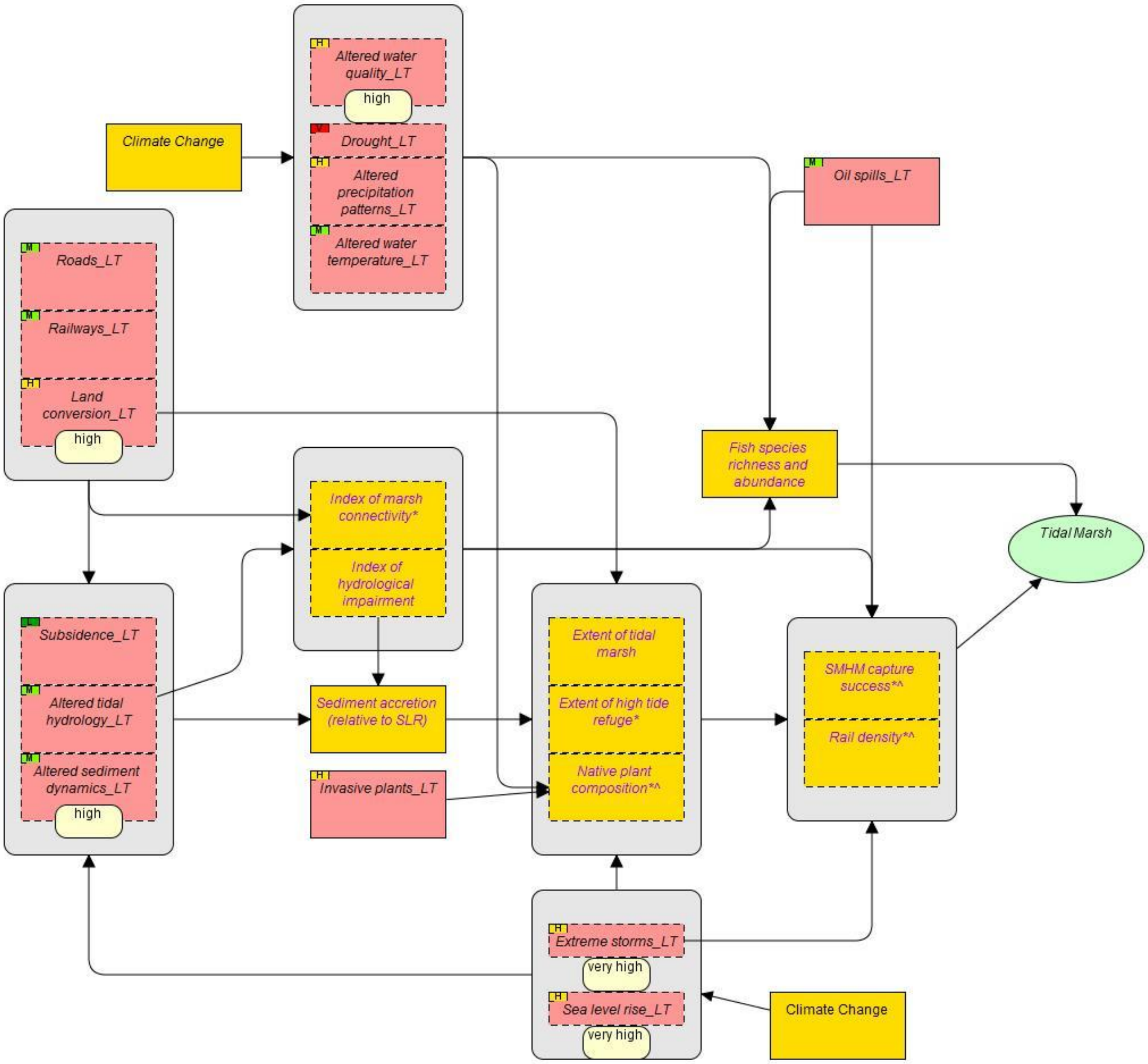


Figure 27. Conceptual model for tidal marsh in the long-term, 2030-2100. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

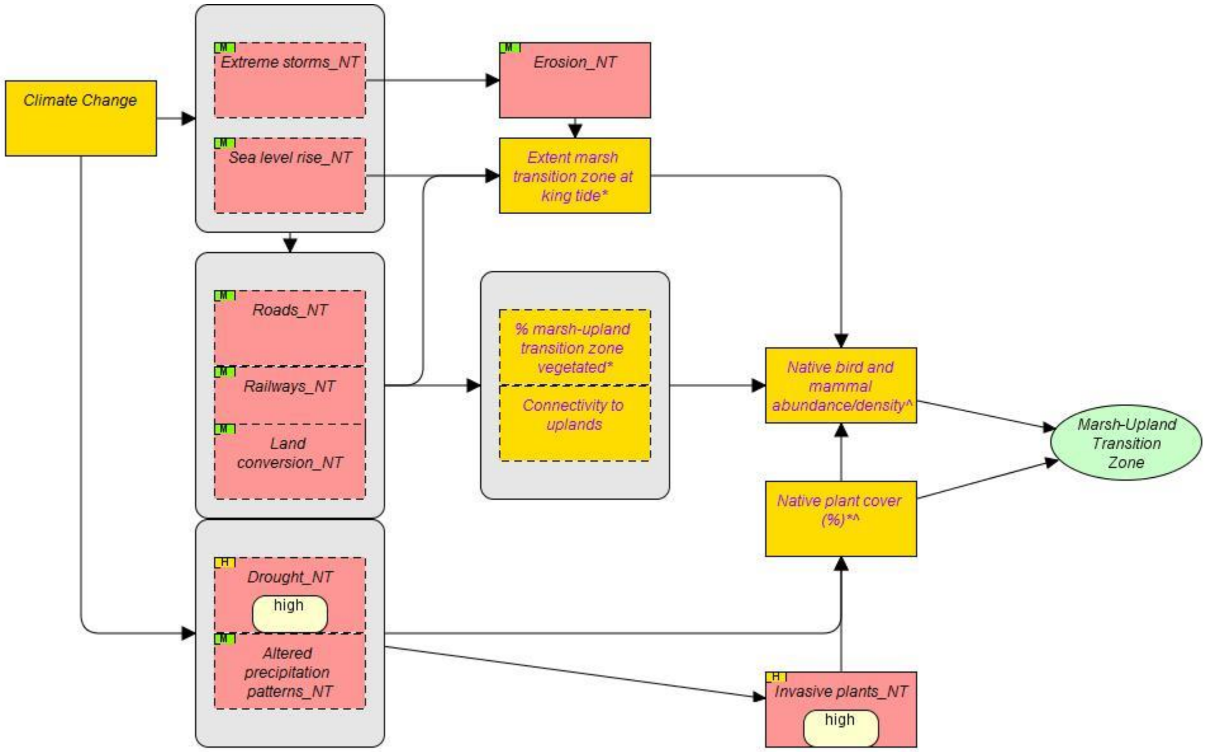


Figure 28. Conceptual model for marsh-upland transition zone in the near-term, current to 2030. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

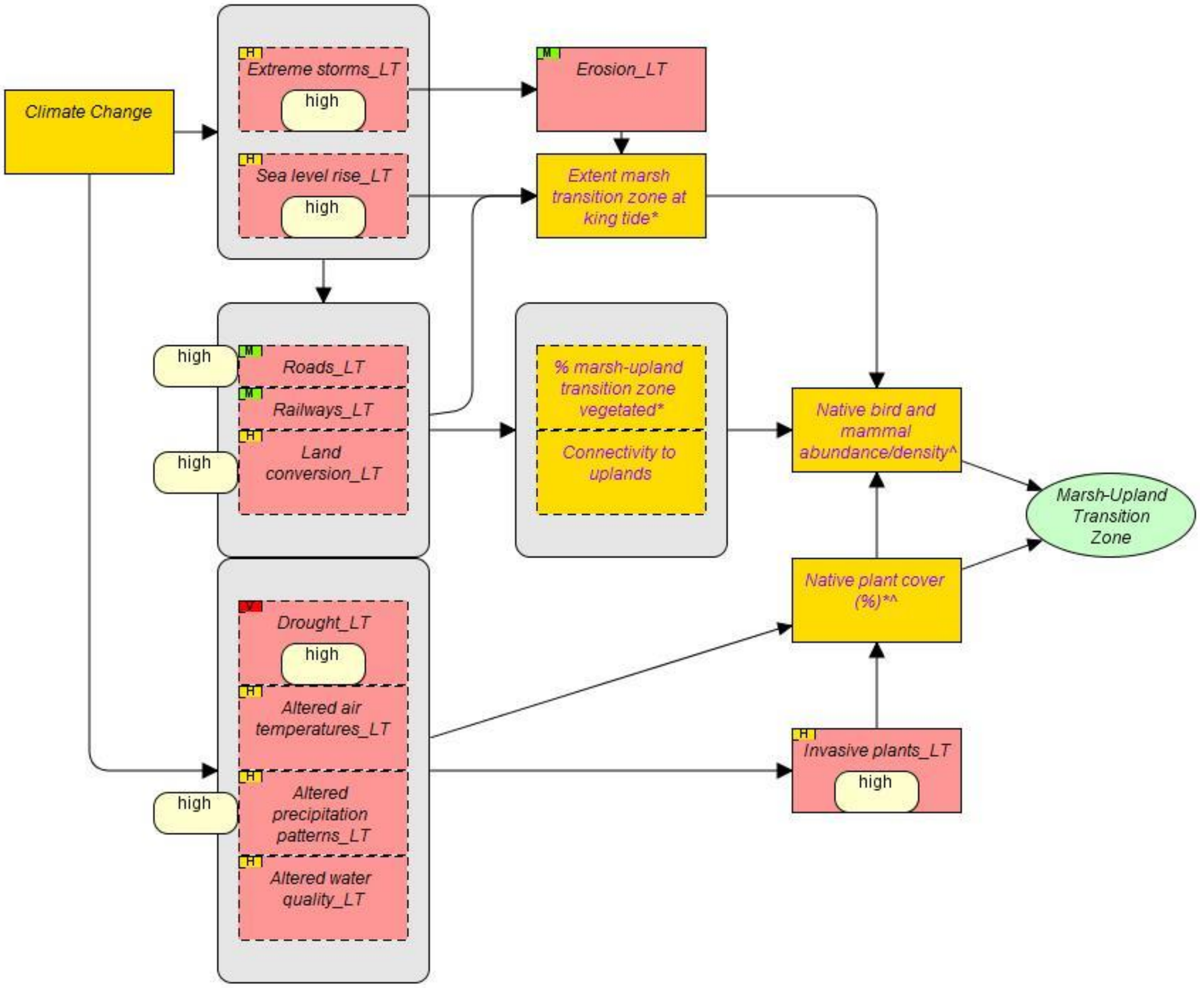


Figure 29. Conceptual model for marsh-upland transition zone in the long-term, 2030-2100. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

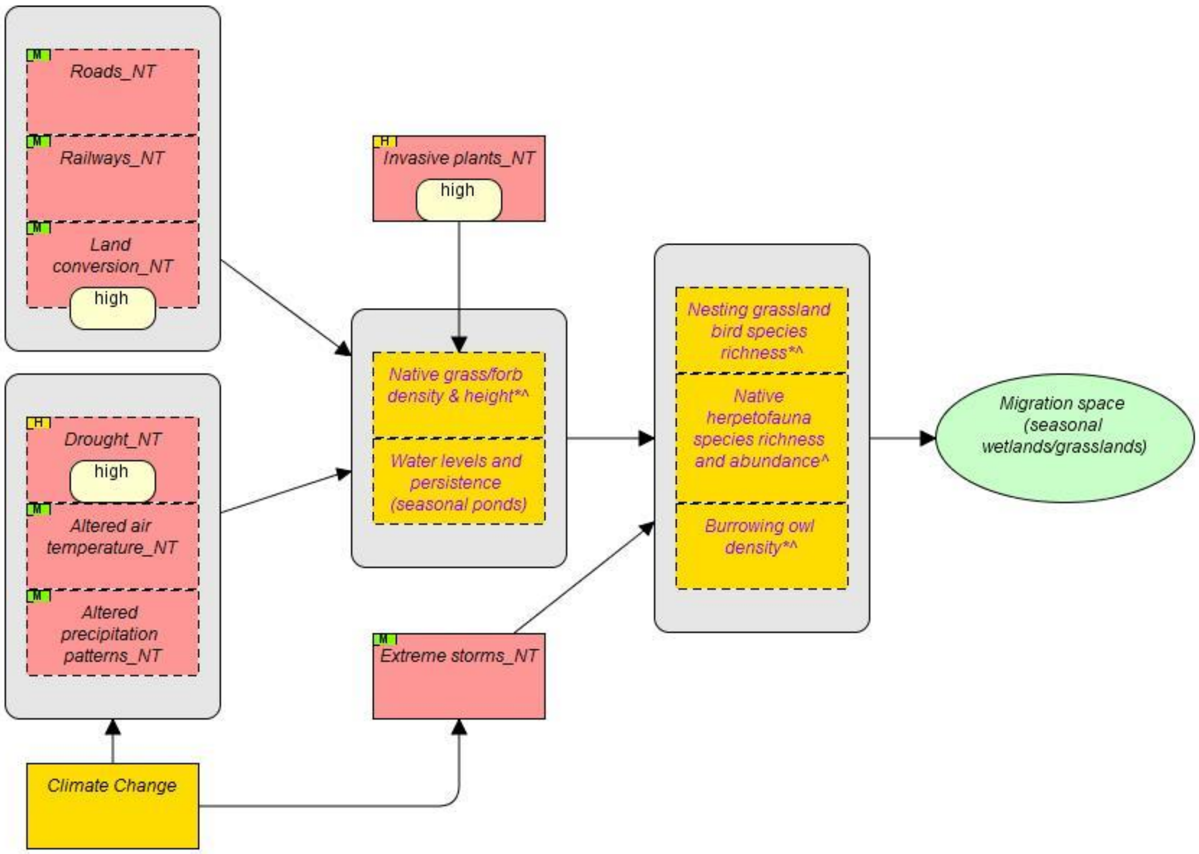


Figure 30. Conceptual model for migration space and grasslands in the near-term, current to 2030. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

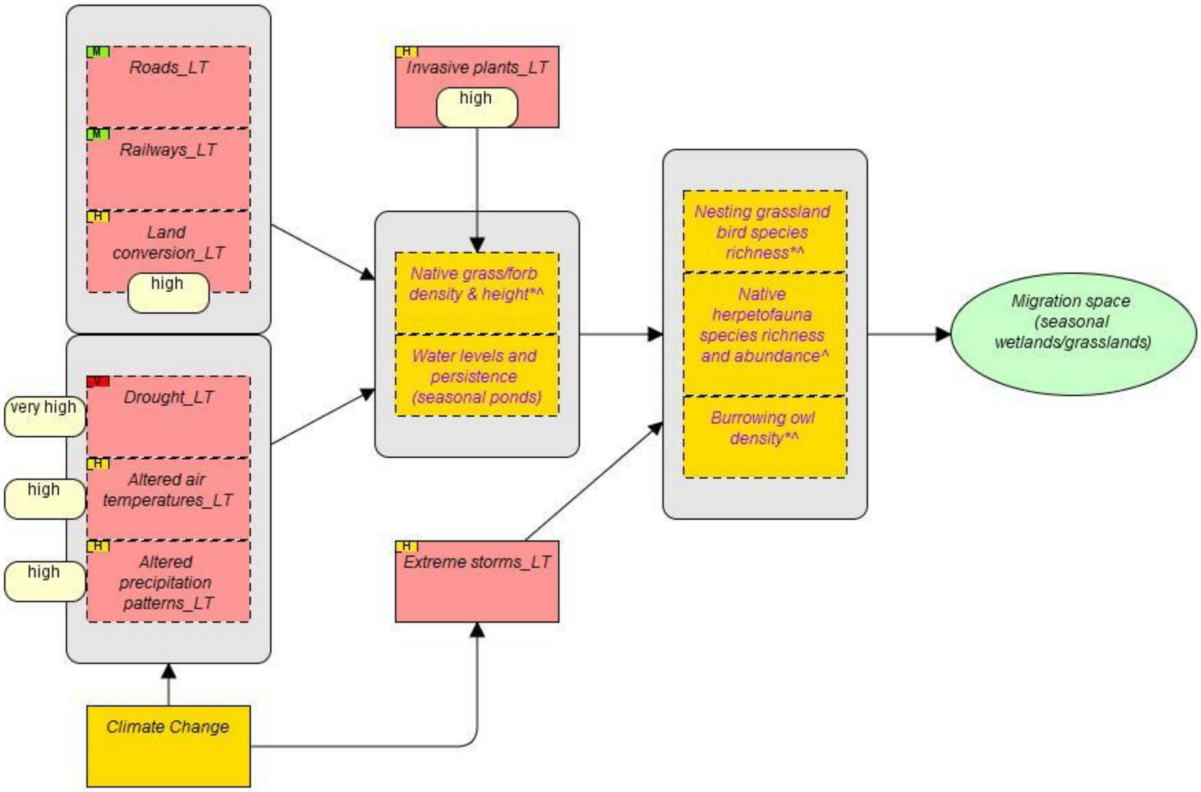


Figure 31. Conceptual model for migration space and grasslands in the long-term, 2030-2100. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

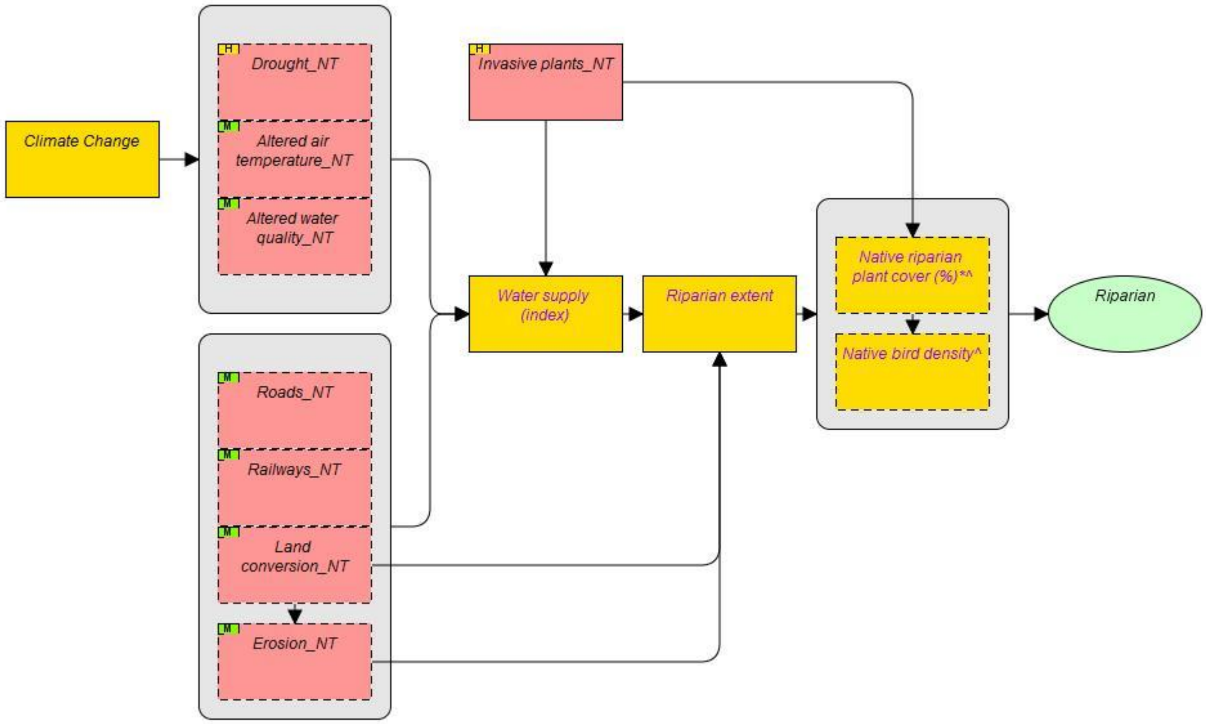


Figure 32. Conceptual model for riparian in the near-term, current to 2030. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

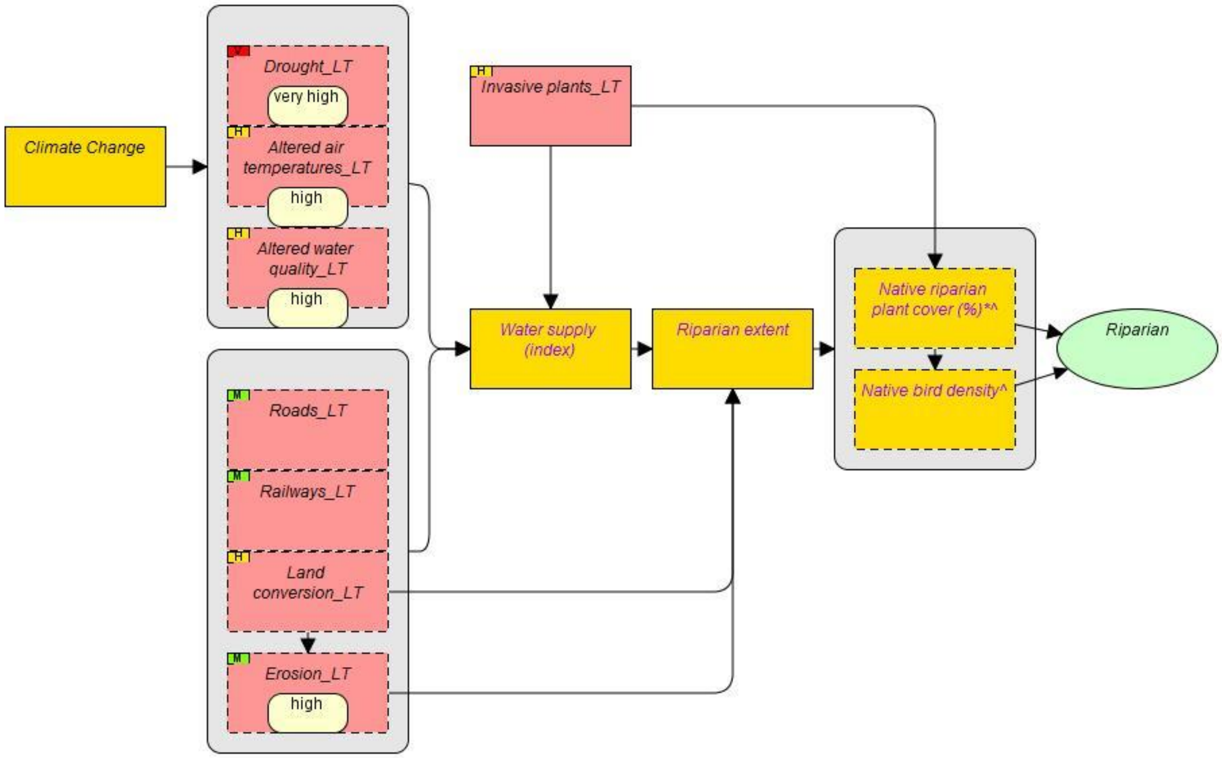


Figure 33. Conceptual model for riparian in the long-term, 2030-2100. Key: target (green oval), key ecological attribute (orange box with purple text), ecosystem driver (orange box with green text), threat (pink box, contributing factor (orange box with black text).

5.3 Strategies

The core team compiled a list of 39 potential strategies to address climate change and other priority threats within the project scope. The strategies were first compiled from the Refuge CCP and larger landscape conservation plans of the San Francisco Estuary or estuarine ecosystems elsewhere (such as the TMRP, Goals Project, CADS Phase I). The larger project team and advisors then met to identify any other potential strategies which may reduce the impacts of climate change and other priority threats. Table 17 provides a description of each strategy and when it should take place (near-term or long-term).

Table 17. List of climate change adaptation strategies that were considered for the Refuge. Category refers to the type of strategy and time frame is the time in which the strategy would be implemented (Near = current to 2030, Long = 2030-2100, Both = work on the strategy would occur in both time frames).

Category	Strategy Name	Description	Time Frame
Acquire land	Acquire Land	Acquire, through willing sellers, Kiser, Leveroni, Detjen, Tubbs Island (portion owned by Vallejo Sanitation District) properties. These properties provide opportunities to enhance or restore tidal marsh in the near and long-term. Sites that are not heavily subsided or contaminated are a high priority for acquisition. This is important to acquire in the near term.	Both
Acquire land	Move Refuge Boundaries Upland	Move refuge boundaries upland as sea level rise occurs.	Long
Create high tide refuge	Create High Tide Refuge	Create high tide refuge in high risk areas. Identify these areas from USGS models. This strategy would include retaining levees and creating marsh. The resultant areas will serve as tidal marsh in the future. This was merged with "Marsh Mounds, Enhance Transition Zone".	Both
Create high tide refuge	Marsh Mounds, Enhance Transition Zone	Create marsh mounds and enhance transition zone in subsided areas. This was merged with "Create High Tide Refuge".	Both
Improve tidal hydrology	Improve Hydrology, Figueras	Improve tidal hydrology in the Figueras unit. This unit is small and has shallow water and poor circulation. It would be difficult to restore and would have a great potential of flooding Highway 37.	Both
Improve tidal hydrology	Improve Hydrology, Lower Tubbs	Restore tidal hydrology and sediment dynamics of Lower Tubbs Island by removing the seven interior culverts. Investment of resources would be in the near term, for the benefit in the long term.	Near
Improve tidal hydrology	Improve Hydrology, Strip Marsh East	Improve tidal hydrology of Strip Marsh East	Both
Improve tidal hydrology	Improve Hydrology Strip Marsh West	Improve tidal hydrology of Strip Marsh West by building a channel through the unit. This activity is slated to happen soon and is inexpensive. Benefits for the near and long term.	Near

Increase hydrological connectivity	Create Tidal Connections 37: Tolay Creek	Create tidal connections under Highway 37 for Tolay Creek. There is an assumption that this strategy would include more than just improving the existing culvert. It is an alternative to raising Highway 37, or at least an interim action.	Both
Increase hydrological connectivity	Create Tidal Connections 37: Sears Point	Create tidal connection between the north end of Sears Point and Tolay Creek near Hwy 37 to facilitate marsh accretion in Sears Point. This is dependent on the projects for removing/moving the railroad and raising Highway 37 in the Tolay Creek area.	Both
Increase hydrological connectivity	Create Tidal Connections 37: Strip Marsh	Create tidal connections under Highway 37 in the Strip Marsh. The near term activity for this strategy is to prioritize it for action and funding, ensuring that it is a priority in discussions. In the long term, the connections will be physically implemented. If this is completed in conjunction with raising Highway 37, the increased tidal circulation would be a big benefit for rails and salt marsh harvest mouse. This area is vulnerable to sea level rise between 2050 and 2080, based on current accretion models.	Near
Increase land elevation	Freshwater/Brackish Marsh Creation	Accelerate marsh accretion with freshwater/brackish marsh creation. Allow organic matter to build up to increase elevation in the grassland and migration space. This is under consideration for Skaggs Island. However, this strategy would require flooding, which means that dredge spoil cannot be used.	Both
Increase land elevation	Beneficial Reuse, Cullinan	Beneficial reuse of dredge material at East Cullinan Unit. This is currently happening and should be complete before 2030.	Near
Increase land elevation	Dredge Offloading Facility	Build a permanent dredge offloading facility outside the Grizzly Island site. The activity would be to advocate for money in the Wetland Resources Development Act (WRDA). This was combined into a "Dredge Acquisition" action that included: Non-U.S. Army Corps of Engineers (Corps) dredgers deliver sediment; Build a permanent dredge offloading facility; eliminate deep-ocean disposal	Both
Increase land elevation	Non-Corps Sediment Delivery	Create additional opportunities for smaller non-Corps dredgers to deliver sediment by addressing cost differential issues. The group decided that the	Both

		cost differential is no different than for Corps dredgers. The refuge will need to be big proponents of this for Skaggs Island. This was combined into a "Dredge Acquisition" action that included: Non-Corps dredgers deliver sediment; Build a permanent dredge offloading facility; eliminate deep-ocean disposal	
Increase land elevation	Eliminate Deep Ocean Disposal	Eliminate deep ocean disposal of dredge. Concern that the refuge would have to compete for this material if it is not disposed of offshore. This was combined into a "Dredge Acquisition" action that included: Non-Corps dredgers deliver sediment; Build a permanent dredge offloading facility; eliminate deep-ocean disposal	Both
Increase land elevation	Raise Elevation of Agricultural Land, Sears Point & Petaluma River	Raise elevations of agriculture lands between Sears Point and Petaluma River. This is important, even though the feasibility and probability of the project occurring are low. The strategy would include a complete restoration of these lands and a means to allow tidal influence. Might involve dredge material, moving the railroads, raising Highway 37. This is the only marsh migration space in the refuge. This strategy would have a very high long term benefit.	Both
Increase land elevation	Sediment Passive Distribution	Passive distribution of sediments that are placed at scour points around the refuge. There is a great deal of uncertainty that would need to be addressed in the near term in the form of adaptive management. If this strategy is shown to work through adaptive management in the near term, it would be considered a top tier strategy in the long term.	Both
Increase land elevation	Thin Layer Sediment Deposition	Thin layer sediment deposition. This would be sediment augmentation that is similar to actions taken at Seal Beach NWR. It would not be helpful for areas with a great deal of subsidence. It would be very important in the long term for keeping pace at high marsh and transition zone elevations that are not receiving sediments from tides. This would be applied where needed.	Both
Migration space/grassland restoration	Nature-based Flood Protection	Encourage nature-based approaches for flood protections. Examples include gradually sloping levees, native plantings along levees. Levees built for flood protection would have to be engineered to meet flood protection	Both

		standards. This strategy with merged with "Flexible Transition Zone Restoration".	
Other	Managed Tidal Marshes	Create 'managed' tidal marshes with levees and water control structures, specifically at Lower Tubbs and Haire Ranch. This could be a long term strategy if restoring hydrology to Lower Tubbs does not work.	Both
Other	Enhance Migratory Bird Habitat	Migratory shorebird habitat enhancement in managed ponds. Mudflats should be plentiful and provide enough habitat for shorebirds.	Long
Public access	Programmatic Planning for Public Access	Programmatic planning for public access	Both
Remove barriers to marsh migration	Raise 37, Petaluma River & Mare Island	Raise Highway 37 between Petaluma River and Mare Island. The activity would be to lobby for a causeway and work with CalTrans to target key locations where elevation must be raised.	Both
Remove barriers to marsh migration	Realign Railway	Realign Railway outside historic extent of Baylands.	Both
Remove barriers to marsh migration	Remove Railroads	Remove railroads from the refuge area. The feasibility is low, but it would be very beneficial. The refuge has no control over this, but would invest resources in advocating. This action would potentially flood the vineyards, so a levee would be needed. It likely is only a long term strategy. This strategy was merged with "Realign Railway".	Both
Restore tidal marsh hydrology	Tidal Marsh Restoration, East Cullinan	Tidal marsh restoration at East Cullinan Unit. Activity would be to breach the eastern half of the Cullinan Ranch restoration unit. This hopefully will be complete by 2030, with monitoring and management necessary in the long term. This can inform restoration activities at other sites.	Near
Restore tidal marsh hydrology	Tidal Marsh Restoration, Skaggs Island	Tidal marsh restoration at Skaggs Island. Activities include dredging slough channels to former widths, using material for Skaggs sediment augmentation all around Skaggs Island, stockpiling upland till from Sonoma County Water Agency, using dredge spoil, considering managing some of the unit as waterfowl habitat in the interim. This would be beneficial in the long term but would be started in the near term.	Both

Restore transition zone	Create Transition Zone Highway 37	Create transition zone along Highway 37 in Strip Marsh. This strategy was eliminated from further consideration because raising Highway 37 is the priority.	Both
Restore transition zone	Marsh-Upland Transition Zone Plant Restoration	Restore plants native to the marsh-upland ecotone. Plant along the levees, focusing on gradually sloping transition zone areas (e.g., East and West Cullinan, Sears Point, Sonoma Creek), rail habitat, and salt marsh harvest mouse habitat. Consider planting native species that can withstand drought or use irrigation systems. There are limited opportunities currently for this, but as more arise, it will become more important.	Both
Restore transition zone	Flexible Transition Zone Restoration	Ongoing flexible transition zone restoration. Creation and contouring of the transition zone in new restoration areas. This is linked to native plant restoration. Some of the levees must be built with flood protection in mind. It will be more beneficial in the long term.	Both
Vegetation management	Eradicate *Spartina*	Detect and eradicate invasive *Spartina* species from tidal marsh. Advocate for regional *Spartina* control to prevent spread. Although the refuge does not currently have much non-native *Spartina,* there is a lot of uncertainty about future levels. This was merged with Invasive Plant Early Detection and Rapid Response and Reduce Extent of *Lepidium* into an "Invasive Plant Management" strategy.	Both
Vegetation management	Invasive Plant Early Detection and Rapid Response	Develop and implement an invasive plant early detection and rapid response program to support landscape level detection and response. This was merged with Eradicate *Spartina* and Reduce Extent of *Lepidium* into an "Invasive Plant Management" strategy.	Both
Vegetation management	Reduce extent of *Lepidium*	Reduce *Lepidium* cover in tidal marsh and the marsh-upland transition zone by 90% of baseline (2005). This was merged with Invasive Plant Early Detection and Rapid Response and Eradicate *Spartina* into an "Invasive Plant Management" strategy.	Both
Vegetation management	Treated Wastewater Use	Use treated wastewater in marshes most affected by drought. Look for opportunities to obtain water- there is no mechanism to deliver wastewater except for just north of Skaggs Island.	Both

Wildlife management	Remove Predator Perches	Remove avian predator perches	Both

5.4 Strategy Ranking Results

For both time frames, the experts' (*n* = 3) ratings resulted in five strategies ranking highest in priority for action among all experts, whereas many of the original rankings differed among experts. Through discussion, we found that these differences in rankings could be attributed to uncertainty about the strategy itself, differences of opinion in impact or likelihood, or uncertainty about how best to rate a strategy in terms of impact versus priority for action. Through the modified Delphi approach to the elicitation process (Kuhnert et al. 2010), experts discussed these uncertainties and differences and arrived at an agreed-upon ranking for each of the strategies. Experts determined that some strategies could be merged, such that the final list of strategies was condensed (Table 18). In particular, all strategies that incorporated an aspect of dredge acquisition were merged into one strategy ("Dredge Acquisition"), strategies related to moving or removing the railroad were merged ("Remove/Realign Railroads"), strategies related to identifying and managing invasive plants were merged ("Invasive Plant Management"), and "Marsh Mounds, Enhance Transition Zone" was merged with "Create High Tide Refuge." In addition, "Create Transition Zone Highway 37" was removed from consideration because the priority action was to raise Highway 37 on a causeway.

5.4.1 Near term (current to 2030)

In the near term (current to 2030), the elicitation results consistently ranked five strategies as the greatest across all three experts (Appendix A1). These strategies, Invasive Plant Management, Acquire Land, Raise 37 at Petaluma River and Mare Island, Tidal Marsh Restoration at East Cullinan, and Create Tidal Connections 37: Tolay Creek, comprised the "Very High" tier for prioritization of action (Table 18; Figure 34). Importantly, the group predicted that some of the Very High strategies, as well as some strategies ranked "High," would have a Low or Medium impact in the near term (Table 18;). The group believed that prioritizing those strategies in the near term would provide for a greater impact in the long term (2030 – 2100; Table 18; Figure 39). In addition, some of the higher ranked strategies had a Low or Medium feasibility. The group recognized that some strategies were so important for climate change adaptation that they should be prioritized for action even in the face of adversity regarding feasibility.

Table 18. Tiers of strategies for prioritization for action (Priority), impact of the strategy on the Refuge ecosystem (Impact), and overall feasibility of a strategy (Feasibility) for the near (current to 2030) and long terms (2030 – 2100).Dark green = very high tier (priority only), light green = high tier, yellow = medium tier, red = low tier.

Category	Strategy Name	Priority	Impact	Feasibility	Priority	Impact	Feasibility
		Near Term			Long Term		
Acquire land	Acquire Land	Very High	Low	Low	Very High	High	Medium
Vegetation management	Invasive Plant Management	Very High	High	High	Very High	High	High
Remove barriers to marsh migration	Raise 37, Petaluma River & Mare Island	Very High	High	Low	Very High	High	Medium
Increase hydrological connectivity	Create Tidal Connections 37: Tolay Creek	Very High	High	High	High	High	High
Restore tidal marsh hydrology	Tidal Marsh Restoration, East Cullinan	Very High	High	High	Low, unless not completed	Medium	High
Restore tidal marsh hydrology	Tidal Marsh Restoration, Skaggs Island	High	Low	Medium	Very High	High	High
Acquire land	Move Refuge Boundaries Upland	Long Term Only	Long Term Only	Long Term Only	Very High	High	Medium
Create high tide refuge	Create High Tide Refuge	High	High	Medium	High	High	High

Increase land elevation	Dredge Acquisition	High	Low	Medium	High	High	Medium
Restore transition zone	Flexible Transition Zone Restoration	High	Medium	Medium	High	High	Medium
Improve tidal hydrology	Improve Hydrology, Strip Marsh East	High	High	High	High	High	High
Restore transition zone	Marsh-Upland Transition Zone Plant Restoration	High	Medium	Medium	High	High	High
Increase land elevation	Raise Elevation of Agricultural Land, Sears Point & Petaluma River	High	Low	Low	High	High	Medium
Increase land elevation	Beneficial Reuse, Cullinan	High	High	Medium	Low	Low	Medium
Increase hydrological connectivity	Create Tidal Connections 37: Strip Marsh	High	Medium	Medium	Low, unless not completed	High	Medium
Improve tidal hydrology	Improve Hydrology, Lower Tubbs	High	High	High	Low, unless not completed	High	High
Improve tidal hydrology	Improve Hydrology Strip Marsh West	High	High	High	Low, unless not completed	High	Medium
Increase hydrological connectivity	Create Tidal Connections 37: Sears Point	Medium	Medium	Medium	High	High	Low

Public access	Programmatic Planning for Public Access	Medium	Medium	High	Medium	Medium	High
Wildlife management	Remove Predator Perches	Medium	Medium	High	Medium	Medium	High
Increase land elevation	Thin Layer Sediment Deposition	Medium	Medium	Medium	High	High	Medium
Remove barriers to marsh migration	Remove/Realign railroads	Medium	Low	Medium	High	High	Medium
Increase land elevation	Sediment Passive Distribution	Medium	Low	Medium	High	High	Medium
Increase land elevation	Freshwater/Brackish Marsh Creation	Low	Low	Medium	Low	Low	High
Improve tidal hydrology	Improve Hydrology, Figueras	Low	Low	High	Medium	Medium	High
Other	Managed Tidal Marshes	Low	Low	Low	Low	Low	Low
Vegetation management	Treated Wastewater Use	Low	Low	Medium	Low	Low	Low
Other	Enhance Migratory Bird Habitat	Long Term Only	Long Term Only	Long Term Only	Low	Low	Medium
Other	Focus on Intertidal	Long Term Only	Long Term Only	Long Term Only	Low	Low	Low

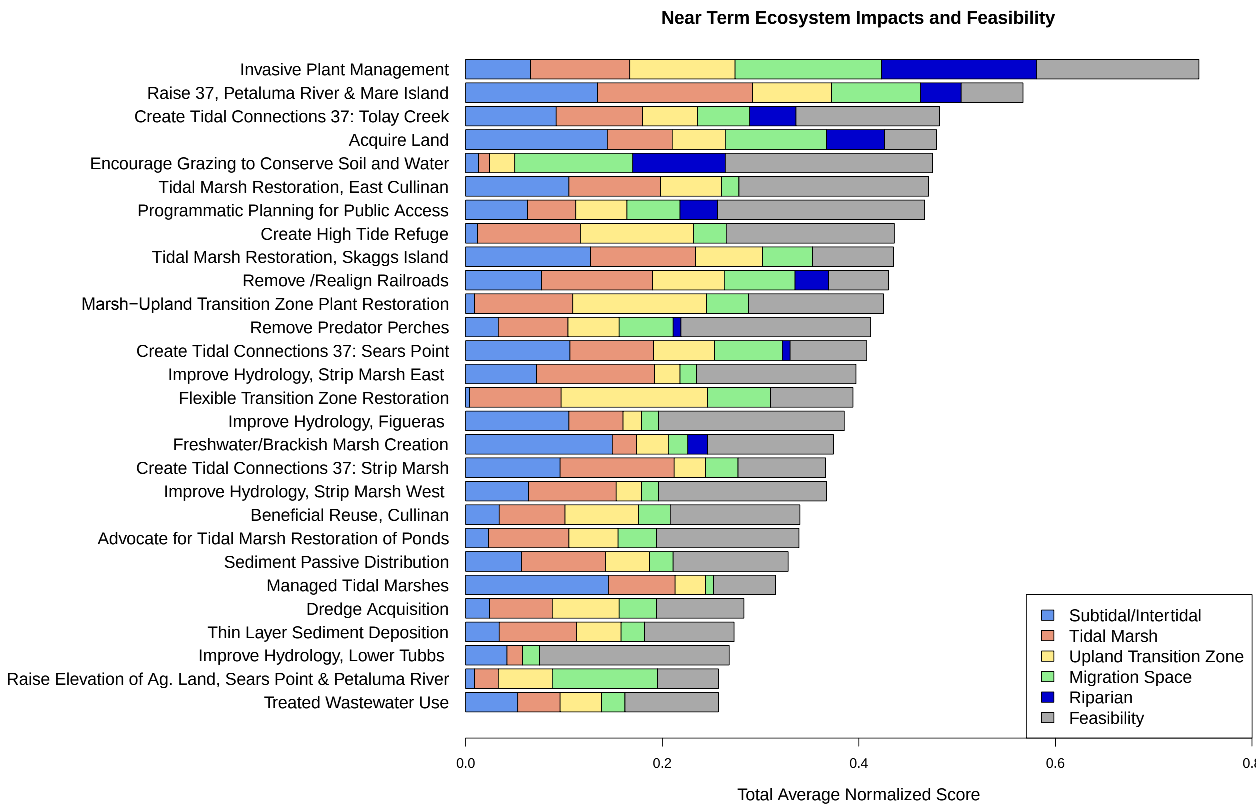


Figure 34. Scores for each management strategy, averaged across experts and normalized, broken down into ecosystems and feasibility for the near term (2016 – 2030). Ecosystem scores are a composite score of the "Spatial Extent" and "Impact" categories from the expert elicitation process. For strategies that were merged, ratings were averaged.

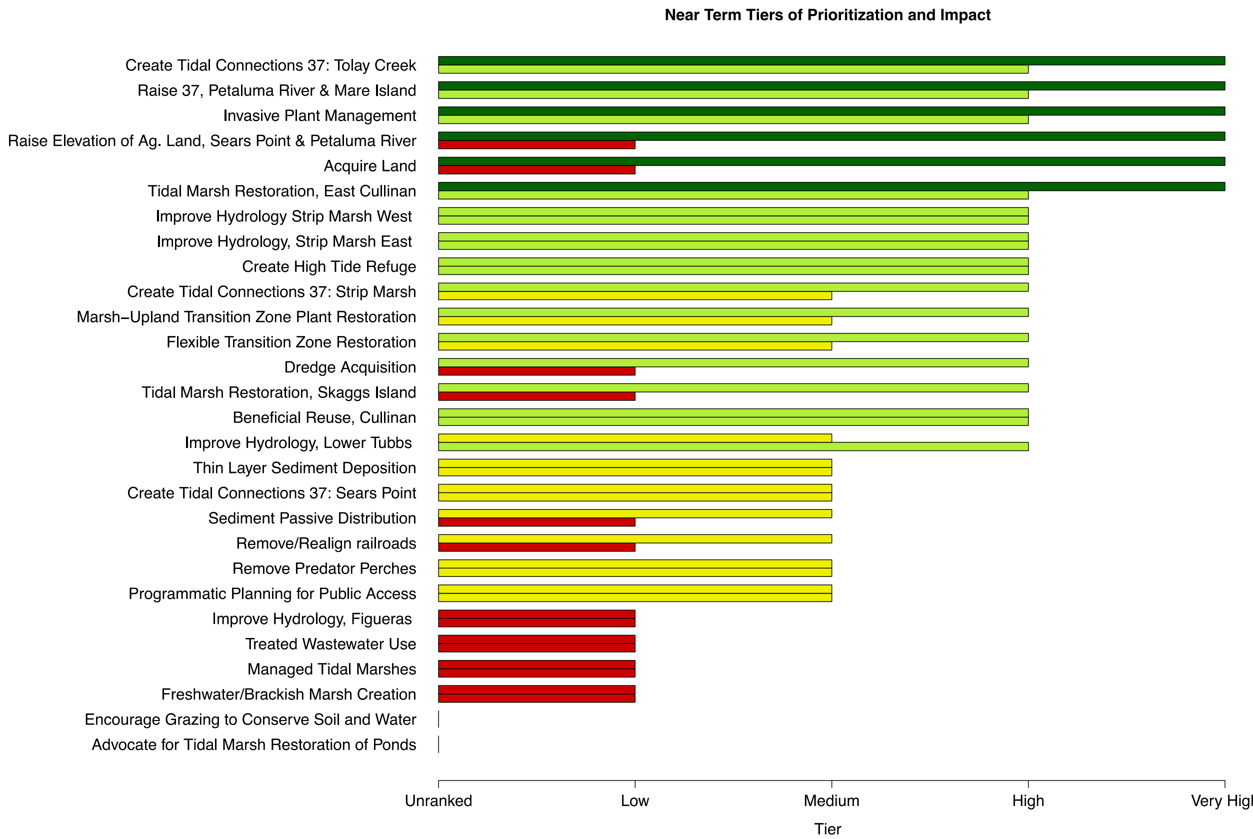


Figure 35. Tiers of priority for action (top bar in each strategy grouping) and impact (bottom bar in each strategy grouping) for each strategy considered in the near term (current to 2030) for climate change adaptation at San Pablo Bay National Wildlife Refuge. Priority tiers were ranked from Low to Very High, whereas Impact tiers were ranked from Low to High.

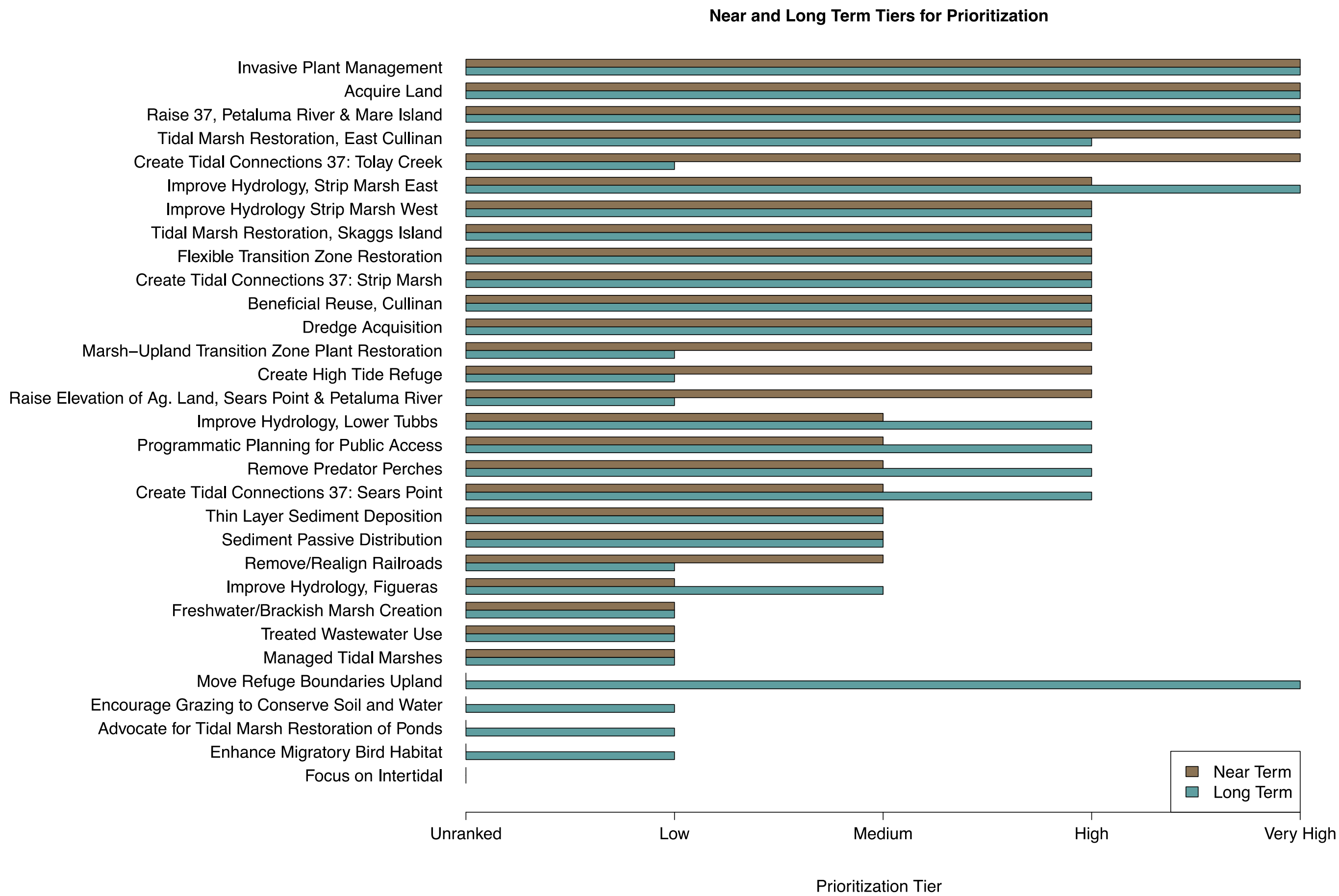


Figure 36. Near (current to 2030) and long term (2030 – 2100) tiers of priority for action of each strategy considered for climate change adaptation in San Pablo Bay National Wildlife Refuge.

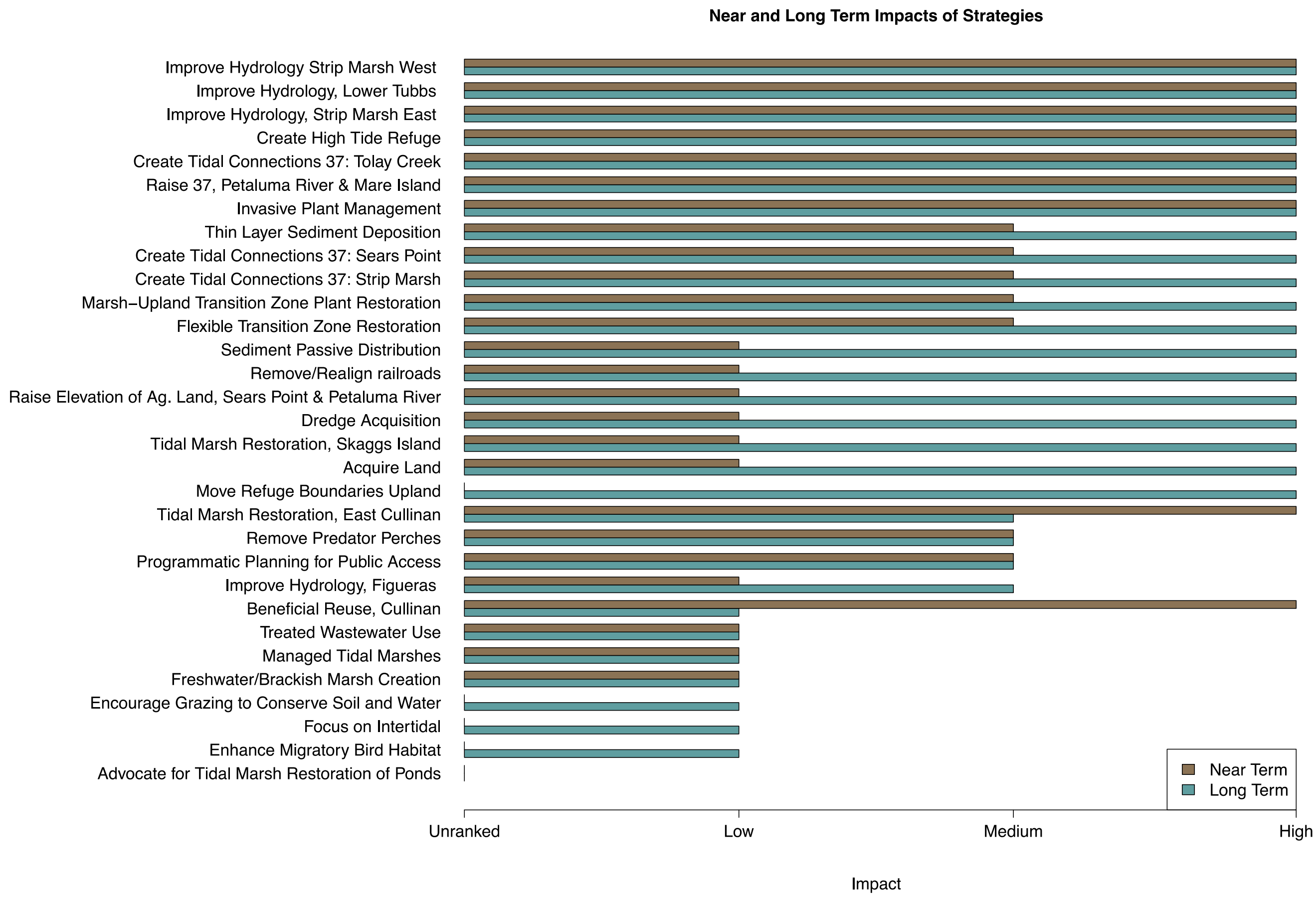


Figure 37. Near (current to 2030) and long term (2030 – 2100) tiers of impact of each strategy considered for climate change adaptation in San Pablo Bay National Wildlife Refuge.

5.4.2 Long term (2030 – 2100)

In the long term (2030 – 2100), experts consistently ranked five strategies the highest. These five strategies, Acquire Land, Invasive Plant Management, Move Refuge Boundaries Upland, Raise 37 from Petaluma River to Mare Island, and Tidal Marsh Restoration at Skaggs Island, comprised the "Very High" prioritization of action tier (Table 18; Figure 38 and Figure 39). Unlike in the near term, all strategies that were ranked Very High or High are expected to have a High impact on the Refuge (Figure 36). With the exception of the Create Tidal Connections 37: Sears Point strategy, the feasibility of all Very High and High strategies in the long term was either Medium or High. Finally, some strategies had qualifiers in the priority rankings. The Sediment Passive Distribution strategy was created as an experimental strategy for the near term, and therefore would be ranked as a High priority only if it is shown to be effective. In addition, four strategies (Tidal Marsh Restoration at East Cullinan, Create Tidal Connections 37: Strip Marsh, Improve Hydrology at Lower Tubbs, and Improve Hydrology at Strip Marsh West) were ranked as a Low priority in the long term because the group expected that these strategies would be completed by 2030. However, if these were not complete, they would be ranked as a High priority for the long term. Strategy ranking scores for each habitat and feasibility are presented in Appendix A2.

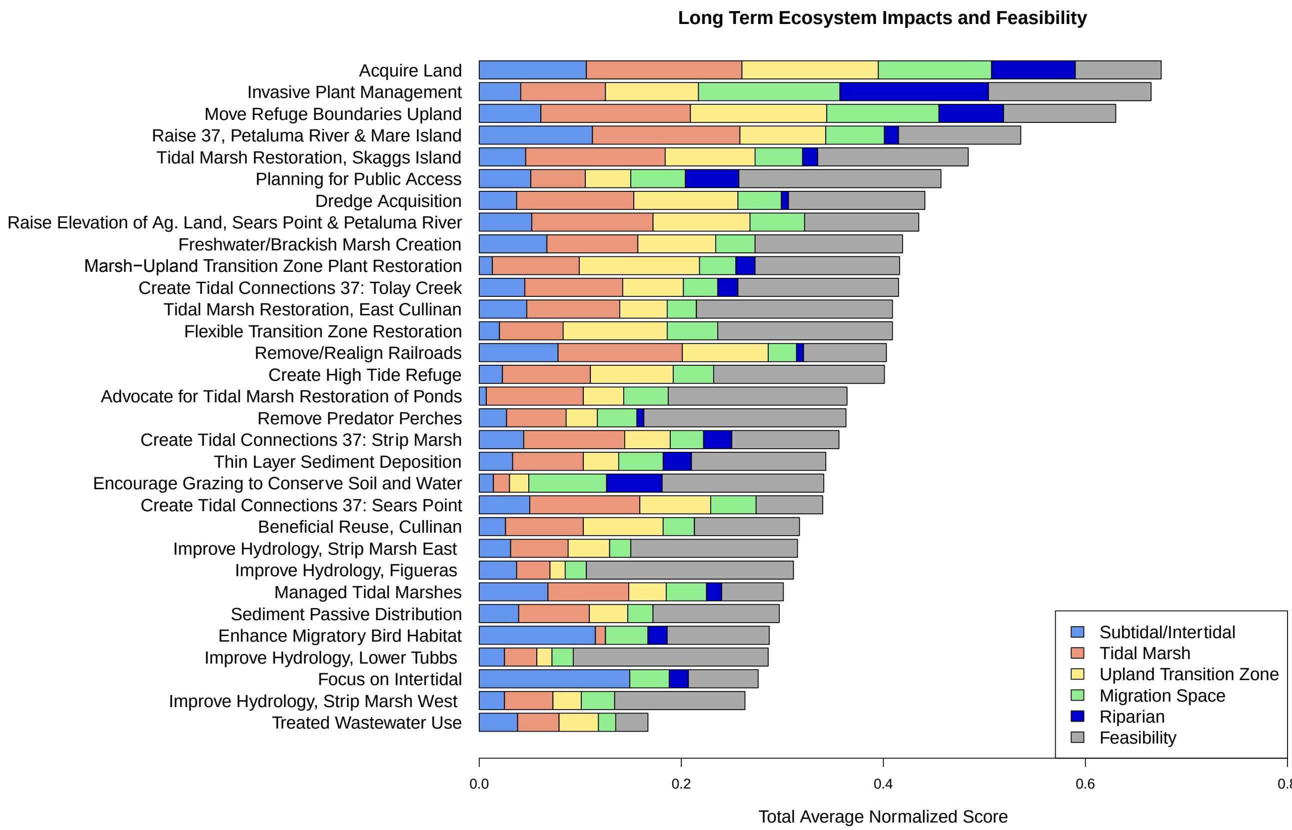


Figure 38. Scores for each strategy, averaged across experts and normalized, broken down into ecosystems and feasibility for the long term (2030 – 2100). Ecosystem scores are a composite score of the "Spatial Extent" and "Impact" categories from the expert elicitation process. Scores were calculated from the original data from the expert elicitation process. Scores were calculated from the original data from the expert elicitation process. For strategies that were merged, ratings were averaged.

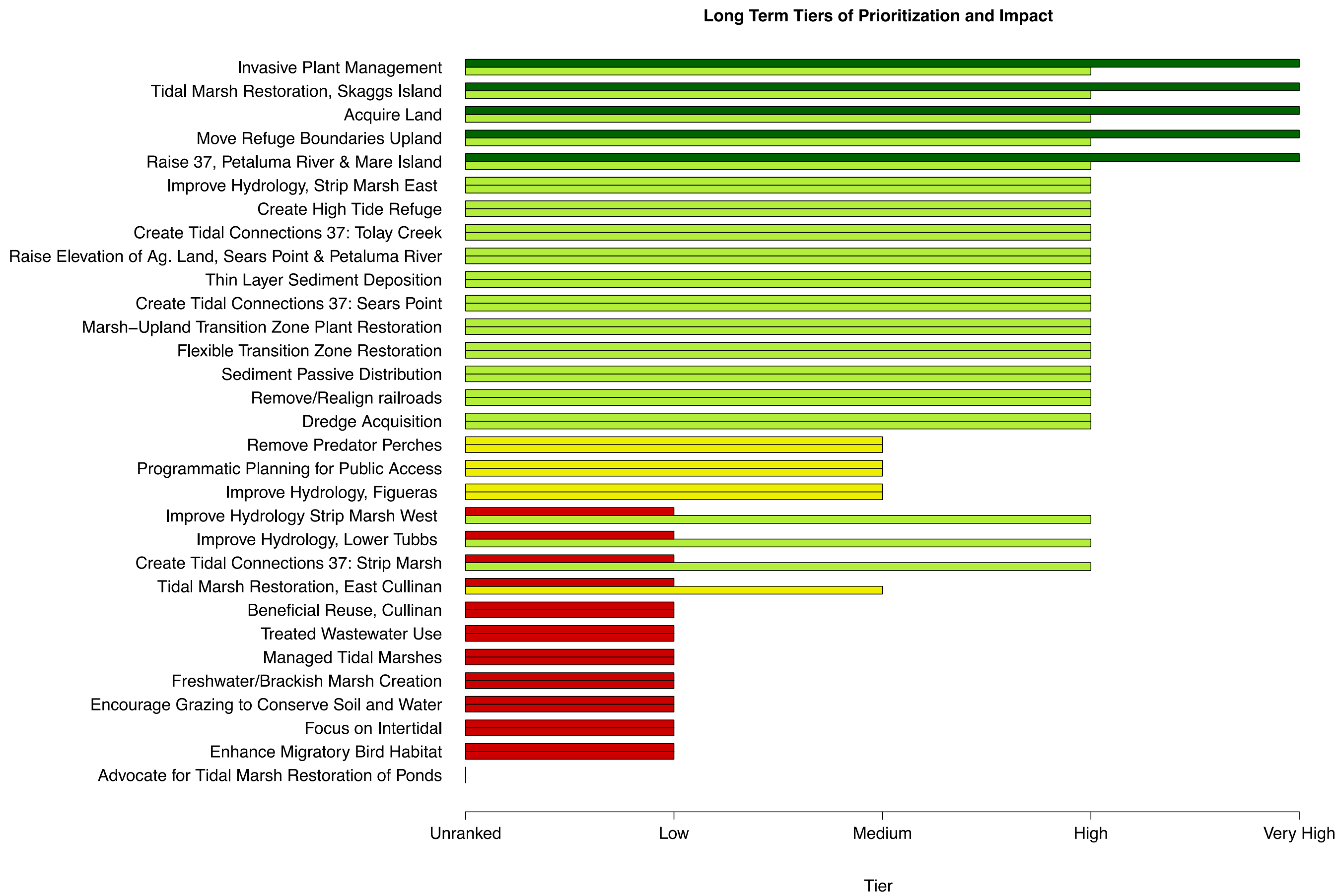


Figure 39. Tiers of priority for strategy (top bar in each strategy grouping) and impact (bottom bar in each strategy grouping) for each strategy considered in the long term (2030 – 2100) for climate change adaptation at San Pablo Bay National Wildlife Refuge. Priority tiers were ranked from Low to Very High, whereas Impact tiers were ranked from Low to High.

6. Proposed Prioritized Adaptation Strategies

6.1 Short term (current to 2030) Strategy & Strategy Objectives

6.1.1 Acquire land, raise Hwy 37 at Petaluma River, acquire land at Mare Island

The intent of this strategy was to remove barriers to tidal marsh migration. Currently, Hwy 37 at the Petaluma River and at Mare Island acts as a physical barrier to marsh migration and surrounding land is privately owned (Figure 40). Protecting private land through easement or fee title from willing sellers and raising Hwy 37 on a causeway would allow the restoration of former wetlands, improve tidal hydrology, and enable marsh migration and accretion. Refuge should raise awareness of the importance of this action to internal leadership, partners, CalTrans, and other regional decision makers who can promote elevating Hwy 37. Staff will work with CalTrans to target key locations where the highway needs to be raised.

6.1.2 Restore tidal marsh at East Cullinan

The eastern half of the Cullinan Ranch property would be restored to tidal action by breaching levees (Figure 40). This project would have benefits both in the short term and long term. Benefits from the project include an increase in tidal marsh habitat and improved tidal hydrology.

6.1.3 Create tidal connections at Hwy 37: Tolay Creek

Currently a dysfunctional culvert connects tidal action along Tolay Creek at Hwy 37 (Figure 40). The culvert needs to be improved to enable sufficient tidal flows. This action could be an alternative to raising Hwy 37 at this location, where it crosses Tolay Creek. This can also be viewed as an interim solution while plans for raising Hwy 37 (from Tolay Creek eastward towards Mare Island) are developed and approved.

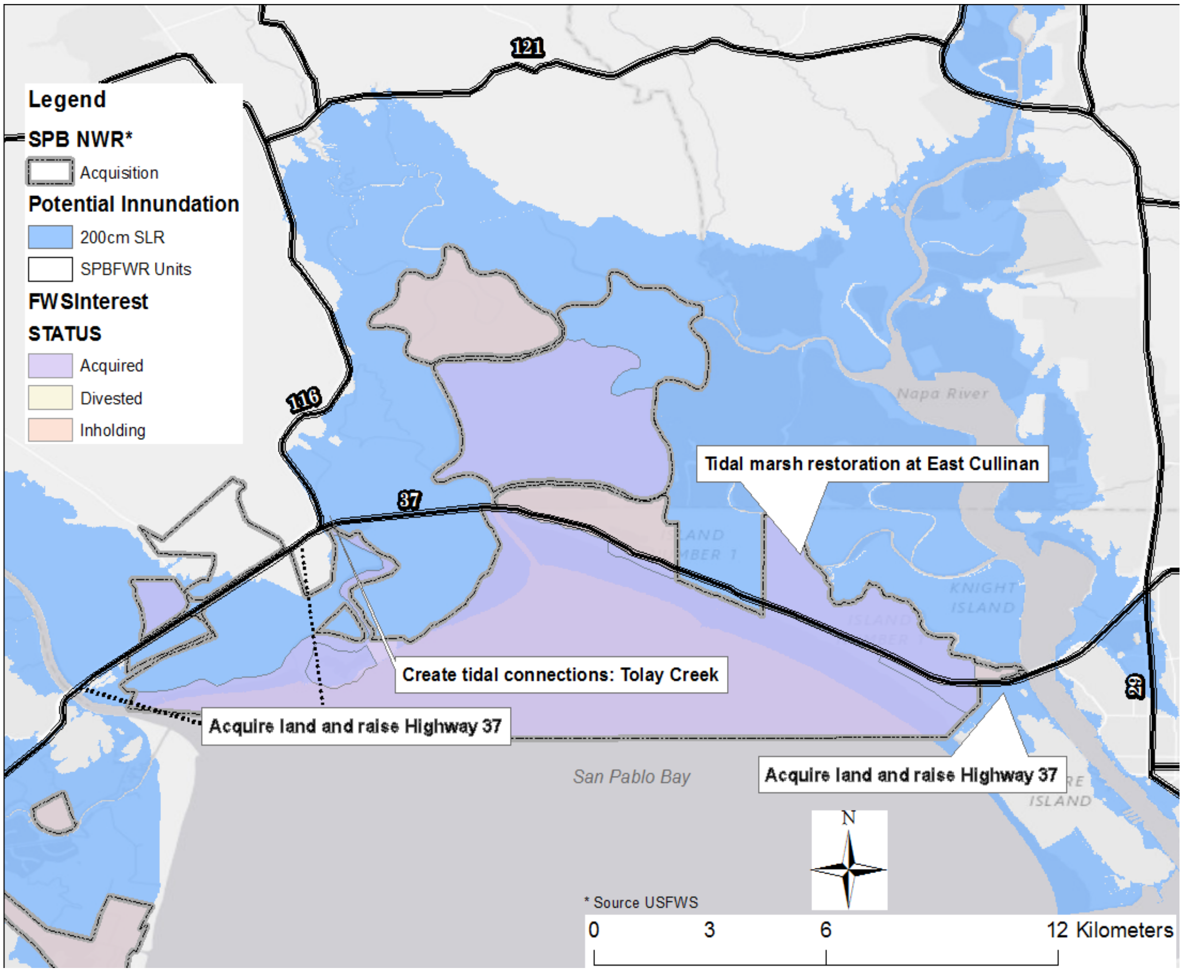


Figure 40. Locations of priority short term strategies.

6.1.4 Manage invasive plants

The expert elicitation group originally identified several strategies that all related to invasive species detection and management.

<u>Invasive plant early detection and rapid response</u>. Develop and implement an invasive plant early detection & rapid response (EDRR) program. Activity: support landscape level EDRR. This strategy is focused on all lands managed by the Refuge.

<u>Reduce extent of *Lepidium latifolium* (pepperweed).</u> Reduce pepperweed cover in tidal marsh and the marsh-upland transition zone by 90% of baseline (2005). Activity- landscape level approach to Lepidium (similar to *Spartina,* see below).

Eradicate non-native *Spartina*. Detect and eradicate invasive *Spartina* species from tidal marsh. Activity- advocate for regional *Spartina* control to prevent spread. The expert elicitation group noted that there is limited non-native *Spartina* currently in present in the refuge although some uncertainty exists. Vigilant detection and eradication could prevent the species from establishing. In addition, the group was not confident that regional *Spartina* control efforts would be successful and/or sustainable in the long term.

6.2 Long term (2030 to 2011) Strategy & Strategy Objectives

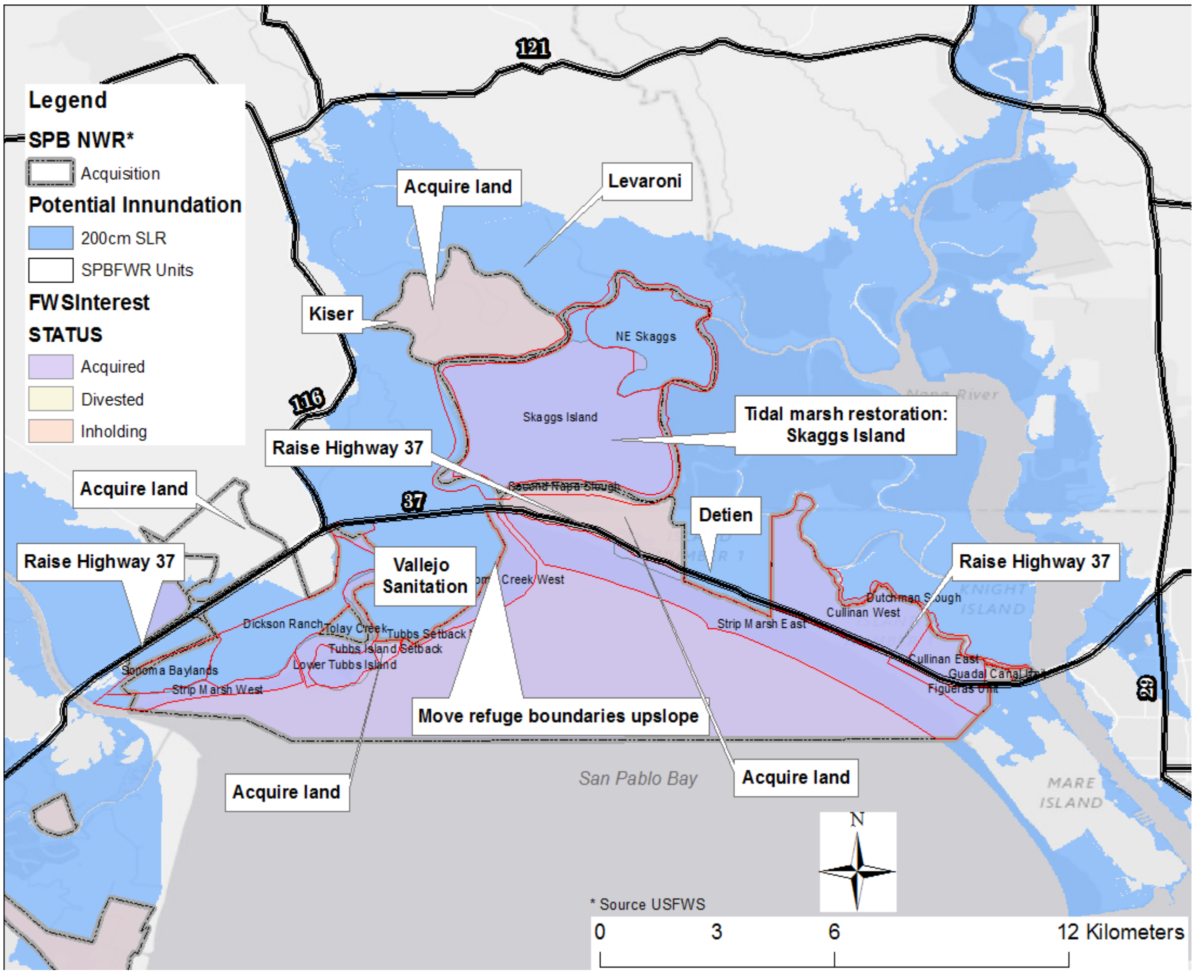


Figure 41. Locations of priority long term strategies.

6.2.1 Protect or acquire land

Working group participants identified four specific properties to protect through easement or acquire from willing sellers over the near and long term: Kiser, Leveroni, Detjen and Tubbs Island. The benefits from protecting or acquiring these properties (including enhancement or restoration of estuarine habitats) would be realized over the long term but benefits would be maximized if the action were taken as soon as possible.

6.2.2 Manage invasive plants

The actions for invasive plant management were the same for near and long term (see 5.1.4).

6.2.3 Move refuge boundaries upland

As sea levels rise, tidal marsh and transition zone habitat will need to move upslope in order to persist. Expanding the refuge boundaries into higher elevation areas would result in refuge staff having direct management control to help facilitate upslope habitat transgression. The working group did not identify specific locations for this strategy, as it is a general strategy that could be explored on all refuge boundaries adjacent to higher elevation areas.

6.2.4 Raise Hwy 37 between the Petaluma River and Mare Island

Highway 37 presents one of the greatest barriers to restoring tidal connections throughout the project extent. The highway is a major transportation artery for the North Bay that is in need of upgrades to accommodate increasing traffic and extensive vulnerabilities to sea level rise. This strategy would be to focus outreach efforts to relevant decision makers to promote the raising the highway as a causeway so that hydrological connections to wetlands and other habitats on both sides of the highway are restored. Efforts will focus on communicating the benefits a causeway would have for ecosystem targets and also raising the awareness of the impacts that alternative strategies would have on ecosystem targets.

6.2.5 Restore tidal marsh at Skaggs Island

Tidal marsh restoration at Skaggs Island will need to start soon but benefits would largely be realized over the long term. The primary objectives of the restoration would be to restore the hydrology of the site and to raise elevations so that marsh accretion will be able to keep pace with future sea level rise. Following restoration the working group acknowledged that the site should initially be managed as subtidal habitat for waterfowl unless bed elevations are raised or sediment added to bring the site to marsh plain level.

The working group identified several potential sources of sediment that could be used to help raise elevations. Many sloughs in the area could be dredged to former widths and the dredge material could be used to augment sediment supplies. Upland till from the Sonoma County Water Agency should be stockpiled to use for future sediment augmentation. Other sources of dredge spoil should also be explored for raising initial site elevations and for augmenting sediment levels.

7. Conclusion and Next Steps

7.1 Next Steps

7.1.1 Strategy activities, assumptions, and SMART goals and objectives

The strategies laid out in this plan are ultimately comprised of a group of actions with a common focus that work together to reduce threats, capitalize on opportunities, or restore natural systems. Identifying and documenting specific actions that are needed, when, and by whom is a critical next step in realizing this plan. Another critical step is laying out assumptions and objectives of each strategy. A results chain (also referred to as a logic chain or theory of change) is a tool conservation practitioners can use to clarify assumptions about how conservation strategies are believed to contribute to reducing threats such as climate change and achieving the conservation of targets. They are diagrams that map out a series of causal statements that link factors in an “if…then” fashion – for example, if an opportunity is taken or a threat is reduced, then a conservation target is enhanced. The conceptual models developed in this plan and priority strategies can serve as a basis for developing results chains and SMART objectives. SMART objectives are specific, measureable, achievable, results-oriented, and time-bound statements about the expected outcomes (or results) of strategies along the way to achieving target-oriented SMART goals. Here, goals refer to the ultimate state of targets in terms of their key ecological attributes and indicators (Table 13). Together, SMART target-oriented goals and threat-reduction objectives provide the mechanism for evaluating conservation progress, learning, and adapting.

7.1.2 Timeline for implementing management actions

The timing of when strategies in this plan would be implemented was categorized as short-term (current to 2030), long-term (2030-2100) or both (i.e., the strategy would need to be implemented now through 2110). This broad categorization was useful for ranking strategies but a more detailed timeline is necessary for Refuge staff seeking to prioritize which strategies need to be implemented in that which years as this information is necessary in developing annual work plans that help guide day-to-day activities. The timeline should also describe when a response in the KEA's should be expected for each conservation action. This information will in turn inform when monitoring should be implemented and when an analysis of the conservation target condition should be implemented. This detailed timeline is necessary to track progress and allow for course corrections if the target is not improving as expected. A lack of improvement could indicate one or more potential problems (e.g., the strategy is not working, the assumptions in the conceptual model were incorrect, or the metrics chosen to represent KEA condition were not appropriate).

7.1.3 Research to address uncertainty

It was not always well known what impacts conservation actions had on targets or what influence various components of the conceptual model had on conservation targets. In many cases, expert opinion was used to describe the relationships among physical and biological drivers and their effect on the conservation target. In some cases, there was high uncertainty in the anticipated effect of strategies on the conservation target. Uncertainty or a lack of confidence was often the source of differences in the expert's strategy rankings. The positive effects of all of the highest priority actions identified in 6.1 and 6.2 are relatively certain. On the other hand, some of the lower ranked actions may have been ranked higher if we were more confident in the feasibility or efficacy of the actions. Targeted research is needed to test the viability of strategies with uncertain outcomes.

A comprehensive evaluation of different strategies for increasing suspended sediment concentrations within the Refuge would help prioritize management actions. In particular, the group wasn't sure if different strategies to augment sediment concentrations would actually increase sediment deposited within the marsh plain. Also, there were concerns that thin layer sediment deposition might have a short term negative impact on some of the conservation targets. Finally, the feasibility of the different sediment augmentation strategies was uncertain. The working group was not concerned that some of the sediment augmentation strategies would be cost prohibitive or that policies or other barriers might prevent these strategies from being implemented in the future. Further research to increase our understanding of the efficacy, impacts and feasibility of sediment augmentation strategies would improve Refuge adaptation planning.

8. Literature Cited

Ballard, G., P. L. Barnard, L. Erikson, M. Fitzgibbon, D. Moody, K. Higgason, M. Psaros, S. Veloz, J. Wood. 2016. Our Coast Our Future (OCOF). Google Chrome. Petaluma, California. www.ourcoastourfuture.org. (Accessed: 9/21/2016).

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick. 2009. Climate change scenarios and sea-level rise estimates for California 2008 climate change scenarios assessment. California Climate Change Center. CEC-500-2009-014-F.

Cayan, D., M. Tyree, D. Pierce, T. Das. 2012. Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment. California Energy Commission. Publication number: CEC- 500-2012-008.

Cloern, J. E., N. Knowles, L. R. Brown, D. Cayan, M. D. Dettinger, T. L. Morgan, D. H. Schoellhamer, M. T. Stacey, M. van der Wegen, R. W. Wagner, and A. D. Jassby. 2011. Projected evolution of California's San Francisco Bay-Delta-River system in a century of climate change. PLoS ONE 6:e24465. doi: 10.1371/journal.pone.0024465.

Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT). 2013. State of California Sea-level Rise Guidance Document. Available from http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf

Conservation Measures Partnership. 2013. Open standards for the practice of conservation (version 3.0).

Flint, L. E., A. L. Flint, J. H. Thorne, and R. Boynton. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecological Processes 2:25.

Fulfrost, B. and D. Thomson. 2015. San Francisco Bay Margin Conservation and Management Decision Support System. Report of pilot project produced for USFWS Coastal Program. Available from http://climate.calcommons.org/dataset/san-francisco-bay-estuarine-terrestrial-transitional-zone-decision-support-system.

Hammond, J. S., R. L. Keeney, and H. Raiffa. 1999. Smart choices: a practical guide to making better life decisions. Broadway Books, New York, NY.

Goals. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015 prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

Kuhnert, P. M., T. G. Martin, and S. P. Griffiths. 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecology Letters 13:900–14.

Martin, K. 2015. Case Study: California Grunion (Leuresthes tenuis) *In* Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015 prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

Mattsson, B.J., B. Huning, G. Block, K. Robinson, C. Sloop, and J. Cummings. 2015. Developing a spatially-explicit climate adaptation framework for estuarine ecosystems of the San Francisco Bay: Climate Adaptation for Decision Support. San Francisco Bay Joint Venture, Fairfax, CA.

Micheli, E., L. Flint, A. Flint, S. Weiss, and M. Kennedy. 2012. Downscaling future climate projections to the watershed scale: a North San Francisco Bay case study. San Francisco Estuary and Watershed Science 10(4).

Moyle, P.B. 2008. The future of fish in response to large-scale change in the San Francisco Estuary, California. American Fisheries Society Symposium 64: 1-17.

National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

North Bay Climate Adaptation Initiative. 2013. Climate Change in the North Bay for Residents of Marin, Sonoma, and Napa Counties. Climate Smart North Bay Fact Sheet Series. North Bay Climate Adaptation Initiative. Santa Rosa, CA.

Nur, N., L. Salas, S. Veloz, J. Wood, L. Liu, and G. Ballard. 2012. Assessing Vulnerability of Tidal Marsh Birds to Climate Change Through the Analysis of Population Dynamics and Viability. Technical Report. Version 1.0 Report to the California Landscape Conservation Cooperative. PRBO Conservation Science, Petaluma, CA, USA, 94954.

Nur, N. and B. Herbold. 2015. Science Foundation Chapter 5: Risks from Future Change for Wildlife *in* Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015 prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

Overton C. T., M. L. Casazza, J. Y. Takekawa, D. R. Strong, and M. Holyoak. 2014. Tidal and seasonal effects on survival rates of the endangered California clapper rail: Does invasive Spartina facilitate greater survival in a dynamic environment? Biological Invasions 16:1897-1914.

Shellhammer, H. 2000. Salt Marsh Harvest Mouse *in* Baylands Ecosystem Habitat Goals Project. 2000. Baylands Ecosystem Species and Community Profiles: Life history and environmental requirements of key plant, fish and wildlife Pp. 219 – 228. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. P. R. Olofson, editor. San Francisco Bay Regional Water Quality Control Board, Oakland, California.

Shellhammer, H. S. and R. R. Duke. 2010. Salt marsh harvest mice and width of salt marshes in the South San Francisco Bay. California Fish and Game 96(2): 165 – 170.

Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.). 2014. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, D.C.

Stralberg, D., M. Brennan, J. C. Callaway, J. K. Wood, L. M. Schile, D. Jongsomjit, M. Kelly, V. T. Parker, and S. Crooks. 2011. Evaluating tidal marsh sustainability in the face of sea-level rise: a hybrid modeling approach applied to San Francisco Bay. PLoS One 6(11): e27388. doi:10.1371/journal.pone.0027388.

Subtidal Habitat Goals Report. 2010. San Francisco Bay Subtidal Habitat Goals Report: Conservation Planning for the Submerged Areas of the Bay. L. O. Viviani, Editor. Oakland, CA. State Coastal Conservancy.

Swanson, K., J. Drexler, D. Schoellhamer, K. Thorne, M. Casazza, C. Overton, J. Callaway, J. Takekawa. 2013. Wetland accretion rate model of ecosystem resilience (WARMER) and its application to habitat sustainability for endangered species in the San Francisco Estuary. Estuaries and Coasts 37:476-492.

Takekawa, J. Y., K. M. Thorne, K. J. Buffington, K. A. Spragens, K. M. Swanson, J. Z. Drexler, D. H. Schoellhammer, C. T. Overton, and M. L. Casazza. 2013. Final report for sea level rise response modeling for San Francisco bay estuary tidal marshes. Vallejo, CA.

Thorne, K. M., J. Y. Takekawa, and D. L. Elliott-Fisk. 2012. Ecological effects of climate change on salt marsh wildlife: a case study from a highly urbanized estuary. Journal of Coastal Research 285:1477–1487.

Thorne, K. M., K. Buffington, J. Y. Takekawa, and K. Swanson. 2013. Storm episodes and climate change implications for tidal marshes in the San Francisco Bay Estuary, California, USA. The International Journal of Climate Change: Impacts and Responses 4:169-190.

U.S. Fish and Wildlife Service. 2011. San Pablo Bay National Wildlife Refuge Final Comprehensive Conservation Plan. 119 pp.

U.S. Fish and Wildlife Service. 2013. Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California. Sacramento, California. xviii+ 605 pp.

Veloz, S., N. Nur, L. Salas, D. Stralberg, D. Jongsomjit, J. Wood, L. Liu, and G. Ballard. 2012. San Francisco Bay Sea-Level Rise Website. A PRBO online decision support tool for managers, planners, conservation practitioners and scientists. Phase II report to the California State Coastal Conservancy. http://data.prbo.org/apps/sfbslr/PRBOCoastalConservancyTechnicalReport_Mar2012.pdf.

Veloz, S. D., N. Nur, L. Salas, D. Jongsomjit, J. Wood, D. Stralberg, and G. Ballard. 2013. Modeling climate change impacts on tidal marsh birds: Restoration and conservation planning in the face of uncertainty. Ecosphere 4(4):49. http://dx.doi.org/10.1890/ES12-00341.1

9. References

BEHGU- Chapter 2. Recommendations (North Bay Subregion and Subregions E, G; pp. 137-154)
http://baylandsgoals.org/wp-content/uploads/2015/10/3-Baylands_Chapter2.pdf

BEHGU- Risks from Future Change for Wildlife
http://baylandsgoals.org/wp-content/uploads/2015/10/BEHGU_SFC5.pdf

Climate Adaptation Decision Support for SF Bay (CADS I)
http://climate.calcommons.org/cads

Climate Ready Sonoma County: Climate Hazards and Vulnerabilities
http://www.sctainfo.org/pdf/Climate%20Ready_Hazards_Vulnerabilities.pdf

De Boeck, H. J., C. M. H. M. Lemmens, B. Gielen, H. Bossuyt, S. Malchair, M. Carnol, R. Merckx, R. Ceulemans, and I. Nijs. 2007. Combined effects of climate warming and plant diversity loss on above- and below-ground grassland productivity. Environmental and Experimental Botany 60:95-104. Available from: http://dx.doi.org/10.1016/j.envexpbot.2006.07.001.

Dukes, J. S. and H. A. Mooney. 1999. Does global change increase the success of biological invaders? Trends in Ecology & Evolution 14: 135-139. Available from: http://dx.doi.org/10.1016/S0169-5347(98)01554-7.

Esralew, R., and S. Michehl. Humboldt Bay National Wildlife Refuge Climate Inventory and Summary. USFWS report by the Pacific Southwest Region Inventory and Monitoring Program.

FOS. 2009. Conceptualizing and Planning Conservation Projects and Programs. Unpublished Training Manual by Foundations of Success.

Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002. Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. Waterbirds 25: 173-183.

Gleick, P., E. L. Chalecki. 1999. The impacts of climatic changes for water resources of the Colorado and Sacramento-San Joaquin River basins. Journal of the American Water Resources Association 35: 1429–1441. doi:10.1111/j.1752-1688.1999.tb04227.x.

Kirwan, M. L., S. Temmermann, E. E. Skeehan, G. R. Guntenspergen, and S. Fagherazzi. 2016. Overestimation of marsh vulnerability to sea level rise. Nature Climate Change 6:253-260.

Knowles, N. and D.R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. Geophysical Research Letters 29: 1-4.

Meyer, J. L., M. J. Sale, P. J. Mulholland, and N. L. Poff. 1999. Impacts of climate change on aquatic ecosystem functioning and health. Journal of the American Water Resources Association 35: 1373–1386. doi:10.1111/j.1752-1688.1999.tb04222.x.

Micheli, L., L. Flint, A. Flint, M. Kennedy, S. Weiss, and R. Branciforte. 2010. Adapting to Climate Change: State of the Science for North Bay Watersheds. Unpublished report prepared for the North Bay Watershed Association. Pepperwood Preserve, CA.

Moore, S.S., N.E. Seavy, and M. Gerhart. 2013. Scenario planning for climate change adaptation: A guidance for resource managers. Point Blue Conservation Science and California Coastal Conservancy.

Northeast Regional Ocean Council. Make Way for Marshes. www.northeastoceancouncil.org/marshmigration.

Palmer, M. A., C. A. R. Liermann, C. Nilsson, M. Florke, J. Alcamo, P. S. Lake, N. Bond. 2008. Climate change and the world's river basins: anticipating management options. Frontiers in Ecology and the Environment 6: 81–89.

Runge, C. M. 2011. An Introduction to Adaptive Management for Threatened and Endangered Species. Journal of Fish and Wildlife Management: Vol. 2, No. 2, pp. 220-233. http://training.fws.gov/courses/programs/decision-analysis/structured-decision-making-overview.html

San Francisco Bay Joint Venture Monitoring and evaluation plan. http://www.sfbayjv.org/monitoring-evaluation.php

Takekawa, J. Y., K. M. Thorne, K. J. Buffington, and C. M. Freeman. 2014. An elevation and climate change assessment of the Tolay Creek restoration, San Pablo Bay National Wildlife Refuge. Unpublished Data Summary Report. U. S. Geological Survey, Western Ecological Research Center, Vallejo, CA. 56pp.

Thorne, K.M., D.L. Elliott-Fisk, G.D. Wylie, W.M. Perry, and J.Y. Takekawa. 2013. Importance of biogeomorphic and spatial properties in assessing a tidal salt marsh vulnerability to sea-level rise. Estuaries and Coasts. DOI 10.1007/s12237-013-9725-x.

Thorne, K.M., K. J. Buffington, D.L. Elliott-Fisk, and J.Y. Takekawa. 2015. Tidal marsh susceptibility to sea-level rise: importance of local-scale models. Journal of Fish and Wildlife Management 6: 290.

Make way for marshes: guidance on using models for tidal marsh migration to support community resilience to sea level rise http://waterviewconsulting.com/make-way-for-marshes/

Appendix A: Strategy Ranking Results

Table A1: Near term (current to 2030) ranks and scores from the expert elicitation rating and ranking process. Scores were normalized for each category (five ecosystems and feasibility) and weighted evenly. The total average score is the total score for a strategy, summed across all categories. The average rank is from the elicitation process. Priority and Impact represent the final tiers in which each strategy was placed after discussions. Dark green = very high tier (priority only), light green = high tier, yellow = medium tier, red = low tier. Avg. = average, "Merged" refers to strategies that were combined with other strategies during discussion, "Omit" refers to strategies that were eliminated from further consideration.

		Normalized Scores from Elicitation									
Category	**Strategy Name**	**Subtidal / Intertidal**	**Tidal Marsh**	**Upland Transition Zone**	**Migration**	**Riparian**	**Feasibility**	**Total Average Score**	**Avg. Rank**	**Priority**	**Impact**
Vegetation management	Invasive Plant Early Detection and Rapid Response	0.066	0.101	0.107	0.149	0.158	0.165	0.745	1	Very High	High
Vegetation management	Reduce Extent of *Lepidium*	0.004	0.116	0.126	0.149	0.158	0.165	0.717	2	Merged	Merged
Remove barriers to marsh migration	Raise 37, Petaluma River & Mare Island	0.134	0.158	0.080	0.091	0.041	0.063	0.568	3	Very High	High
Increase hydrological connectivity	Create Tidal Connections 37: Tolay Creek	0.092	0.088	0.056	0.053	0.047	0.146	0.483	4	Very High	High
Acquire land	Acquire Land	0.144	0.066	0.054	0.103	0.059	0.053	0.479	5	Very High	Low

Restore tidal marsh hydrology	Tidal Marsh Restoration, East Cullinan	0.105	0.093	0.062	0.018	0.000	0.193	0.471	7	Very High	High
Public access	Programmatic Planning for Public Access	0.063	0.049	0.052	0.054	0.038	0.211	0.467	8	Medium	Medium
Create high tide refuge	Marsh Mounds, Enhance Transition Zone	0.012	0.105	0.115	0.033	0.000	0.171	0.437	9	High	High
Restore tidal marsh hydrology	Tidal Marsh Restoration, Skaggs Island	0.127	0.107	0.068	0.051	0.000	0.082	0.435	10	High	Low
Remove barriers to marsh migration	Remove Railroads	0.077	0.113	0.073	0.072	0.034	0.061	0.431	11	Medium	Low
Restore transition zone	Marsh-Upland Transition Zone Plant Restoration	0.009	0.100	0.136	0.043	0.000	0.137	0.425	12	High	Medium
Remove barriers to marsh migration	Realign Railway	0.077	0.113	0.073	0.069	0.027	0.061	0.422	13	Merged	Merged
Wildlife management	Remove Predator Perches	0.033	0.071	0.052	0.055	0.008	0.193	0.412	14	Medium	Medium

Increase hydrological connectivity	Create Tidal Connections 37: Sears Point	0.106	0.085	0.062	0.069	0.008	0.078	0.407	15	Medium	Medium
Improve tidal hydrology	Improve Hydrology, Strip Marsh East	0.072	0.120	0.026	0.017	0.000	0.162	0.396	16	Medium	Medium
Restore transition zone	Flexible Transition Zone Restoration	0.004	0.093	0.149	0.064	0.000	0.084	0.395	17	High	Medium
Vegetation management	Eradicate *Spartina*	0.089	0.080	0.029	0.017	0.000	0.178	0.393	18	Merged	Merged
Improve tidal hydrology	Improve Hydrology, Figueras	0.105	0.055	0.019	0.017	0.000	0.189	0.384	19	Low	Low
Increase land elevation	Freshwater/Brackish Marsh Creation	0.149	0.025	0.032	0.020	0.020	0.128	0.375	20	Low	Low
Increase hydrological connectivity	Create Tidal Connections 37: Strip Marsh	0.096	0.116	0.032	0.033	0.000	0.089	0.367	21	High	Medium
Improve tidal hydrology	Improve Hydrology, Strip Marsh West	0.064	0.089	0.026	0.017	0.000	0.171	0.366	22	High	High
Restore transition zone	Create Transition Zone Highway 37	0.014	0.071	0.145	0.017	0.000	0.116	0.362	23	Omit	Omit

Create high tide refuge	Create High Tide Refuge	0.018	0.064	0.066	0.048	0.000	0.152	0.348	24	High	High
Increase land elevation	Beneficial Reuse, Cullinan	0.034	0.067	0.075	0.032	0.000	0.132	0.339	25	High	High
Increase land elevation	Sediment Passive Distribution	0.057	0.085	0.045	0.024	0.000	0.117	0.329	27	Medium	Low
Other	Managed Tidal Marshes	0.145	0.068	0.031	0.008	0.000	0.063	0.315	28	Low	Low
Increase land elevation	Non-Corps Sediment Delivery	0.024	0.064	0.068	0.038	0.000	0.089	0.282	29	High (Merged)	Low
Increase land elevation	Thin Layer Sediment Deposition	0.034	0.079	0.045	0.024	0.000	0.091	0.274	30	Medium	Medium
Increase land elevation	Dredge Offloading Facility	0.024	0.083	0.083	0.038	0.000	0.046	0.274	31	High (Merged)	Low
Increase land elevation	Eliminate Deep Ocean Disposal	0.044	0.059	0.038	0.017	0.000	0.112	0.269	32	High (Merged)	Low
Improve tidal hydrology	Improve Hydrology, Lower Tubbs	0.042	0.016	0.000	0.017	0.000	0.193	0.268	33	High	High
Increase land elevation	Raise Elevation of Agricultural Land, Sears Point &	0.009	0.024	0.055	0.107	0.000	0.062	0.257	34	High	Low

	Petaluma River										
Vegetation management	Treated Wastewater Use	0.053	0.043	0.042	0.024	0.000	0.095	0.257	35	Low	Low

Table A2: Long term (2030 – 2100) ranks and scores from the expert elicitation rating and ranking process. Scores were normalized for each category (five ecosystems and feasibility) and weighted evenly. The total average score is the total score for a strategy, summed across all categories. The average rank is from the elicitation process. Priority and Impact represent the final tiers in which each strategy was placed after discussions. Dark green = very high tier (priority only), light green = high tier, yellow = medium tier, red = low tier. "Merged" refers to strategies that were combined with other strategies during discussion.

		Normalized Scores from Elicitation									
Category	**Strategy Name**	**Subtidal / Intertidal**	**Tidal Marsh**	**Upland Transition Zone**	**Migration**	**Riparian**	**Feasibility**	**Total Average Score**	**Average Rank**	**Priority**	**Impact**
Acquire land	Acquire Land	0.106	0.154	0.135	0.112	0.083	0.085	0.675	1	Very High	High
Vegetation management	Invasive Plant Early Detection and Rapid Response	0.041	0.084	0.092	0.140	0.147	0.161	0.666	2	Very High	High
Vegetation management	Reduce Extent of *Lepidium*	0.006	0.103	0.107	0.124	0.132	0.161	0.634	3	Merged	Merged
Acquire land	Move Refuge Boundaries Upland	0.061	0.148	0.135	0.111	0.064	0.111	0.630	4	Very High	High
Remove barriers to marsh migration	Raise 37, Petaluma River & Mare Island	0.112	0.146	0.085	0.058	0.014	0.121	0.536	5	Very High	High
Restore tidal marsh hydrology	Tidal Marsh Restoration, Skaggs Island	0.046	0.138	0.089	0.047	0.015	0.149	0.485	6	Very High	High
Public access	Planning for Public Access	0.051	0.054	0.045	0.054	0.053	0.200	0.457	7	Medium	Medium

Increase land elevation	Non-Corps Sediment Delivery	0.037	0.116	0.103	0.043	0.007	0.135	0.441	8	High	High
Increase land elevation	Raise Elevation of Agricultural Land, Sears Point & Petaluma River	0.052	0.120	0.096	0.054	0.000	0.113	0.436	9	High	High
Increase land elevation	Dredge Offloading Facility	0.037	0.137	0.120	0.053	0.007	0.073	0.426	10	High	High
Increase land elevation	Freshwater/Brackish Marsh Creation	0.067	0.090	0.077	0.039	0.000	0.146	0.419	11	Low	Low
Restore transition zone	Marsh-Upland Transition Zone Plant Restoration	0.013	0.086	0.119	0.036	0.019	0.143	0.417	12	High	High
Increase hydrological connectivity	Create Tidal Connections 37: Tolay Creek	0.045	0.097	0.060	0.034	0.020	0.159	0.416	13	High	High
Restore tidal marsh hydrology	Tidal Marsh Restoration, East Cullinan	0.047	0.092	0.047	0.029	0.000	0.194	0.410	14	Low, unless not complete	Medium
Migration space/grassland restoration	Nature-based Flood Protection	0.020	0.063	0.103	0.050	0.000	0.173	0.409	15	Merged	Merged
Remove barriers to marsh migration	Remove Railroads	0.078	0.123	0.085	0.028	0.007	0.082	0.403	16	High	High
Create high tide refuge	Create High Tide Refuge	0.023	0.087	0.082	0.040	0.000	0.169	0.402	17	High	High

Remove barriers to marsh migration	Realign Railway	0.078	0.123	0.085	0.028	0.007	0.061	0.382	18	Merged	Merged
Vegetation management	Eradicate *Spartina*	0.060	0.063	0.029	0.028	0.000	0.190	0.369	19	Merged	Merged
Wildlife management	Remove Predator Perches	0.027	0.059	0.031	0.039	0.007	0.200	0.363	21	Medium	Medium
Increase hydrological connectivity	Create Tidal Connections 37: Strip Marsh	0.044	0.100	0.045	0.033	0.028	0.106	0.357	22	Low, unless not complete	High
Restore transition zone	Flexible Transition Zone Restoration	0.010	0.081	0.134	0.039	0.000	0.085	0.349	23	High	High
Increase land elevation	Thin Layer Sediment Deposition	0.033	0.070	0.035	0.044	0.028	0.133	0.342	24	High	High
Increase hydrological connectivity	Create Tidal Connections 37: Sears Point	0.050	0.109	0.070	0.045	0.000	0.066	0.340	26	High	High
Increase land elevation	Beneficial Reuse, Cullinan	0.026	0.077	0.079	0.031	0.000	0.104	0.317	27	Low	Low
Improve tidal hydrology	Improve Hydrology, Strip Marsh East	0.031	0.057	0.041	0.021	0.000	0.165	0.314	28	High	High
Create high tide refuge	Marsh Mounds, Enhance Transition Zone	0.006	0.060	0.073	0.025	0.000	0.149	0.314	29	High	High
~~Restore transition zone~~	~~Create Transition Zone Highway 37~~	0.006	0.039	0.070	0.035	0.019	0.144	0.313	30	Low	Low

Improve tidal hydrology	Improve Hydrology, Figueras	0.037	0.033	0.015	0.021	0.000	0.205	0.311	31	Medium	Medium
Other	Managed Tidal Marshes	0.068	0.080	0.037	0.040	0.015	0.061	0.301	32	Low	Low
Increase land elevation	Sediment Passive Distribution	0.039	0.070	0.038	0.025	0.000	0.125	0.297	33	High	High
Increase land elevation	Eliminate Deep Ocean Disposal	0.026	0.059	0.030	0.048	0.000	0.129	0.292	34	High	High
Other	Enhance Migratory Bird Habitat	0.115	0.010	0.000	0.042	0.019	0.101	0.287	35	Low	Low
Improve tidal hydrology	Improve Hydrology, Lower Tubbs	0.025	0.032	0.015	0.021	0.000	0.193	0.286	36	Low, unless not complete	High
Other	Focus on Intertidal	0.149	0.000	0.000	0.039	0.019	0.069	0.276	37	Low	Low
Improve tidal hydrology	Improve Hydrology, Strip Marsh West	0.025	0.048	0.028	0.033	0.000	0.129	0.263	38	Low, unless not complete	High
Vegetation management	Treated Wastewater Use	0.038	0.041	0.039	0.017	0.000	0.032	0.168	39	Low	Low

Appendix B. Threat Ranking Results

Table B1. The degree of potential destruction or degradation of subtidal and intertidal mudflat conservation targets by threats in the near term (current to 2030) and long term (to 2100) was ranked by the team. (1 = Low: threat likely to slightly degrade the target or reduce its occurrence by 1-10% ; 2 = Medium: threat likely to moderately degrade the target or reduce its occurrence by 11-30%; 3 = High: threat likely to seriously degrade/reduce the target or reduce its occurrence by 31-70%; 4 = Very High: threat likely to destroy or eliminate the target, or reduce its occurrence by 71-100%.)

Threat category	***Subtidal threat***	***Near-term rank***	***Long-term rank***
Climate change	Algal blooms	2	3
Climate change	Altered air temperatures	1	2
Climate change	Altered precipitation patterns	1	2
Climate change	Altered water quality	2	3
Climate change	Altered water temperatures	2	3
Climate change	Drought	1	2
Climate change	Extreme storms	2	3
Climate change	Sea level rise	2	2
Human disturbance	Illegal activities	1	1
Human disturbance	Recreational activities	1	2
Human disturbance	Refuge management activities	1	1
Nuisance species	Invasive invertebrates	3	3
Nuisance species	Invasive plants	2	2
System changes	Altered sediment dynamics	2	3
System changes	Altered tidal hydrology	2	2
System changes	Erosion	2	2
System changes	Land conversion	1	2
Pollution	Agricultural pollutants	2	2
Pollution	Air-borne pollutants	1	1
Pollution	Herbicides	1	2
Pollution	Mosquito pesticides	2	2
Pollution	Oil spills	3	2

Table B2. The degree of potential destruction or degradation of tidal marsh conservation targets by threats in the near term (current to 2030) and long term (to 2100) was ranked by the team. (1 = Low: threat likely to slightly degrade the target or reduce its occurrence by 1-10% ; 2 = Medium: threat likely to moderately degrade the target or reduce its occurrence by 11-30%; 3 = High: threat likely to seriously degrade/reduce the target or reduce its occurrence by 31-70%; 4 = Very High: threat likely to destroy or eliminate the target, or reduce its occurrence by 71-100%.)

Threat category	***Tidal marsh direct threat***	***Near-term rank***	***Long-term rank***
Climate change	Algal blooms	2	2
Climate change	Altered air temperatures	1	2
Climate change	Altered precipitation patterns	2	2
Climate change	Altered water quality	2	3
Climate change	Altered water temperatures	1	2
Climate change	Drought	2	2
Climate change	Extreme storms	3	4
Climate change	Sea level rise	2	4
Disease	West Nile virus	1	2
Human disturbance	Illegal activities	2	2
Human disturbance	Recreational activities	1	1
Human disturbance	Refuge management activities	1	1
Nuisance species	Increased predators	2	3
Nuisance species	Invasive invertebrates	2	2
Nuisance species	Invasive plants	2	3
System changes	Altered sediment dynamics	2	4
System changes	Altered tidal hydrology	2	2
System changes	Erosion	1	2
System changes	Land conversion	2	3
System changes	Subsidence	2	2
Policy	Regulatory constraints	3	3
Pollution	Agricultural pollutants	2	1
Pollution	Air-borne pollutants	1	1
Pollution	Herbicides	1	2
Pollution	Mosquito control pesticides	2	2
Pollution	Oil spills	2	2

Transportation	Railways	2	2
Transportation	Roads	2	2

Table B3. The degree of potential destruction or degradation of transition zone conservation targets by threats in the near term (current to 2030) and long term (to 2100) was ranked by the team. (1 = Low: threat likely to slightly degrade the target or reduce its occurrence by 1-10% ; 2 = Medium: threat likely to moderately degrade the target or reduce its occurrence by 11-30%; 3 = High: threat likely to seriously degrade/reduce the target or reduce its occurrence by 31-70%; 4 = Very High: threat likely to destroy or eliminate the target, or reduce its occurrence by 71-100%.)

Threat category	***Transition zone threat***	***Near-term rank***	***Long-term rank***
Climate change	Altered air temperatures	1	2
Climate change	Altered precipitation patterns	2	3
Climate change	Altered water quality	1	2
Climate change	Drought	3	3
Climate change	Extreme storms	2	3
Climate change	Sea level rise	2	4
Human disturbance	Illegal activities	2	2
Human disturbance	Recreational activities	2	2
Human disturbance	Refuge management activities	1	1
Nuisance species	Increased predators	2	2
Nuisance species	Invasive plants	3	3
Policy	Regulatory constraints	2	3
Pollution	Air-borne pollutants	1	1
Pollution	Herbicides	2	2
Pollution	Oil spills	1	2
System changes	Erosion	2	2
System changes	Land conversion	2	3
Transportation	Railways	2	3
Transportation	Roads	2	3

Table B4. The degree of potential destruction or degradation of grassland conservation targets by threats in the near term (current to 2030) and long term (to 2100) was ranked by the team. (1 = Low: threat likely to slightly degrade the target or reduce its occurrence by 1-10% ; 2 =

Medium: threat likely to moderately degrade the target or reduce its occurrence by 11-30%; 3 = High: threat likely to seriously degrade/reduce the target or reduce its occurrence by 31-70%; 4 = Very High: threat likely to destroy or eliminate the target, or reduce its occurrence by 71-100%)

Threat category	***Grassland threat***	***Near-term rank***	***Long-term rank***
Climate change	Altered air temperatures	2	3
Climate change	Altered precipitation patterns	2	3
Climate change	Altered water quality	1	2
Climate change	Drought	3	4
Climate change	Extreme storms	2	2
Disease	Botulism	1	2
Disease	West Nile virus	1	2
Human disturbance	Illegal activities	1	2
Human disturbance	Recreational activities	2	2
Human disturbance	Refuge management activities	2	2
Nuisance species	Increased predators	2	3
Nuisance species	Invasive plants	3	3
System changes	Erosion	1	2
System changes	Land conversion	3	3
Policy	Regulatory constraints	1	2
Pollution	Agricultural pollutants	2	2
Pollution	Air-borne pollutants	1	1
Pollution	herbicides	2	2
Pollution	Mosquito control pesticides	2	2
Transportation	Railways	2	3
Transportation	Roads	2	3

Table B5. The degree of potential destruction or degradation of grassland conservation targets by threats in the near term (current to 2030) and long term (to 2100) was ranked by the team. (1 = Low: threat likely to slightly degrade the target or reduce its occurrence by 1-10% ; 2 = Medium: threat likely to moderately degrade the target or reduce its occurrence by 11-30%; 3 = High: threat likely to seriously degrade/reduce the target or reduce its occurrence by 31-70%; 4 = Very High: threat likely to destroy or eliminate the target, or reduce its occurrence by 71-100%)

Threat category	*Riparian threat*	*Near-term rank*	*Long-term rank*
Climate change	Altered air temperatures	2	3
Climate change	Altered precipitation patterns	2	3
Climate change	Altered water quality	2	2
Climate change	Drought	2	4
Disease	West Nile virus	2	2
Human disturbance	Illegal activities	1	2
Human disturbance	Recreational activities	1	2
Human disturbance	Refuge management activities	1	2
Nuisance species	Increased predators	2	3
Nuisance species	Invasive plants	2	3
System changes	Erosion	2	3
System changes	Land conversion	2	3
Policy	Regulatory constraints	2	2
Pollution	Agricultural pollutants	2	2
Pollution	Herbicides	2	2
Pollution	Mosquito control pesticides	2	2
Pollution	Oil spills	1	1
Transportation	Railways	2	2
Transportation	Roads	2	2

Decision Support Tools

Future San Francisco Bay Tidal Marshes. www.pointblue.org/sfbayslr

Our Coast Our Future. www.pointblue.org/ocof

Climate summaries for planning unit watersheds. http://geo.pointblue.org/watershed-analyst/

Glossary

Project scope	The spatial boundary of the San Pablo Bay NWR climate adaptation plan. The scope encompasses the area where the refuge may expend resources to achieve its conservation goals via on-the-ground actions, natural resource surveys, or advocacy.
Conservation target	Species, communities, or ecosystems that best represent the biodiversity and purpose of the refuge and are the focus of natural resource management. Another words, the natural resources are you ultimately trying to conserve or restore. Typically an ecosystem.
Nested target	A nested target is a species, community or ecological process that is also conserved if the conservation target is conserved. Typically comprised of species or communities that are a high conservation priority or are representative of the overall biodiversity or integrity of the ecosystem.
Key ecological attribute	Aspects of a conservation target's biology or ecology that, if present, define a healthy conservation target but, if missing or altered, would lead to the outright loss or extreme degradation of that conservation target over time. Examples include population size, reproductive success, distribution, community composition or structure, habitat connectivity, hydrological regime, sediment dynamics, and fire regime.
Indicator	A unit of information measured over time that documents changes in a specific condition (key ecological attribute).
Direct threat	A human-induced action that stresses—or has the potential to stress—one or more conservation targets. Examples include sea level rise, logging, contaminants, invasive species introductions, land/habitat conversion, fire suppression, altered hydrology, and human disturbance.
Contributing factor	A contributing factor is something that drives or contributes to a direct threat, referred to as an indirect threat or opportunity. For example, 1) increased housing demand leading to the threat of land conversion, 2) levee improvements exacerbating or leading to the threat of invasive plants, 3) demand for more public transportation leading to road construction, 4) climate change leading to sea level rise, increased temperatures, or increased extreme storm events.
Stress	The expression of a threat on a conservation target or how it negatively impacts the target. The negative alteration of a key ecological attribute. Examples include reduced population/ecosystem size or extent, reduced reproductive success, habitat loss, altered community composition or structure.
Strategy	A group of actions with a common focus that work together to reduce one or more threats or directly restore natural systems.