DELTA STEWARDSHIP COUNCIL

A California State Agency

DELTA ADAPTS

DRAFT ECOSYSTEM TECHNICAL MEMO

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ACRONYMS AND OTHER ABBREVIATIONS

CCVA	Climate Change Vulnerability Assessment
cm	centimeters
Delta	San Francisco-San Joaquin Delta, including the Suisun Marsh
DEM	Digital Elevation Model
DSM2	Delta Simulation Model II
EH	Extreme heat
ft	feet
GIS	geographic information system
in	inches
LOCA	Localized Climate Analogues
MHHW	mean higher high water
MHW	mean high water
MLLW	mean lower low water
MLW	mean low water
MSL	mean sea level
RCP	regional climate projection
SLR	sea level rise
USGS	U.S. Geological Survey
VegCAMP	Vegetation Classification and Mapping Program

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CHAPTER 1. METHODS

(INCL. TM2; SEC. 4.1 GENERAL ASSESSMENT FRAMEWORK; 4.5 ECOSYSTEMS)

This section presents the methodology for assessing the vulnerability of ecosystem assets (habitat types) to primary and secondary climate drivers in the Delta and Suisun Marsh, evaluated further by subregion for sea level rise (SLR) analyses. As shown in Table 1, the vulnerability of ecosystem assets to both climate stressors and hazards were addressed in this assessment. The primary climate drivers air temperature and local precipitation were assessed quantitatively with a qualitative application, whereas SLR was assessed quantitatively. Secondary climate drivers, which include wind and water temperature, were assessed qualitatively. Climate hazards such as extreme heat, extreme precipitation events and drought were similarly assessed qualitatively.

Table 1. Primary and Secondary Climate Stressors and Climate Hazards Evaluated in Ecosystems Assessment

Climate Drivers	**Primary: Local Precipitation**	**Primary: Air Temperature**	**Primary: Sea Level Rise**	**Secondary: Wind**	**Secondary: Water Temperature**
Climate Stressors	Change over time in amount and timing of rainfall	Change over time in air temperature, seasonal changes, maximum air temperature used as proxy	Increase in sea level	Change in wind patterns over time, proximity to the Central Valley and the coast	Change over time in water temperature, directly corresponds to air temperature – dependent on atmospheric forcing, riverine flows and tidal dispersion
Climate Hazards	Extreme precipitation events/ drought	Extreme heat events	Flooding/ levee overtopping	No wind hazards assessed	No water temperature hazards assessed

Understanding impacts of climate stressors over a longer time period exemplifies how these changes can lead to eventual ecosystem decoupling, whereas evaluating climate hazards (extreme events) demonstrates how these events may lead to catastrophic failures within the Delta over the short- and long terms.

Climate vulnerability to the aforementioned stressors and hazards can be defined as (1) the *exposure* of a given species, habitat, resource, or region to climate changes, (2) the *sensitivity* or response to such changes, and (3) the *adaptive capacity* or inherent safeguards or coping mechanisms to deal with such changes (Glick et al. 2011).

AECOM and the Delta Stewardship Council conducted a collaborative climate vulnerability assessment to address the exposure, sensitivity, and adaptive capacity of dominant ecosystem types (drawn from the San Francisco Estuary Institute (SFEI): A Delta Transformed; Table 2) to climate change variables within the Delta and Suisun Marsh project area (Figures 1 and 2).

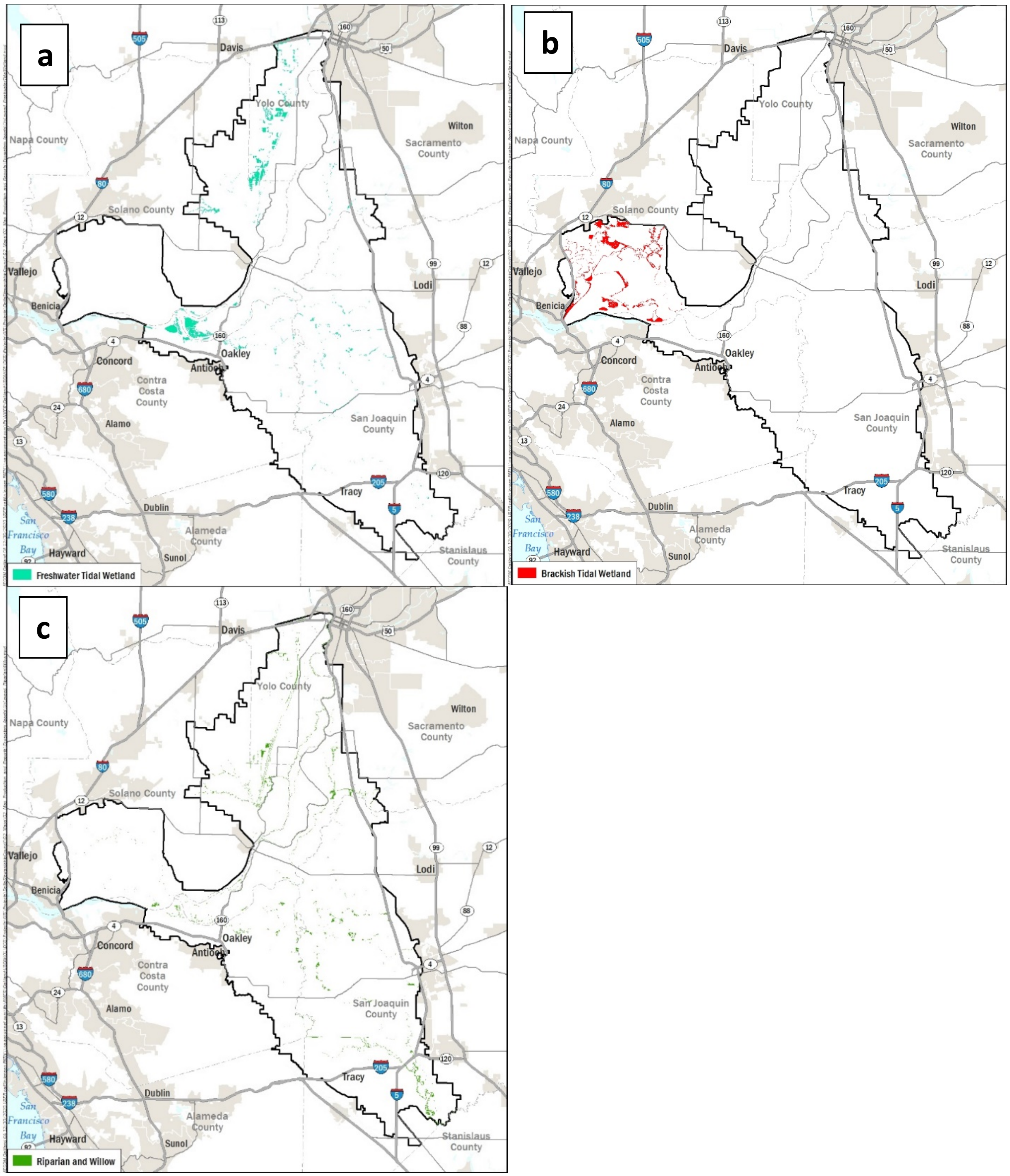

Figure 1 a-c. Existing un-leveed ecosystems in the legal Delta and Suisun Marsh. Panel is comprised of three maps showing different ecosystem types: freshwater tidal wetland (a), brackish tidal wetland (b), and riparian and willow (c).

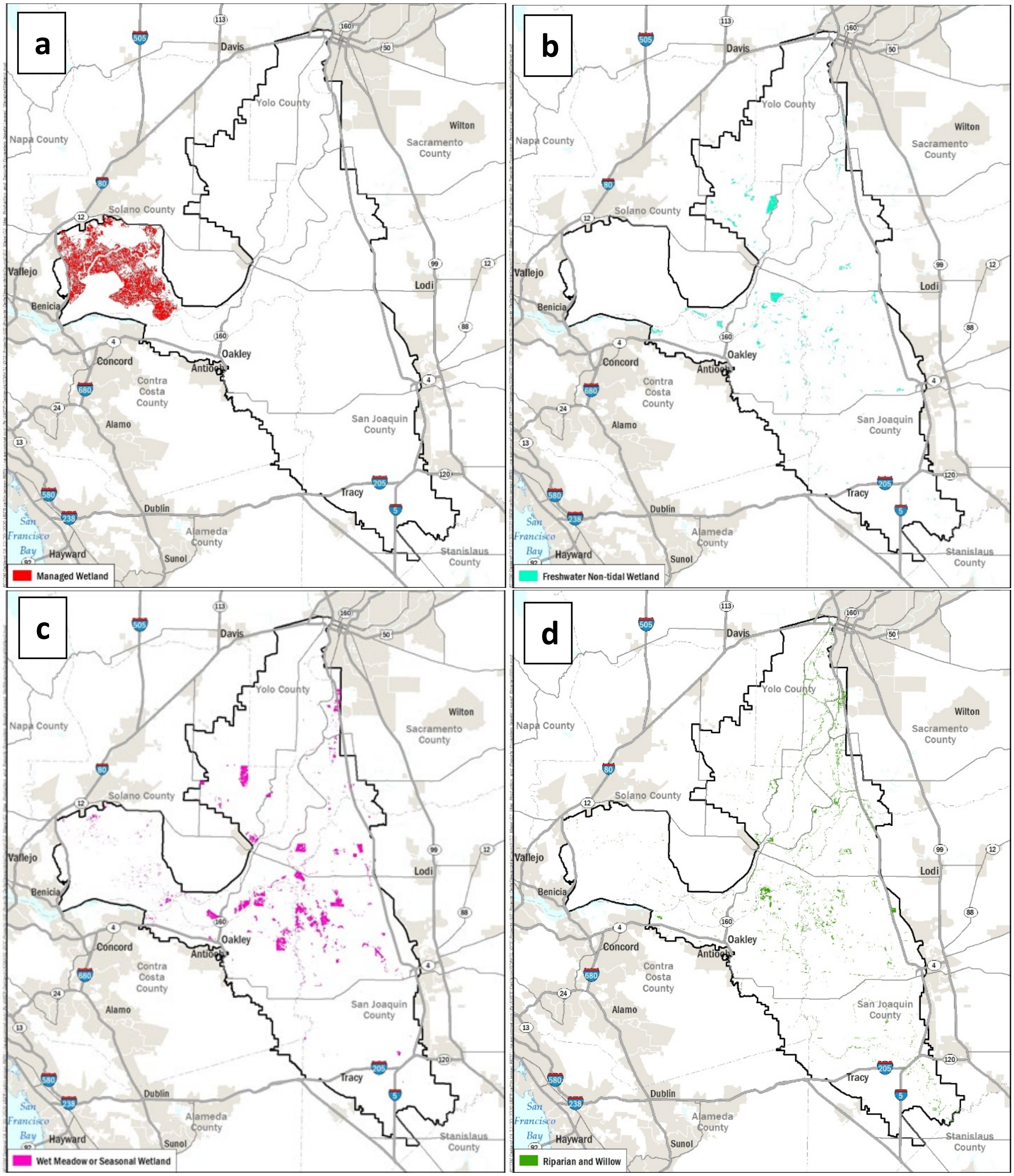

Figure 2 a-d. Existing leveed ecosystems in the legal Delta and Suisun Marsh. Panel is comprised four maps: managed wetlands (a), freshwater non-tidal wetland (b), wet meadow or seasonal wetland (c), and riparian and willow (d).

For the purposes of this assessment, vulnerability can be simply described as:

Vulnerability = Exposure + Sensitivity – Adaptive Capacity

More detailed explanations of these variables, in relation to climate vulnerability ecosystem assessments, are drawn from Dawson et al. (2011) and are provided below.

Vulnerability "is the extent to which a species or population is threatened with decline, reduced fitness, genetic loss, or extinction owing to climate change."

Exposure "refers to the extent of climate change likely to be experienced by a species or locale.

Exposure depends on the rate and magnitude of climate change (temperature, precipitation, sea level rise, flood frequency, and other hazards) in habitats and regions occupied by the species."

Sensitivity "is the degree to which the survival, persistence, fitness, performance, or regeneration of a species or population is dependent on the prevailing climate, particularly on climate variables that are likely to undergo change in the near future. More sensitive species are likely to show greater reductions in survival or fecundity with smaller changes to climate variables. Sensitivity depends on a variety of factors, including ecophysiology, life history, and microhabitat preferences. These can be assessed by empirical, observational, and modeling studies."

Adaptive capacity "refers to the capacity of a species or constituent populations to cope with climate change by persisting in situ, by shifting to more suitable local microhabitats, or by migrating to more suitable regions. Adaptive capacity depends on a variety of intrinsic factors, including phenotypic plasticity, genetic diversity, evolutionary rates, life history traits, and dispersal and colonization ability. Like sensitivity, these can be assessed by empirical, observational, and modeling studies."

For the purpose of this assessment, adaptive capacity is further defined as a two-part component—the first being the inherent and natural adaptive capacity of the species or habitat without human intervention (Dawson et al. 2011), and the second being the policy adaptive capacity, which refers to existing resource management of the natural system by humans.

Climate Drivers

For the primary climate drivers air temperature and local precipitation, we applied downscaled global climate models (GCMs) to obtain projections of climate change into the future for the greater Delta and Suisun Marsh area and then qualitatively applied those findings to understand the vulnerability of ecosystems assets. For SLR, ecosystem asset exposure was quantitatively evaluated using geographic information, digital elevation models, and flood hazard models to depict whether the ecosystem types will be inundated or not under the various modeling scenarios.

Sensitivity was determined by review and analysis of geographic exposure and expert knowledge. Methodology for each primary climate driver differs slightly and is described further below in this memorandum.

For the secondary climate drivers – vulnerability was assessed differently for each stressor/hazard. Changes in wind that are projected for the Delta region was assessed using peer-reviewed literature to qualitatively assign vulnerability to ecosystem assets, whereas drought and water temperature are related to changes in local precipitation patterns and air temperature, and thus were discussed in the vulnerability rankings for each ecosystem asset in Section 4.2.

1.1 Ecosystem Assets

The Vegetation Classification and Mapping Program (VegCAMP) for the Delta, Suisun Marsh, and the Vegetation and Land Use Classification and Map Update of the Sacramento-San Joaquin River report (Kreb et al. 2019) were used to delineate the different ecosystems considered in the study. The vegetation communities in VegCamp were assigned to the ecosystems identified in the report 'A Delta Transformed' (SFEI-ASC 2014; Table 2). The ecosystem types 'Willow Thicket', 'Willow Riparian Scrub or Shrub', and 'Valley Foothill Riparian' were combined into a single type ('Riparian/Willow Ecosystems).

In the vulnerability analysis, ecosystem types were included that are not protected by levees ("un-leveed"; Figure 1):

- Freshwater Emergent Wetland,
- Brackish Emergent Wetland,
- Riparian/Willow Ecosystems, and
- Grasslands.

An additional four ecosystem types were included that are protected by levees ("leveed"; Figure 2):

- Non-tidal Freshwater Wetland,
- Managed Wetland, and
- Wet Meadow or Seasonal Wetland,
- Alkali Seasonal Wetland Complex,
- Agricultural areas that provide wildlife resources.

The effects of climate change on two additional, ecologically important ecosystem assets that are not identified by the VegCAMP data set are discussed in section 2.4: (1) Floodplains can contain different ecosystems but as a unit will be affected by climate change, and (2) cold-water pools in reservoirs lining the Central Valley are used to manage in-stream temperatures for salmon, sturgeon, and other fish species.

1.1.1 Asset Categories: Ecosystem Types

The Delta is a dynamic inland deltaic system located at the confluence of the Sacramento and San Joaquin Rivers. This region is situated on the North America's Pacific coast and experiences a Mediterranean climate that consists of hot, dry summers and cool, wet winters. It is located within the California Floristic Province—a biodiversity hotspot characterized by rare and endemic species. Since the mid 1800's there has been abundant anthropogenic modifications to the region that has altered the once thriving greater ecosystem to one that remains productive, yet is highly managed, has undergone significant land conversion, and has witnessed species declines and the influx of nonnative species (DSC 2019).

Table 2. Asset Categories: Ecosystem types

Habitat Type	Description
Water[X]	Tidal mainstem channel: Rivers, major creeks, or major sloughs forming Delta islands where water is understood to have ebb and flow in the channel at times of low river flow. These delineate the islands of the Delta. Fluvial mainstem channel: Rivers or major creeks with no influence of tides. Tidal low order channel: Dendritic tidal channels (i.e., dead-end channels terminating within wetlands) where tides ebb and flow within the channel at times of low river flow. Fluvial low order channel: Distributaries, overflow channels, side channels, swales. No influence of tides. These occupy non-tidal flood-plain environments or upland alluvial fans. Freshwater pond or lake: Permanently flooded depressions, largely devoid of emergent Palustrine vegetation. These occupy the lowest-elevation positions within wetlands. Freshwater intermittent pond or lake: Seasonally or temporarily flooded depressions, largely devoid of emergent Palustrine vegetation. These are most frequently found in vernal pool complexes at the Delta margins and in the non-tidal floodplain environments.
Emergent Wetlands[*^]	*Tidal freshwater emergent wetland*: Perennially wet, high water table, dominated by emergent vegetation. Woody vegetation (e.g., willows) may be a significant component for some areas, particularly the western-central Delta. Wetted or inundated by spring tides at low river stages (approximating high tide levels). *Non-tidal freshwater emergent wetland*: Temporarily to permanently flooded, permanently saturated, freshwater non-tidal wetlands dominated by emergent vegetation. In the Delta, occupy upstream floodplain positions above tidal influence. *Tidal brackish emergent wetland*: Intertidal emergent wetland at the confluence of fresh and saltwater dominated by grasses, forbs, and shrubs and tolerant to moderate salinities.
Willow Thicket [*^]	Perennially wet, dominated by woody vegetation (e.g., willows). Emergent vegetation may be a significant component. Generally located

Habitat Type	Description
	at the “sinks” of major creeks or rivers as they exit alluvial fans into the valley floor.
Willow Riparian Scrub or Shrub *^	Riparian vegetation dominated by woody scrub or shrubs with few to no tall trees. This habitat type generally occupies long, relatively narrow corridors of lower natural levees along rivers and streams.
Valley Foothill Riparian *^	Mature riparian forest usually associated with a dense understory and mixed canopy, including sycamore, oaks, willows, and other trees. Historically occupied the supratidal natural levees of larger rivers that were occasionally flooded.
Wet Meadow or Seasonal Wetland^	Temporarily or seasonally flooded, herbaceous communities characterized by poorly drained, clay-rich soils. These often comprise the upland edge of perennial wetlands.
Vernal Pool ComplexX	Areas of seasonally flooded depressions characterized by a relatively impermeable subsurface soil layer and distinctive vernal pool flora. These often comprise the upland edge of perennial wetlands.
Alkali Seasonal Wetland Complex^	Temporarily or seasonally flooded, herbaceous or scrub communities characterized by poorly drained, clay-rich soils with a high residual salt content. These often comprise the upland edge of perennial wetlands.
Stabilized Interior Dune VegetationX	Vegetation dominated by shrub species with some locations also supporting live oaks on the more stabilized dunes with more well-developed soil profiles.
Grassland*^	Low herbaceous communities occupying well-drained soils and composed of native forbs and annual and perennial grasses and usually devoid of trees. Few to no vernal pools present.
Wildlife-associated Agriculture^	Cultivated lands that were identified in the literature to be associated with wildlife species and include the following crop types: Alfalfa and Alfalfa Mixtures; Corn, Sorghum and Sudan; Idle; Miscellaneous Field Crops; Miscellaneous Grain and Hay; Miscellaneous Grasses; Miscellaneous Truck Crops; Mixed Pasture; Potatoes and Sweet Potatoes; Rice; Safflower; Sunflowers; Tomatoes; Wheat; Wild Rice
Managed Wetland^	Areas that are intentionally flooded and managed during specific seasonal periods, often for recreational uses such as duck clubs.
Urban/BarrenX	Developed, built-up land often classified as urban, barren or developed. Includes rock riprap bordering channels.

[1] Derived from SFEI’s A Delta Transformed (SFEI-ASC 2014)

* Effects of gradual sea level rise for areas not protected by levees were analyzed

^ Effects of episodic sea level rise for areas protected by levees were analyzed
[x] Not analyzed as part of this effort

1.2 Assessing Vulnerability

Ecosystem vulnerability to climate change is a function of exposure, sensitivity, and adaptive capacity of an ecosystem to the effects of climate change. The following section explain how these three aspects were assessed for the climate drivers air temperature, local precipitation, and SLR.

1.2.1 Exposure

The exposure analysis evaluates an asset's susceptibility to climate variables. In this assessment, all ecosystems were assessed for susceptibility to each climate variable independently. The exposure analysis identifies the ecosystem asset (e.g. Tidal Freshwater Emergent Wetland or Grasslands) with exposure to projected changes in climate variables – air temperature, local precipitation, and sea-level rise.

1.2.1.1 Air Temperature and Local Precipitation

For air temperature and precipitation, the climate variables that relate to direct atmospheric conditions, exposure is more difficult to quantify due to the degree of detail and uncertainty in the downscaled models. Therefore, these climate stressors were assessed at a project-wide level using downscaled data specific to the Delta and Suisun Marsh project area. More fine-scale analyses to show local variations in air temperature and precipitation changes are presented in Section 1.4 and Section 1.5 for the project area.

1.2.1.2 Sea Level Rise

To understand the exposure of ecosystem assets to SLR, digital elevation data, average daily water levels, and peak water levels at multiple locations were generated under different SLR scenarios. Spatially explicit modeling was conducted to explore where the different ecosystems will be exposed to SLR in future scenarios. Using a geographic information system (GIS) layer of hydrologically connected areas, the ecosystems in Table 2 were subset into un-leveed (hydrologically connected to tidal or riverine flow) and leveed (hydrologically disconnected from tidal or riverine flow) categories (Figure 3) and analyzed separately.

Exposure was rated based on the percent of acres of a particular ecosystem type at risk from flooding. The rating of unleveed ecosystems was based on a deterministic scenario where the sea level is projected to increase by 3.5 ft by the end of the century. The rating of leveed ecosystems was based on a probabilistic scenario, where a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period) is projected by the end of the century. Assets with 1-33% at risk were given an exposure score of 1 (low); 33-66% were given a score of 2 (moderate); and 66-100% were given a score of 3 (high).

For tidal freshwater and brackish wetlands, the Wetland Accretion Rate Model of Ecosystem

Figure 3. Un-leveed ecosystems are connected to water (Panel A); Leveed ecosystems are disconnected from water (Panel B). (Images from California Department of Water Resources)

Resilience (WARMER, Swanson et al. 2015) was used to determine exposure. This quantitative framework is detailed in Section 1.6.2, and allowed for comparing various scenarios to determine exposure. Because this model takes accretion into account, it includes some measure of sensitivity; thus, for tidal freshwater and brackish wetlands, the same score was given for exposure and sensitivity.

1.2.2 Sensitivity

For this assessment, sensitivity factors were selected based on primary ecosystem functions of the ecosystem types outlined in Section 1.1.1. Sensitivity was qualitatively assessed for each asset based on the natural history of each ecosystem type, associated fish and wildlife species, and foundational physical processes according to the expert knowledge of scientists familiar with Delta ecology and peer-reviewed literature (see Chapter 2 Results, Table 12).

To determine ecosystem sensitivity, each was assessed under three subcomponents:

- Dominant Vegetative Communities: These are the dominant plant species that are known to occur in a given ecosystem type.
- Fish and Wildlife Species: These are the associated animal species known to occur in and be dependent on a specific ecosystem type.
- Physical Processes: These are the physical processes that support primary habitat functioning such as soil moisture content, evapotranspiration, sedimentation/accretion, water quality, tidal exchange, and related factors.

Each ecosystem subcomponent was assessed and scored on a scale of 1-3 for sensitivity to air temperature, local precipitation, and sea-level rise. The scores were then summed into a total sensitivity score for that ecosystem type. Total scores were categorized using the following impact scale (Table 3). Ecosystem types that scored a moderate or high score were further assessed for their exposure and adaptive capacity. As an ecosystem's natural adaptive capacity is inherently tied to its sensitivity to a particular climate stressor, its natural adaptive capacity is included in this sensitivity assessment. Secondary climate stressors (wind and water temperature) were not included in the sensitivity matrix.

For SLR, sensitivity of un-leveed ecosystems was qualitatively assessed based on expert knowledge of the effects of flooding on the ecosystems.

Table 3. Asset sensitivity scale to climate variables and secondary impacts

Asset Category	**None -** *No impact to asset function*	**Low -** *Asset still functional*	**Medium -** *Asset function compromised*	**High -** *Asset no longer functional*
Ecosystems	Negligible or no change to ecosystem function	Short term, minor but reversible interruption to ecosystem function	Significant but not permanent loss of ecosystem function	Widespread and permanent loss of ecosystem function

1.2.3 Adaptive Capacity

For natural systems, adaptive capacity can be divided into natural adaptive capacity – the inherent ability or resiliency of a particular habitat to respond to climate changes, and institutional adaptive capacity – which includes policies and management measures already in place to protect that habitat. The sensitivity analysis considered each ecosystem asset's inherent ability to adjust to changes in temperature, local precipitation and SLR in order to maintain its ecosystem function.

Institutional adaptive capacity was assessed qualitatively based on a set of considerations unique to each asset category and was assessed based on the natural history of each habitat type, using the expert knowledge of Delta scientists. For the preexisting policies and natural resource management components of adaptive capacity, professional opinions of Delta Stewardship Council staff and the project Technical Advisory Committee were included.

1.2.4 Vulnerability

The vulnerability of ecosystem types to air temperature and local precipitation is calculated based on the scoring used in the sensitivity analysis. This approach takes exposure and inherent adaptative capacity into consideration. Scores are based on a 1-3 scale for each subcomponent (vegetative communities, fish and wildlife, and physical properties), resulting in overall vulnerability scores ranging from 3-9.

Ecosystems with low vulnerability to air temperature or local precipitation received scores of 3 (since these two stressors are not binary and all ecosystem types will be exposed to some degree of warming or variation in precipitation, thus no scores of 0 were possible), moderate vulnerability received scores of 4-6, and high vulnerability received scores of 7-9.

To arrive at SLR vulnerability scores, low, moderate, and high exposure, sensitivity, and adaptive capacity ratings were translated into scores of 1, 2, and 3, respectively.

The vulnerability score was then calculated using this formula:

Vulnerability = Exposure + Sensitivity – Adaptive Capacity

This could result in vulnerability scores ranging from -1 to 5.

Low vulnerability was assigned to scores of -1 to 1, moderate vulnerability was assigned to a score of 2-3, and high vulnerability was assigned to scores of 4-5.

1.3 Finer Scale Vulnerability

In addition to analyzing the overall vulnerability of each climate variable independently, and with respect to annual changes throughout the century, a finer level of detail was applied to the primary climate stressors to assess spatial and temporal variability. SLR was assessed according to spatial variability within the Delta, whereas air temperature and local precipitation were assessed in terms of temporal variability (seasonality) throughout the year. Temperature and local precipitation were not assessed for spatial variability due to the negligible differences obtained during preliminary analyses. Both spatial and temporal variability are described in more detail below.

1.3.1 Spatial Variability – Delta Regions

Within the Delta, considerable spatial differences exist between its regions. For SLR analyses, the Delta was delineated into five regions by grouping conservation units (Blue Ribbon Taskforce 2008). The five regions of the project area (Figure 4) are outlined below.

1. Cache-Yolo: Cache Slough, Yolo Bypass
2. North Delta Region: Netherlands, East Side (North), Sutter Island, Prospect Island, Mokelumne/Cosumnes Corridor.
3. Central Delta Region: Deep Delta, Deepest Delta, East Side (South), Dutch Slough, Southwest Delta, Stockton, Southwest Delta Cities, Western Delta Islands
4. South Delta Region: South Delta
5. Suisun Marsh Region: Suisun Marsh

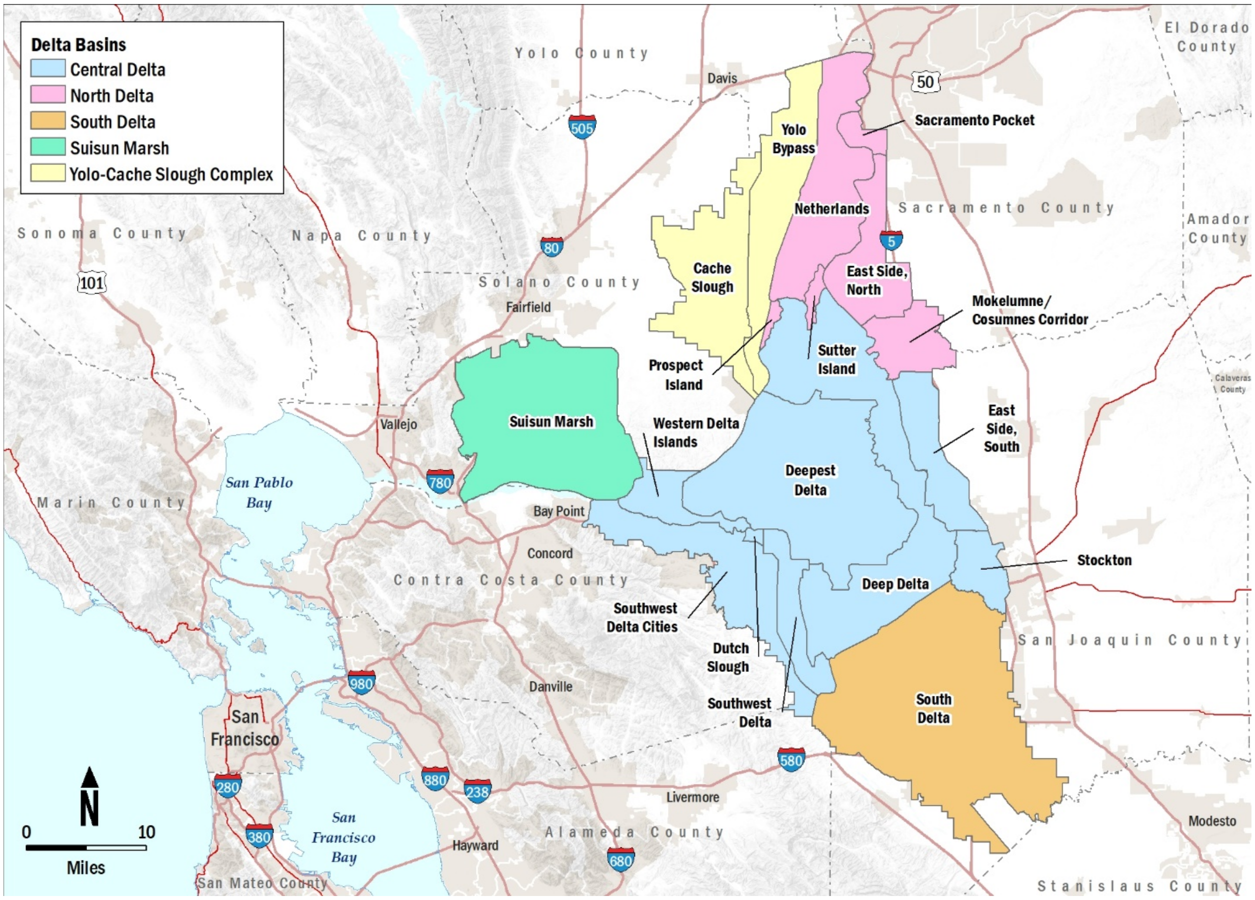

Figure 4. The Delta Project Area is separated into five regions – Cache-Yolo, North Delta, Central Delta, South Delta, and Suisun Marsh. The subregions are the original conservation units used to develop the regions.

1.3.2 Temporal Variability – Seasonality

Given the Delta's Mediterranean climate, temporal variability was considered in order to understand the sensitivity of habitats to climate change by season. Seasonality plays a key role in determining key ecosystem processes such as reproduction, growth, and survival of organisms (phenology). Seasonal data were used to analyze shifts in temperature and precipitation regimes, and to compare projected changes between seasons.

Seasonal data for temperature and precipitation were divided into the seasons as follows:

1. Winter: December, January, February
2. Spring: March, April, May
3. Summer: June, July, August
4. Fall: September, October, November

1.4 Air Temperature

1.4.1 Data Sources

Historical and projected air temperature and precipitation data for the Delta and Suisun Marsh were obtained from Cal-Adapt[1]. The data were derived from CMIP5 global climate models (GCMs) downscaled using the Localized Constructed Analogues (LOCA), a statistical method which is highly-resolved in both space (1/16° grid, ca. 3.7 miles × 3.7 miles) and time (daily resolution) (Cal-Adapt; Pierce et al. 2018).

For this assessment, 10 out of 32 GCMs[2] identified by California's Climate Action Team Research Working Group were averaged to obtain one output per variable of interest for the analysis of projected temperature and precipitation changes in the Delta (Cal-Adapt). Models were averaged together to acquire an output more likely than any one individual model, however, individual model values yield a more accurate depiction of the range of possible temperature and precipitation outcomes for the future. Out of the 10 models, the maximum and minimum values were used to present the range of temperature and precipitation possibilities surrounding the average output. All averaged values were then used to differentiate changes from historical conditions. Modeled historical values (based upon observed values) were subtracted from the modeled temperature and precipitation projections to demonstrate absolute changes for the remainder of the century from a historical baseline.

The data were divided into 30-year periods and include:

1. Modelled historical: 1961 – 1990,
2. Mid-Century: 2035 – 2064, and
3. Late-Century: 2070 – 2099

Projection scenarios, or representative concentration pathways (RCPs) were also denoted. RCPs encapsulate different climate futures depending on greenhouse gas and aerosol emission scenarios in years to come. Two RCP scenarios were applied for this analysis (1) RCP 4.5: where emissions peak around 2040, then decline, and (2) RCP 8.5: the "business as usual scenario" where emissions continue to rise strongly through 2050 and plateau around 2100 (Cal-Adapt).

[1] Cal-Adapt was developed to provide an interactive geospatial tool for localized climate projections in California. The tool allows users to explore projected changes in temperature, extreme heat, precipitation, snowpack, wildfire, and sea level rise across the state, based on a variety of climate models and future emission scenarios. Cal-Adapt 2.0 includes high-resolution, local climate projections, using LOCA downscaling methods and emission scenarios that align with the Intergovernmental Panel on Climate Change's Fifth Assessment Report.

[2] List of 10 GCMs designated by California's Climate Action Team for performance in California and four of which were designated as priority models*: HadGEM2-ES * (Warm/Drier); CNRM-CM5 * (Cooler/Wetter); CanESM2 * (Average); MIROC5 * (Complement); ACCESS1-0; CCSM4; CESM1-BGC; CMCC-CMS; GFDL-CM3; and HadGEM2-CC

1.4.2 Average Annual Temperature

Average annual temperature in the Delta was evaluated to understand how thermal changes (namely thermal stress) may gradually impact the vulnerability of ecosystem assets over time. Maximum average annual air temperatures were obtained from Cal-Adapt to more accurately portray the range of model outputs. Results were compared to modeled historical data to understand maximum temperature changes under each scenario (RCP 4.5 and 8.5) into the future.

1.4.3 Seasonal Temperature

Seasonal temperature was addressed in the same manner as Section 3.4.1 to understand how projected changes (by scenario and time period) may impact the sensitivity of vegetative communities, fish and wildlife species, and physical processes, all of which are dependent on certain thermal ranges throughout the year in order to function properly and persist into the future.

1.4.4 Literature Review

According to the literature, average daily, and thus annual temperatures, will increase over the century – the severity of these increases are directly correlated to the global emission scenario that unfolds. Some literature suggests that the *difference* between daily minimum and maximum temperatures in coastal California may actually decrease over the century with minima temperatures increasing at faster rates than maxima. Extreme heat days and events will become more extreme when compared to historical baseline data – these extreme events will also occur with more frequency and for longer durations in the coming century (Dettinger et al. 2016; DSC Climate Change: A synthesis, 2018; DSC Ecosystem Tech Memo, 2019; Lebassi et al. 2009).

Air temperature in the Delta and Suisun Marsh was assessed as follows:

1. Average annual air temperature (stressor): average maximum daily temperatures as a proxy for average annual temperature changes within the Delta throughout the century.
2. Annual averages (stressor comparison): average maximum daily temperatures as a proxy for average annual temperature changes in the Delta project area compared to those in California's Central Valley.
3. Seasonal averages (stressor): average maximum daily temperatures as a proxy for seasonal changes per year to better understand impacts on a finer scale to both organisms and ecosystem-wide.
4. Extreme heat (climate hazard).

1.5 Local Precipitation

1.5.1 Data Sources

Data for precipitation projections were obtained and analyzed using the same methods as air temperature described in detail within Section 3.4.1.

1.5.2 Average Annual Precipitation

Average annual precipitation was assessed to understand how local rainfall changes (climate stressor) may gradually affect the vulnerability of an ecosystem asset over time. Average annual precipitation data were adopted from Cal-Adapt to more accurately portray the range of model outputs and were calculated for the entire Delta and Suisun Marsh Region.

1.5.3 Seasonal Precipitation

Seasonal precipitation data were obtained to better understand potential changes in phenology – the timing of recurring natural events (e.g. flowering, or bird migrations) in relation to seasonal climatic changes, and/or shifts within ecosystem assets due to shifts in precipitation regime. The data were calculated in the same manner as described in Section 3.4.1.

1.5.4 Extreme Hydrological Events: Precipitation and Drought

For extreme hydrological events, climate vulnerability to ecosystems includes a high-level discussion based on literature review, with no detailed data analysis.

1.5.5 Literature Review

Unlike temperature where there is greater consensus that a warming trend is occurring in all climate scenarios, projections for precipitation are less certain (He et al. 2018). Local precipitation projections for the Delta show high inter-annual variability with seasonal shifts (Houlton et al. 2018). In general, models project an increase in winter precipitation with declines in spring and fall precipitation. By mid-century many models show a reduction in the number of days when it will rain but the intensity of storms will increase (e.g., increase in atmospheric river events). With increasing temperatures, dry years will become drier and wet years wetter, and droughts and floods will increase in magnitude and frequency (Dettinger et al. 2016; DSC Climate Change: A synthesis, 2018).

Precipitation was assessed as follows:

1. Average annual local precipitation changes (stressor): Delta regional annual precipitation showing change from historical baseline and projected changes in average annual precipitation for the Delta and Suisun Marsh.

2. Seasonal averages (stressor): Projected average seasonal precipitation changes to better understand potential phenological impacts to ecosystem types due to altered precipitation regimes): by Subregion (Suisun Marsh preliminary example
3. Extreme precipitation and drought (hazard).

1.6 Sea Level Rise

1.6.1 Scenarios

For the exposure analysis of leveed ecosystems, probabilistic flood maps developed for the Flood Hazard Analysis were used to determine areas exposed to flooding. Scenarios include low, medium, high, and very high probability of flooding in 2030, 2050, and 2085 respectively (see Flood Hazard Technical Memo for full details).

Tidal wetland SLR modeling requires specific timeframes. Therefore, for the exposure analysis of un-leveed ecosystems, the deterministic SLR scenarios selected for the flood hazard analysis were used and each scenario was associated with a specific year. In addition, a more extreme scenario (6 feet SLR by 2100) was explored to assess the exposure of un-leveed ecosystem assets to more severe climate change (Table 4).

Table 4. Summary of deterministic SLR scenarios for flood hazard mapping adapted for ecosystem assets

Mapping Scenario	Planning Horizon	Sea Level Rise	Watershed Hydrology	Storm Event
M-2	2050	12”	Mid-century (2035-2064) RCP 8.5	100-year water level
M-3	2050	24”	Mid-century (2035-2064) RCP 8.5	100-year water level
M-4	2050+ (2085 for tidal wetlands modeling	42”	End-of-century (2070-2099) RCP 8.5	100-year water level
M-5 (Un-leveed areas)	2100	72”	End-of-century (2070-2099) RCP 8.5	100-year water level

1.6.2 SLR Exposure Analysis Methods

Generally, SLR is expected to have a more gradual effect on un-leveed ecosystems, and an acute effect on leveed ecosystems as a result of levee overtopping during episodic high-water events described in the Flood Hazard section. See Figure 5 for a detailed account of the exposure modeling workflow.

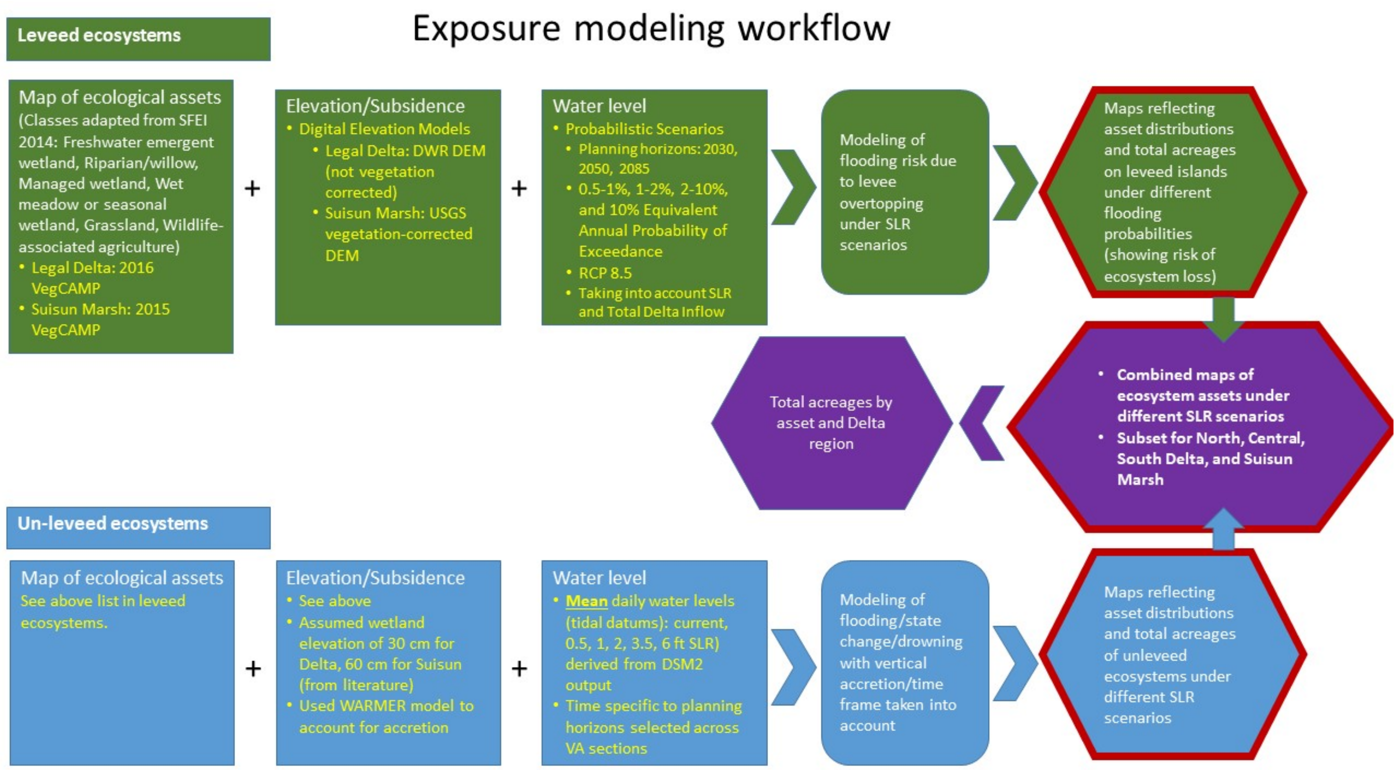

Figure 5. Exposure modeling workflow. Exposure modeling workflow

1.6.2.1 *Un-leveed Ecosystems*

Tidal Datums

Using the Delta Simulation Model II (DSM2, see Flood Hazard Technical Memo for full details), tidal datums were generated at 430 nodes located throughout the Delta with 1, 2, 3, 4, 5, and 6 feet of SLR (deterministic scenarios). The 3.5-foot scenario was generated using the mean of the corresponding whole numbers. DSM2 nodes were associated with the nearest corresponding ecosystem patches for un-leveed ecosystems, as described below.

Un-leveed Tidal Wetlands

Tidal wetlands have intrinsic feedback processes, driven by mineral sediment accretion and organic matter production that are able to maintain wetland surface elevations under moderate rates of SLR (Swanson et al. 2015; Schile et al. 2014). To assess the potential impact of SLR on wetland persistence, mechanistic models are used to predict wetland surface elevations under different SLR scenarios over time. Recent efforts have expanded field-based observations of accretion rates and organic matter production by tidal wetland plant species in wetlands on Prospect Island in the North Delta, Browns Island in the Central Delta, and Rush Ranch in Suisun Marsh (Buffington et al. in prep). To determine the potential for tidal wetland persistence in the Delta and Suisun Marsh under the different SLR scenarios (see above), a team from the USGS used these data to parameterize the WARMER marsh accretion model

(Swanson et al. 2015, Buffington et al. in prep). This model incorporates mineral sediment accretion (based on soil core data), organic matter accretion (based on marsh plant productivity curves characteristic of different salinity regimes), and feedbacks between sea level and plant productivity to model marsh surface over time. Full documentation of the WARMER model parameterizations used for this project will be available in Buffington et al. (in prep). The model update builds on the previous WARMER model by incorporating organic productivity data for a range of regionally specific plant species related to salinity level, propagating parameter uncertainty into projections of marsh elevation with accelerating SLR, and including rates of mineral sediment accretion derived from soil cores.

Tidal freshwater and brackish wetland vegetation is dense, causing LIDAR-derived DEMs to reflect wetland surface elevations inaccurately unless they have been corrected (Buffington et al. 2017, Schile et al. 2015). A corrected DEM exists for Suisun Marsh, but not for the entire Delta. Because tidal wetlands occupy the elevation range between mean lower low water and mean high water, Swanson et al. (2015), who modeled marsh surface elevations under changing sea levels, used 20 centimeters (cm), 30 cm, and 40 cm above mean sea level (MSL) as current wetland elevations. Using the median scenario in Swanson et al. (2015), in the landscape-scale analysis presented here 30 cm above MSL was used as the starting elevation of mid/high marshes in the Delta. 20 cm and 40 cm starting elevations were also analyzed, but did not change outcomes. All wetland surfaces below MSL were classified as low marsh. Similarly to the starting elevation sensitivity analysis, a different cut-off point for low marshes was tested (-10cm below MSL for the Delta and MSL for Suisun Marsh), but did not result in different results.

The starting elevation value for Suisun Marsh (60 cm) was derived by calculating the mean of the tidal marsh elevations of 10x10m grid cells of tidal marsh identified using the vegetation-corrected DEM (Buffington et al. 2019). For each of the five Delta regions, the means of the tidal datum values were calculated (mean lower low water [MLLW], mean low water [MLW], MSL, mean high water [MHW], mean higher high water [MHHW]) predicted under the selected SLR scenarios (Table 4) by the DSM2 model, and then the WARMER model was run for the selected SLR scenarios to produce annual marsh surface elevations. Marsh surface elevations were classified into mid/high marsh (above MSL), low marsh (below MSL) and drowned (below MLLW). Transitions from mid/high marsh to low marsh indicate a decrease in ecosystem quality and function, while drowned marshes no longer provide the benefits of tidal marsh ecosystems. Both transitions to low marsh and marsh drowning were considered as a part of wetland SLR exposure.

The WARMER model output was applied to the tidal marshes in the different Delta regions. Rush Ranch parameters were used for Suisun Marsh, Browns Island parameters for the Central and South Delta, and Prospect Island parameters for the North Delta and Cache Slough/Yolo Bypass complex. To extract tidal marsh polygons, wetland ecosystems were clipped from VegCamp to Delta waterways in each of the five Delta regions. The layers for the Cache-Yolo region include freshwater wetlands that are inundated when the Yolo Bypass floods. While these patches are not currently tidal, they are connected to the system’s hydrology in a way that leveed ecosystems are not and are likely to become tidal as sea level rises, thus they were included in the un-leveed exposure analysis.

There is high uncertainty about the future of sediment availability in the Delta and Suisun Marsh, with evidence that sediment may increase (Stern et al. 2020) or decrease (Cloern et al. 2011) over the coming century. Therefore, a range of scenarios and their potential impacts on marsh resilience was explored. Across the Delta regions, three sediment scenarios (declining, constant, and increasing) were used to determine the sensitivity of marsh persistence to sediment availability. The constant scenario was modeled as 60% of the historical sediment supply, the declining scenario was modeled as a 1.6% annual reduction from the constant scenario, and the increasing scenario included 125% of the historical baseline to capture the potential for more sediment supply caused by increased precipitation as a result of climate change.

Compared to the analysis approaches used for other ecosystem assets, using the WARMER model to take into account changes in marsh surface elevation incorporates inherent adaptive capacity into the exposure analysis. Therefore, the 6 foot SLR scenario was used as a more extreme late-century scenario to calculate the exposure scores for these assets.

The modeling approach taken here, while helpful for landscape-scale planning, does not account for site-level variability in elevation and other conditions. The larger marshes studied in the Delta have been largely classified as high marsh (Schile et al. 2014, Swanson et al. 2015, Sloey et al. 2015, Sloey et al. 2016). Adding a low marsh starting point expands on the high marsh starting points from Swanson et al. 2015, but these results should still be considered with caution at the site level.

For additional caveats and considerations regarding this approach, please see Section 2.2.1.3.

Un-leveed Grasslands and Riparian/Willow Ecosystems

For each 2.5 x 2.5 m grid cell of un-leveed grassland and riparian/willow ecosystem, the elevation was determined using the 2019 DWR Delta Digital Elevation Model (DEM) and the U.S. Geological Survey (USGS) Suisun Marsh vegetation-corrected DEM (Buffington et al. 2019).

To determine local rates of SLR, all grassland and riparian/willow ecosystem grid cells were associated with the nearest DSM2 nodes. Based on general physiological tolerances of ecosystem assets, grassland persistence was determined by retaining grid cells with an elevation greater than the mean sea level (MSL) at the nearest DSM2 node under each SLR scenario. Riparian/willow ecosystem persistence was determined by retaining grid cells with an elevation greater than the mean low water level, to reflect the ability of riparian forest to be inundated (Stella et al. 2011). Under each SLR scenario, the size and number of grassland and riparian/willow ecosystem patches and the total area at risk of flooding of these two ecosystems were calculated.

1.6.2.2 Leveed Ecosystems

For leveed ecosystems, probabilistic flood maps developed for the Flood Hazard Analysis were used to determine areas exposed to flooding under different scenarios (see Figure 6 and Tables 43-45 in the Flood Hazard Technical Memorandum). For each ecosystem asset, VegCAMP layers were clipped to flood risk layers to determine the total acreage located on islands in the different Delta regions at risk of flooding under the different scenarios. Because most islands in the Delta are at or significantly below sea level, all ecosystems on islands predicted to flood are assumed at risk, regardless of their actual elevation. Operationally, more subsided islands are likely to be more difficult to recover in the event of flooding, so ecosystems at lower elevations may be at higher risk of being permanently lost, but that analysis is beyond the scope of this effort.

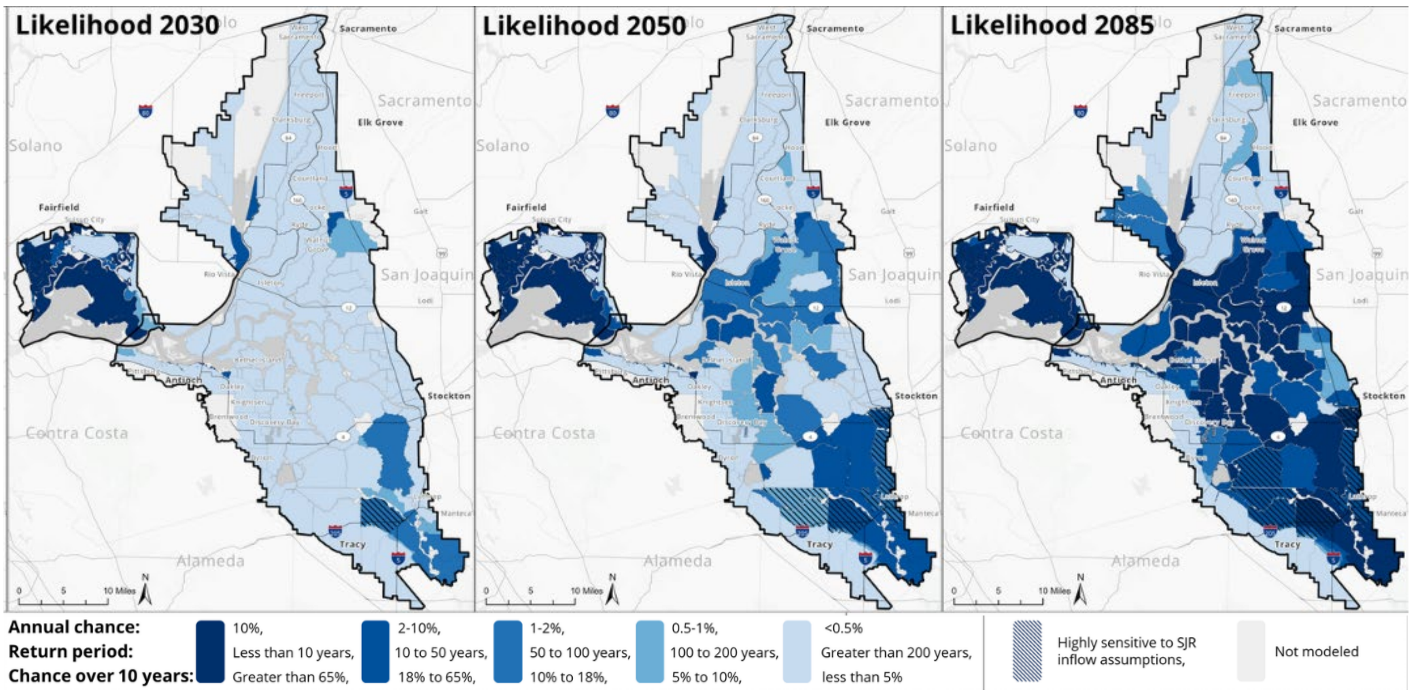

Figure 6. Probabilistic flood hazard maps developed for the Flood Hazard Analysis and used for the leveed ecosystem exposure analysis.

1.6.2.3 Accommodation Space

To explore the potential for un-leveed ecosystems to move upland in response to SLR, projected sea level elevations and current elevation distributions were mapped using data developed for the update to Chapter 4 of the Delta plan (DSC 2020, Siegel and Gillenwater 2020). These data were subset into elevation classes reflecting current elevations and the potential of a given area to support future tidal wetland habitats at its current elevation. Levels of SLR were subset into elevation classes for low SLR (+0 to 2.5 feet MHHW), mid-high SLR (+2.5 to 7 feet), and extreme SLR (+7 to 10 feet). These layers were mapped with tidal wetland layers to qualitatively assess where accommodation space exists adjacent to existing tidal wetlands.

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CHAPTER 2. RESULTS/DISCUSSION
(VA REPORT SEC. 5.3 ECOSYSTEM)

2.1 Exposure

2.1.1 Air Temperature

2.1.1.1 Average Annual Temperature: Climate Stressor

Modelled historical average annual maximum air temperature in the Delta and Suisun Marsh was approximately 73.8°F during the time period 1961-1990. Maximum daily air temperature changes from the historical baseline can be seen in the maps of projected change (Figure 7). These maps demonstrate that maximum air temperatures are likely to increase throughout the century regardless of the time period and emission scenario. The late-century, RCP 8.5 emission scenario shows the most dramatic increases.

Although maximum air temperatures are forecasted to rise across the Delta and Suisun Marsh, localized variations in these increases may be explained by topographic differences, proximity to the coast, cooler oceanic water input, onshore winds, and coastal fog (Lebassi et al. 2009; Dettinger et al. 2016; DSC 2018a). The Suisun Marsh is projected to remain cooler than the remainder of the Delta, consistent with present day conditions (Figure 7). The north Delta is expected to be cooler than the South Delta. Table 5 illustrates predicted warming within the Delta and Suisun Marsh for the time horizons and emission scenarios used in this report. These data suggest that in the Delta average annual maximum temperatures could warm as little as 3.2°F (mid-century, RCP 4.5) and as much as 9.6°F (late-century, RCP 8.5).

Within the broader Central Valley, the average annual maximum daily temperature by 2100 is forecasted to remain warmer than in the Delta and Suisun Marsh by approximately 2.0°F, though local variations in both regions will likely persist (Cal-Adapt). These temperature differences suggest that the Delta could be used as a location of suitable habitat by species forced out of the Central Valley to seek thermal refuge in the Delta where they could find similar landforms and ecosystems to support their growth and survival (Schmitz et al. 2015). According to the literature, and more comprehensive assessments of temperature changes throughout California, it is likely that the Delta could serve as a climate refugium with respect to surrounding areas due to cooling Delta breezes, availability of water, coastal fog, and other critical physical processes that may act to offset increasing temperatures (Lebassi et al. 2009).

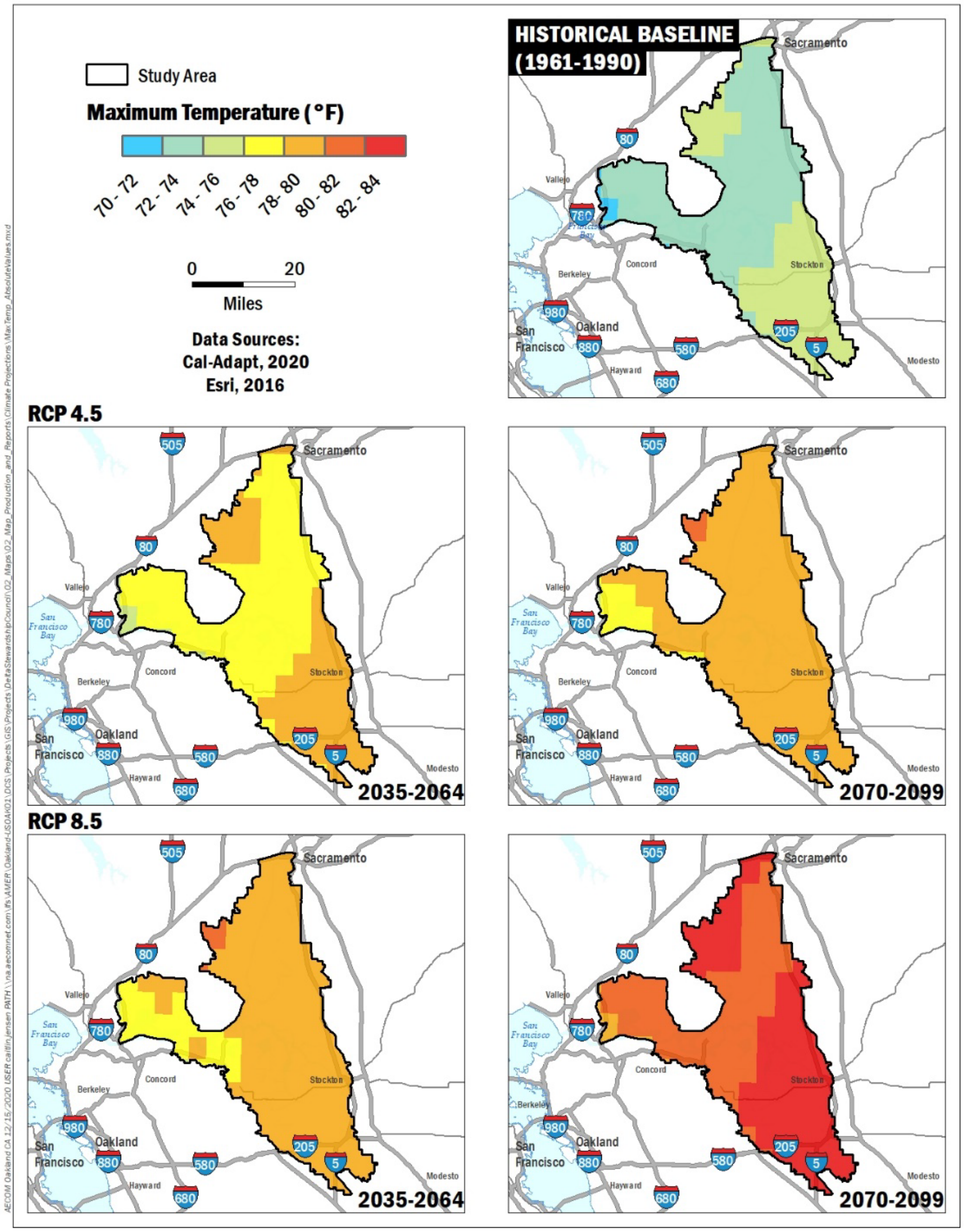


Figure 7. Spatial variability of projected changes in absolute average daily maximum temperature in the Delta.

Table 5. Projected changes in average annual maximum air temperatures for the Delta and Suisun Marsh presented as changes from the historical baseline

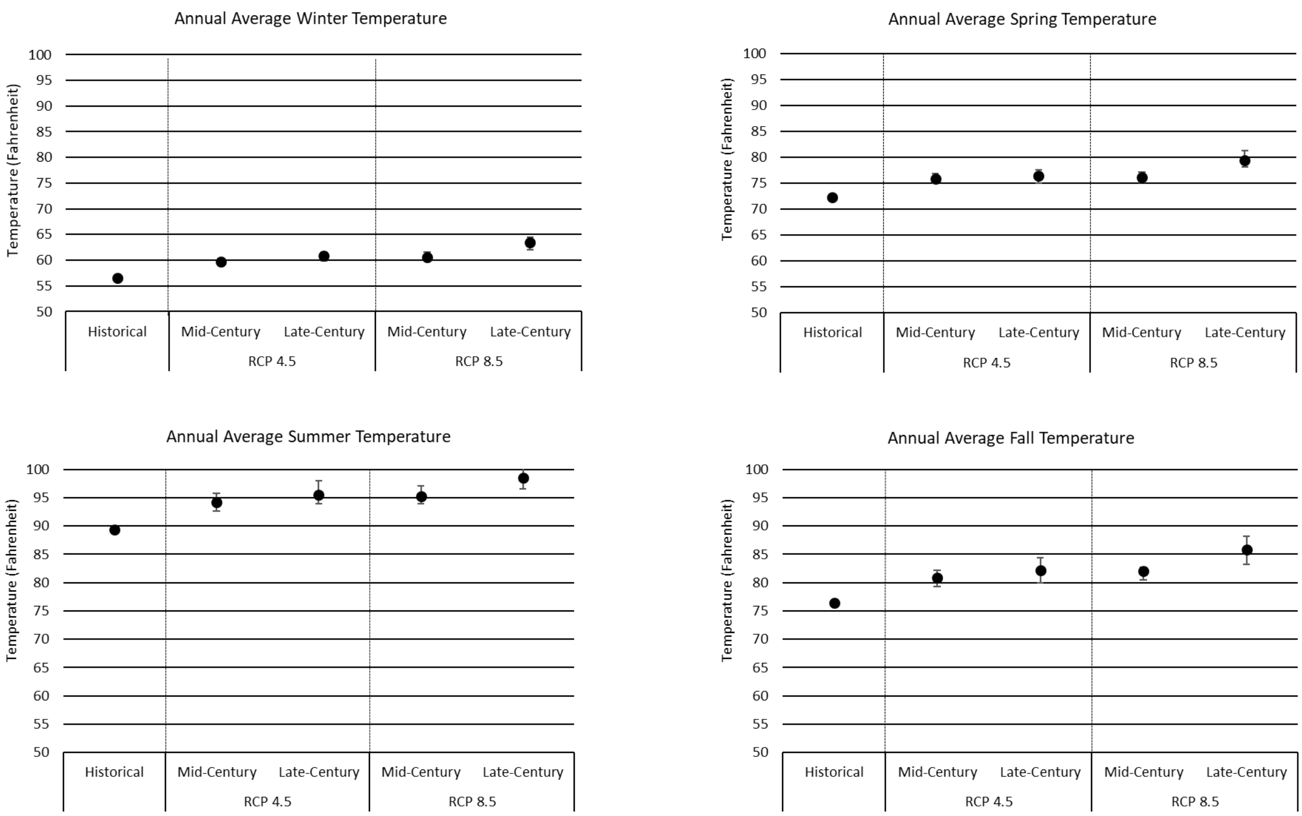
Emission Scenario	Time Horizon	Average Annual Maximum Temperature (°F) and Range (Min, Max)
Historical	Modelled Historical (1961-1990); Range (Min, Max)	73.8°F (70.7 – 77.4°F)
RCP 4.5	Mid-Century (2035-2064)	+3.9°F (+3.2°F to +4.8°F)
RCP 8.5	Mid-Century (2035-2064)	+4.9°F (+4.0°F to +5.8°F)
RCP 4.5	Late-Century (2070-2099)	+5.1°F (+3.6°F to +6.3°F)
RCP 8.5	Late-Century (2070-2099)	+8.1°F (+6.5°F to +9.6°F)

Notes:
°F = degrees Fahrenheit
RCP = Representative Concentration Pathway
Annual average values were calculated for each 30-year time period for 10 of the 32 Localized Constructed Analogs (LOCA) downscaled global climate models (GCMs) under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt for the Delta and Suisun Marsh.

2.1.1.2 Seasonal Temperature: Climate Stressor

In order to gain a better understanding of inter-annual maximum air temperature variability within the Delta, daily maximum air temperatures were averaged across seasons. The data suggest that summer and fall maximum air temperatures will increase at a greater rate than winter and spring temperatures. The range of possible temperature increases projected across all seasons span as low as 2.4°F under RCP 4.5, mid-century winter projections to as much as 12.0°F under RCP 8.5, late-century summer projections based off minimum and maximum outputs from the 10 models used for this analysis (Figure 8).

On average, across all 10 GCMs and both RCPs, air temperatures are expected to increase as follows and are presented as ranges based on the minimum and maximum outputs from the 10 models (Figure 8): winter (3.1 – 6.8°F), spring (3.6 – 7.2°F), summer (4.8 – 9.2°F), and fall (4.4 – 9.4°F).



Notes:

°F = degrees Fahrenheit

RCP = Representative Concentration Pathway

Average values were calculated for each 30-year time period for 10 of the 32 Localized Constructed Analogs (LOCA) downscaled global climate models (GCMs) under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt for the Delta and Suisun Marsh.

Figure 8. Projected Average Seasonal Air Temperatures from Historical Under RCP 4.5 and 8.5 Scenarios

Extreme Heat: Climate Hazard

Increasing average annual temperatures also impact extreme heat conditions. Extreme heat days are defined as temperatures that exceed the 98th percentile of observed historical temperatures for a particular location (Cal-Adapt). For much of the Delta, the 98th percentile for air temperature corresponds to days with temperatures over 100 degrees. Historical extreme heat conditions in the Delta average about 4 or 5 days per year and are projected to increase throughout the century (mid-century range of 17 to 24 days per year; late-century range of 22 to 41 days per year).

2.1.2 Local Precipitation

2.1.2.1 Average Annual Local Precipitation: Climate Stressor

Based on the GCMs selected for this analysis, average annual precipitation is projected to increase across the Delta with localized differences occurring due to topography and proximity to the coast (Figure 8). Average annual precipitation trends indicate that the north Delta and Suisun Marsh will receive more rainfall compared to the central and south Delta regions. These changes are most pronounced with the late-century, RCP 4.5 and RCP 8.5 emission scenarios with highest increases in rainfall projected for late-century, RCP 8.5. Central and south Delta regions are projected to experience little to no change in precipitation.

Projected average annual precipitation shows little variation between the climate emission scenarios (Figure 9). Historical average annual precipitation in the Delta was approximately 15.0 inches, whereas average annual projected precipitation ranges from 15.6 inches at the mid-century, RCP 4.5 emission scenario to 16.5 inches at the late-century, RCP 8.5 emission scenario. The emissions scenario did not appear to impact average annual precipitation, and the models used did not agree on a consistent trend during the next century (precipitation decreases and increases from annual average across the 10 models ranged from -2.3 – +4.7 inches in the mid-century, RCP 4.5 emission scenario to -2.7 – +4.5 inches in the late-century, RCP 8.5 emission scenario (Table 6). Projected precipitation trends are often the least certain aspects of climate models, as the downscaled models are not able to resolve many of the fine-scale and complex interactions that occur locally. Additionally, the Delta region presently experiences high interannual precipitation variability making it difficult to detect a strong signal in future precipitation projections when considering average annual local precipitation levels. Averaging across the 10 GCMs to obtain the average outputs smooths out the noise of individual models which show very diverse outcomes for precipitation into the future.

Despite these variable model outcomes within the Delta, there is agreement across models that overall precipitation in the Delta is likely to increase. By mid-century many models show a reduction in the number of days when it will rain but the intensity of storms will increase due to an increase in the frequency of large storm and atmospheric river events.

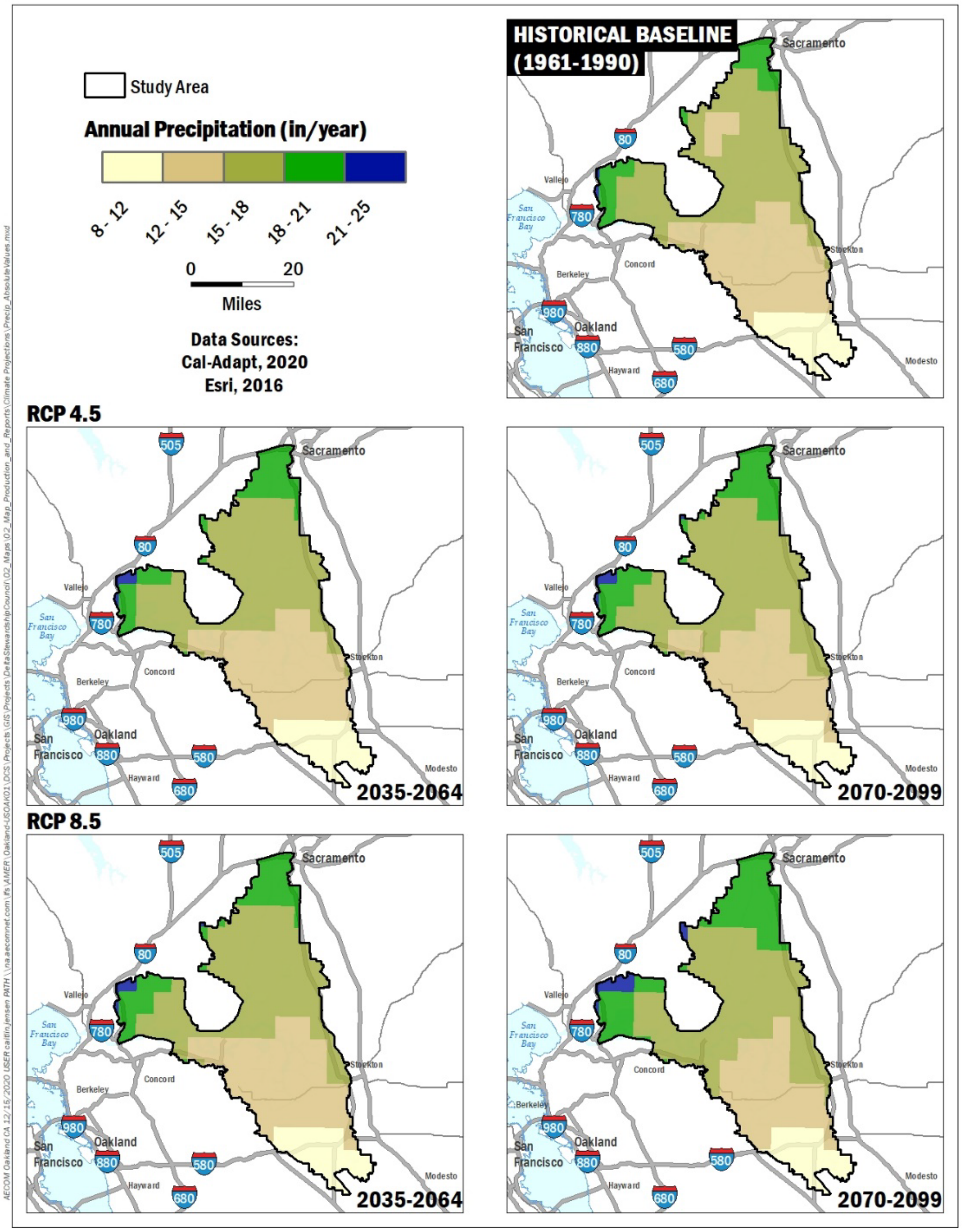


Figure 9. Spatial variability of projected changes in annual average precipitation in the Delta

Table 6. Projected Changes in Average Annual Precipitation for the Delta and Suisun Marsh

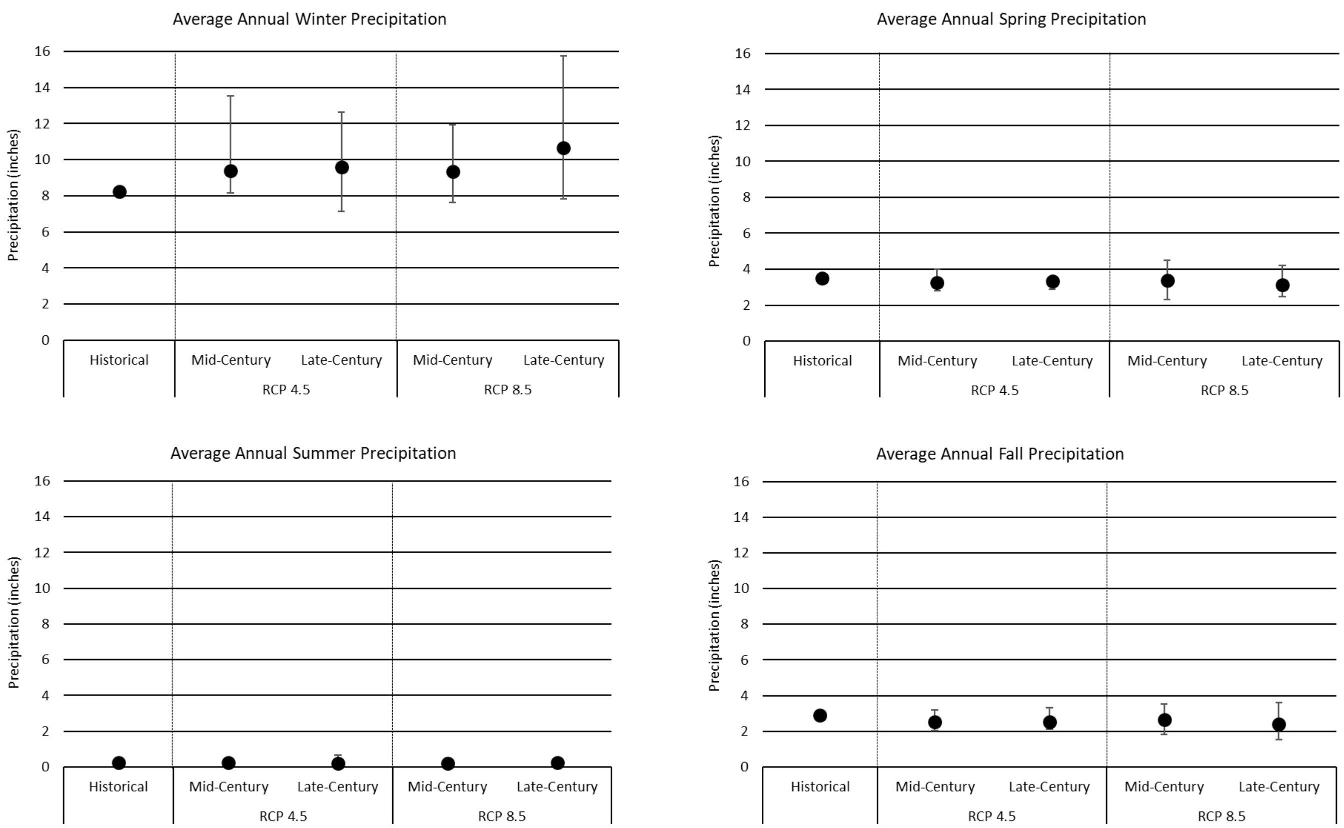
Emission Scenario	Time Horizon	Average Annual Precipitation Changes (in) and Range (Min,Max)
Historical	Modelled Historical (1961-1990)	15.0 inches (4.2 to 31.0 inches)
RCP 4.5	Mid-Century (2035-2064)	15.6 inches
RCP 4.5	Mid-Century Range (Min,Max)	-2.3 to +4.7 inches
RCP 8.5	Mid-Century (2035-2064)	15.8 inches
RCP 8.5	Mid-Century Range (Min,Max)	-2.6 to +3.8 inches
RCP 4.5	Late-Century (2070-2099)	15.8 inches
RCP 4.5	Late-Century Range (Min,Max)	-2.8 to +3.5 inches
RCP 8.5	Late-Century (2070-2099)	16.5 inches
RCP 8.5	Late-Century Range (Min,Max)	-2.7 to +4.5 inches

Notes:
RCP = Representative Concentration Pathway
Average values were calculated for each 30-year time period for 10 of the 32 Localized Constructed Analogs (LOCA) downscaled global climate models (GCMs) under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt for the Delta and Suisun Marsh.

2.1.2.2 Seasonal Precipitation: Climate Stressor

To account for California's Mediterranean rainfall patters of wet winters and dry summers, seasonal precipitation data were analyzed to better understand interannual precipitation changes and their potential phenological impacts of ecosystems. Winter rainfall is expected to increase under all scenarios, with the highest increases seen under the late-century, RCP 8.5 projection (average increase of 2.4 inches, range -0.4 to 7.5 inches) (Figure 10).

Spring and fall precipitation are projected to decrease under all scenarios with minimal variability across average projected changes (spring decrease range -0.2 to -0.4 inches; fall decrease range -0.2 to -0.5 inches). Summer precipitation remains largely unaffected with average rainfall at 0-inches (range -0.1 to 0.4 inches) across all emission scenarios and time horizons.



Notes:

RCP = Representative Concentration Pathway

Average values were calculated for each 30-year time period for 10 of the 32 Localized Constructed Analogs (LOCA) downscaled global climate models (GCMs) under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt for the Delta and Suisun Marsh. values were calculated for each 30-year time period for 10 of the 32 LOCA downscaled GCMs under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt for the Delta and Suisun Marsh.

Figure 10. Projected Average Seasonal Precipitation from Historical Under RCP 4.5 and 8.5 Scenarios

2.1.2.3 Climate Hazard: Extreme Precipitation and Drought

Climate change is expected to increase the frequency and magnitude of both floods – due to extreme precipitation events – and droughts (Diffenbaugh 2015; Dettinger et al. 2016). Extreme precipitation and drought events, and predicted changes throughout the 21st century, were interpreted and reported based upon a literature review of relevant research. These changes to the hydrologic extremes are driven by altered event magnitudes and novel combinations of events that reinforce one another (Dettinger et al. 2016). For example, by mid-century many models show a reduction in the number of days when it will rain but the intensity of storms will increase (e.g., increase in atmospheric river events) and with increasing temperatures, dry years are expected to become drier and wet years wetter (Dettinger et al. 2016; DSC Climate Change: A synthesis, 2018). Recent climate change research has identified the potential for a hydrological cycle intensification known as 'climate whiplash'. This precipitation volatility occurs when there is a fast transition from extremely dry to extremely wet conditions and these whiplash events are expected to increase by 25% to 100% by 2100 (Swain et al. 2018).

2.1.3 Sea Level Rise

2.1.3.1 Un-leveed Ecosystems

Tidal Freshwater Wetland

For mid-century (2050) scenarios with modeled constant sediment scenario for un-leveed freshwater tidal wetlands starting at approximately 1 foot (~30cm) above MSL, 100% of ecosystems are at risk to transitioning to low marsh under 2 feet of SLR by 2050. Under 1 foot SLR by 2050, all of these ecosystems will lose some elevation relative to MSL, but are not at risk of transitioning to low marsh.

For late-century (2085 and 2100 with modeled constant sediment scenario) for un-leveed freshwater tidal wetlands starting at approximately 1 foot (~30cm) above MSL, 100% of ecosystems are at risk to transitioning to low marsh under 3.5 feet SLR by 2050 and 100% of ecosystems are at risk of drowning and transitioning to open water under the 6 feet SLR by 2100. Under 2 feet SLR by 2085, all of these ecosystems will lose some elevation relative to MSL, but are not at risk of transitioning to low marsh.

For the constant sediment scenario, alternative starting elevations were also tested. Starting elevations of 1.31 feet (40cm) and 0.67 feet (20cm) were also tested and produced the same results as the 1 foot (30cm) scenario. To test the sensitivity of low marsh ecosystems, a starting elevation of -0.33 feet (-10cm) was evaluated. Under this scenario, all tidal freshwater wetlands drowned under 3.5 feet of SLR by 2085.

In addition to the constant sediment scenario used for the results above (60% of historical), scenarios for increasing sediment (125% of historical availability), and decreasing sediment (60% of historical with 1.6% decrease each year) were also tested. While these scenarios produced different outcomes, their results did not change the exposure results, resulting in the same overall levels of risk in the system.

Year	Scenario	**Delta Freshwater** + 1 ft MSL Starting Elevation	**Suisun Brackish** + 2 ft MSL Starting Elevation	**Low Marsh Start** -0.33 ft and 0 ft MSL Starting Elevation
2050	1 foot	High/Mid Marsh	High/Mid Marsh	Low Marsh
	2 Feet	Low Marsh	High/Mid Marsh	Low Marsh
2085	2 feet	High/Mid Marsh	High/Mid Marsh	Low Marsh
	3.5 Feet	Low Marsh	Low Marsh	Drowned
2100	6 Feet	Drowned	Drowned	Drowned

Figure 11. Predicted state changes of un-leveed freshwater and brackish tidal wetlands under different sea level rise scenarios. Under 3.5 ft SLR by 2085, 2% of Delta freshwater wetlands and 7% of Suisun Brackish wetlands are at risk of drowning. When assuming a low marsh as the starting elevation, the predicted state changes are the same for freshwater and brackish tidal wetlands.

Tidal Brackish Wetland

Under the constant sediment scenario, un-leveed tidal brackish wetland ecosystems in Suisun Marsh (with a starting elevation of 2 ft) are expected to have high exposure to moderate rates of SLR, with 7% of current total acres at risk of loss for all scenarios under 3.5 and 6 feet of SLR, and all high marsh expected to transition to low marsh by 3.5 feet (Table 7). Based on the analysis, un-leveed tidal wetlands in the legal Delta and Suisun Marsh have low exposure to SLR through 3.5 ft by 2085.

For mid-century (2050) scenarios with modeled constant sediment scenario for un-leveed brackish tidal wetlands starting at approximately 2 feet (~60cm) above MSL, these ecosystems will lose elevation relative to MSL, but are not at risk of transitioning to low marsh under 1 or 2 feet of SLR by 2050.

For late-century (2085 and 2100 with modeled constant sediment scenario), un-leveed brackish tidal wetlands starting at approximately 2 feet (60cm) above MSL, 100% of ecosystems are at risk to transitioning to low marsh under 3.5 feet SLR by 2050 and 99% of ecosystems are at risk of drowning and transitioning to open water under the 6 feet SLR by 2100. Under 2 feet SLR by 2085, all of these ecosystems will lose some elevation relative to MSL, but are not at risk of transitioning to low marsh.

For the constant sediment scenario, alternative starting elevations were also tested. Starting elevations of 2.62 feet (80cm) and 1.31 feet (40cm) were also tested and produced the same results as the 2 feet above MSL (60cm) scenario. To test the sensitivity of low marsh ecosystems, a starting elevation of 0 feet above MSL (0cm) was evaluated. Under this scenario, 100% of tidal brackish wetlands were drowned under 3.5 feet of SLR by 2085.

In addition to the constant sediment scenario used for the results above (60% of historical sediment availability reflecting changes to sediment supply in the 20th century), scenarios for increasing sediment (125% of historical availability), and decreasing sediment (60% of historical with 1.6% decrease each year) were also tested. While these scenarios produced different outcomes for final wetland surface elevations, their results did not change the exposure results, resulting in the same overall levels of risk in the system.

Riparian and Willow Ecosystems

Un-leveed riparian and willow ecosystems in the Delta and Suisun marsh are expected to have low exposure to moderate rates of SLR, with less than 1% of current total acres at risk with 0.5 feet of SLR, approximately 2% at risk with 1 foot of SLR, 6% at risk with 2 feet SLR, and 18% at risk with 3.5 feet of SLR (Table 7, Figure 12). Under the 6 foot scenario, these ecosystems are expected to have moderate exposure, with approximately 38% of current total acres at risk. Regionally, South Delta riparian areas are expected to have the lowest exposure, with 16% at risk under 6 feet SLR, and Central Delta riparian areas are expected have the highest exposure, with 67% at risk.

Accretion rates for un-leveed riparian/willow ecosystems in the Delta are not known (but see Stella et al. 2011 for accretion rates in the Sacramento River north of the Delta). Thus, these results do not account for potential vertical accretion in riparian/willow ecosystems subject to SLR, and additional research is needed to determine these rates.

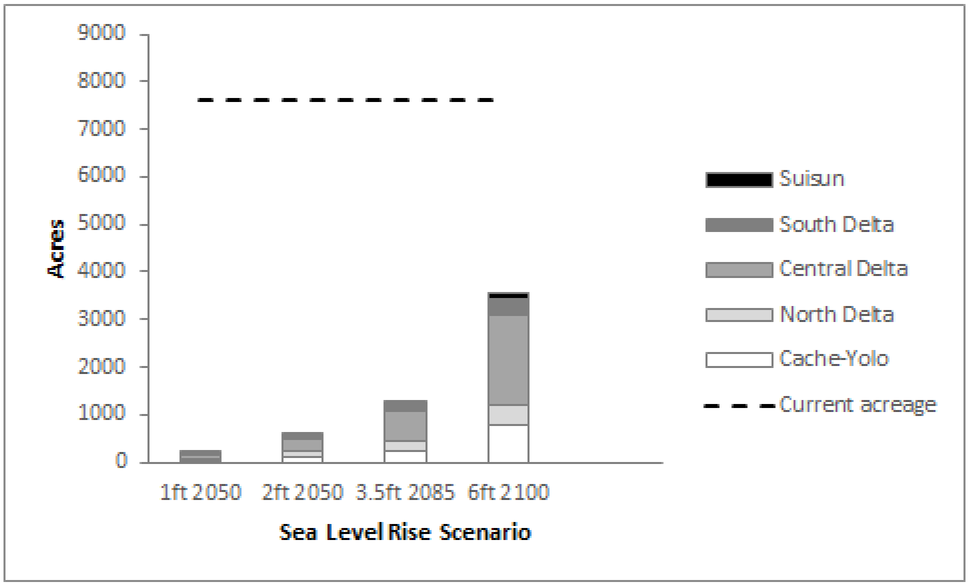


Figure 12. Number of acres of un-leveed riparian and willow ecosystems at risk of permanent flooding under different sea level rise scenarios. The dashed line indicates the current acreage of riparian and willow ecosystems. The first two bars depict risk of flooding in 2050 under different sea level rise scenarios.

Grassland

Un-leveed grassland ecosystems in the Delta and Suisun marsh are expected to have low exposure to moderate rates of SLR, with 2% of current total acres at risk for all scenarios under 2 feet of SLR, 13% at risk with 3.5 foot of SLR, and 30% at risk with 6 feet SLR (Table 7, Figure 13). Regionally, North Delta grasslands are expected to have the lowest exposure, with 9% at risk under 6 feet SLR, and Cache Yolo grasslands are expected to have the highest exposure, with 67% at risk.

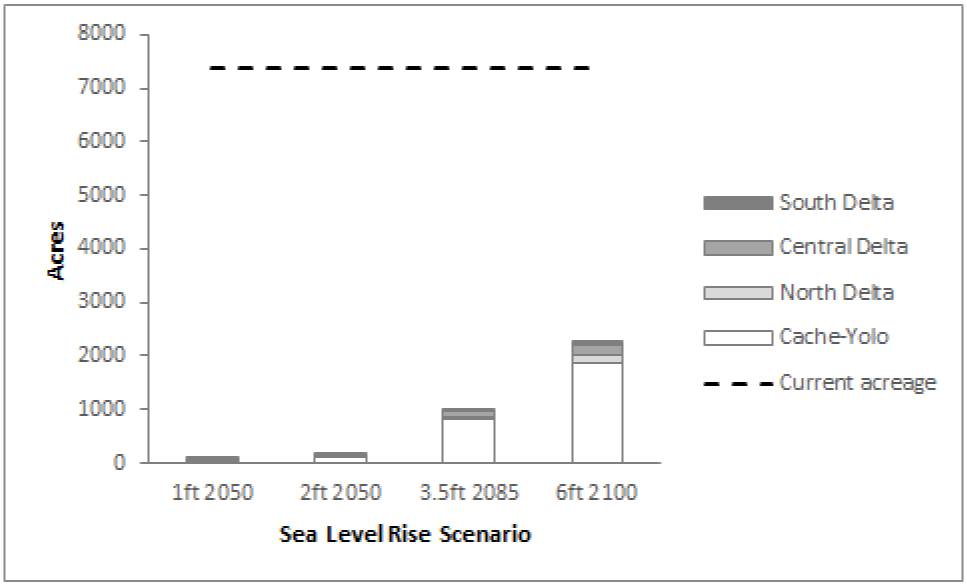


Figure 13. Number of acres of un-leveed grassland ecosystems at risk of permanent flooding under different sea level rise scenarios. The dashed line indicates the current acreage of grassland ecosystems. The first two bars depict risk of flooding in 2050 under different sea level rise scenarios.

Table 7. Un-leveed tidal wetland acres and percentage at risk under SLR scenarios. Risk is assessed in 2 ways. *Transition risk* reports the number of acres at risk of falling below mean sea level and transitioning from High/Mid Marsh to Low Marsh. *Drowning risk* reports the number of acres at risk of falling below mean lower low water and being lost to drowning (Thorne et al. 2019, Swanson et al. 2015, Schile et al. 2014). Scenarios in this table are based on starting elevations of 1 foot (30cm) above MSL for freshwater tidal wetlands and 2 feet (60cm) above MSL for brackish tidal wetlands and a constant sediment supply.

Ecosystem Asset	Region	Current Acres	**1 ft by 2050 Transition Risk Drowning Risk** (acres, %)	**2 ft by 2050 Transition Risk Drowning Risk** (acres, %)	**2 ft by 2085 Transition Risk Drowning Risk** (acres, %)	**3.5 ft by 2085 Transition Risk Drowning Risk** (acres, %)	**6 ft by 2085 Transition Risk Drowning Risk** (acres, %)
Tidal Freshwater Wetland	Cache/ Yolo	4,941	0 (*0%*) 0 (*0%*)	4,941 (*100%*) 0 (*0%*)	0 (*0%*) 0 (*0%*)	4,941 (*100%*) 0 (*0%*)	0 (*0%*) 4,941 (*100%*)
	North Delta	675	0 (*0%*) 0 (*0%*)	675 (*100%*) 0 (*0%*)	0 (*0%*) 0 (*0%*)	629 (*93%*) 46 (*7%*)	0 (*0%*) 675 (*100%*)
	Central Delta	6,101	0 (*0%*) 0 (*0%*)	6,101 (*100%*) 0 (*0%*)	0 (*0%*) 0 (*0%*)	6,060 (*>99%*) 41 (*<1%*)	0 (*0%*) 6,101 (*100%*)
	South Delta	232	0 (*0%*) 0 (*0%*)	211 (*91%*) 21 (*9%*)	0 (*0%*) 0 (*0%*)	105 (*46%*) 127 (*54%*)	0 (*0%*) 232 (*100%*)
	Delta	**11,950**	**0 (*0%*)** **0 (*0%*)**	**11,929 (*>99%*)** **21 (<1%)**	**0 (0%)** **0 (0%)**	**11,735 (*98%*)** **214 (*2%*)**	**0 (*0%*)** **11,950 (100%)**
Tidal Brackish Wetland	**Suisun**	**8,691**	**0 (0%)** **0 (0%)**	**8,691 (*100%*)** **0 (*0%*)**	**0 (0%)** **0 (0%)**	**8,124 (*93%*)** **567 (*7%*)**	**58 (*1%*)** **8,633 (*99%*)**

Table 8. Un-leveed riparian/willow ecosystems and grasslands risk under SLR scenarios

Ecosystem Asset	Region	Current Acres	Acres at risk (%) 6" by 2030	Acres at risk (%) 12" by 2050	Acres at risk (%) 24" by 2050	Acres at risk (%) 42" by 2085	Acres at risk (%) 72" by 2100
Riparian/ Willow	Cache-Yolo	1,484	1 (<1%)	19 (1%)	113 (8%)	236 (16%)	797 (54%)
	North Delta	966	28 (3%)	54 (6%)	121 (13%)	213 (22%)	395 (41%)
	Central Delta	2,840	41 (1%)	81 (3%)	236 (8%)	614 (22%)	1904 (67%)
	South Delta	2,032	19 (1%)	47 (2%)	88 (4%)	192 (9%)	315 (15%)
	Suisun	301	1 (1%)	2 (1%)	10 (3%)	22 (7%)	126 (42%)
	Delta and Suisun	**7,623**	**89 (1%)**	**203 (3%)**	**568 (7%)**	**1,277 (17%)**	**3,536 (46%)**
Grassland	Cache-Yolo	4868	28 (1%)	42 (1%)	111 (2%)	828 (17%)	1879 (39%)
	North	1396	3 (<1%)	7 (1%)	17 (1%)	46 (3%)	131 (9%)
	Central	601	15 (3%)	21 (3%)	34 (6%)	80 (13%)	185 (31%)
	South	513	1 (<1%)	2 (<1%)	2 (<1%)	3 (1%)	68 (13%)
	Suisun	0	0	0	0	0	0
	Delta and Suisun	**7,377**	**47 (1%)**	**71 (1%)**	**164 (2%)**	**957 (13%)**	**2262 (31%)**

2.1.3.2 Leveed Ecosystems

Non-tidal Freshwater Wetland

Leveed non-tidal freshwater wetland ecosystems in the Delta are expected to have high exposure to moderate rates of SLR, with 80% of current total acres at risk in 2085 with a medium probability of flooding (Table 9, Figure 14). Regionally, Cache-Yolo leveed non-tidal freshwater wetlands are expected to have the lowest exposure, with 53% at risk, and Central

Delta non-tidal freshwater wetlands are expected to have the highest exposure, with 89% at risk.

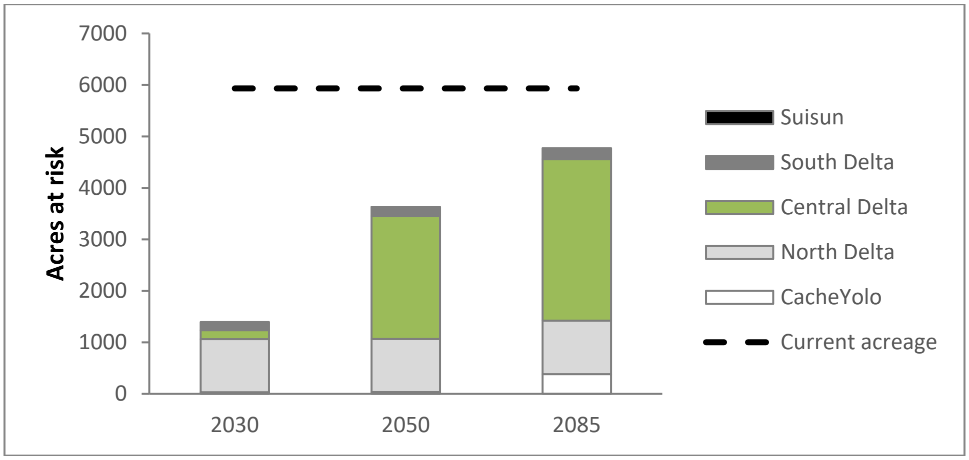


Figure 14. Number of acres of leveed freshwater non-tidal wetlands at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of leveed freshwater non-tidal wetlands.

Managed Wetlands in Suisun

Managed wetlands in Suisun Marsh have high exposure to moderate rates of SLR, with 100% of current total acres at risk in 2085 with a medium probability of flooding (Table 9, Figure 15).

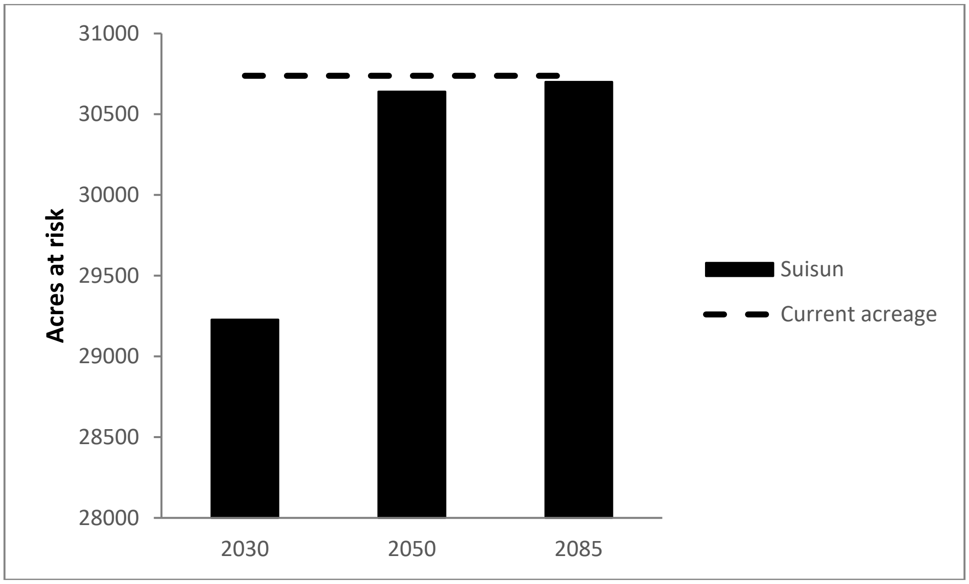


Figure 15. Number of acres of managed wetlands in Suisun Marsh at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of managed wetlands in Suisun Marsh.

Riparian and Willow Ecosystems

Leveed riparian and willow ecosystems in the Delta and Suisun marsh are expected to have moderate exposure to moderate rates of SLR, with 64% of current total acres at risk in 2085 with a medium probability of flooding (Table 9, Figure 16). Regionally, North Delta riparian areas are expected to have the lowest exposure, with 22% at risk, and Suisun Marsh and South Delta riparian areas are expected to have the highest exposure, with 98% and 99% at risk, respectively.

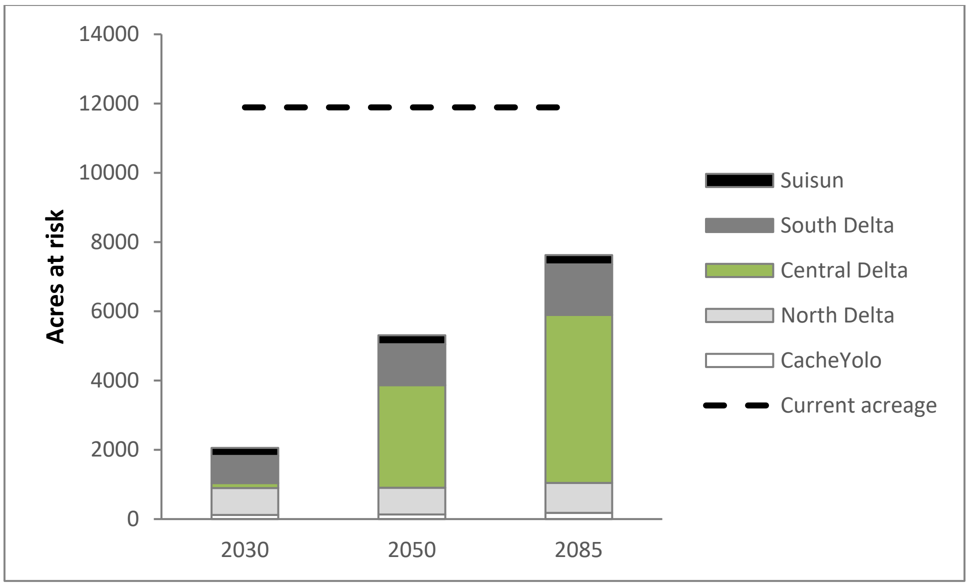


Figure 16. Number of acres of leveed riparian and willow ecosystems at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of leveed riparian and willow ecosystems.

Wet Meadow and Seasonal Wetlands

Leveed wet meadow and seasonal wetland ecosystems in the Delta and Suisun marsh are expected to have high exposure to high rates of SLR with 81% at risk in 2085 with a medium probability of flooding (Table 9, Figure 17). Regionally, wet meadow and seasonal ecosystems are expected to have the lowest exposure in the North Delta, with 6% at risk, and the highest exposure in Suisun Marsh, with 100% at risk.

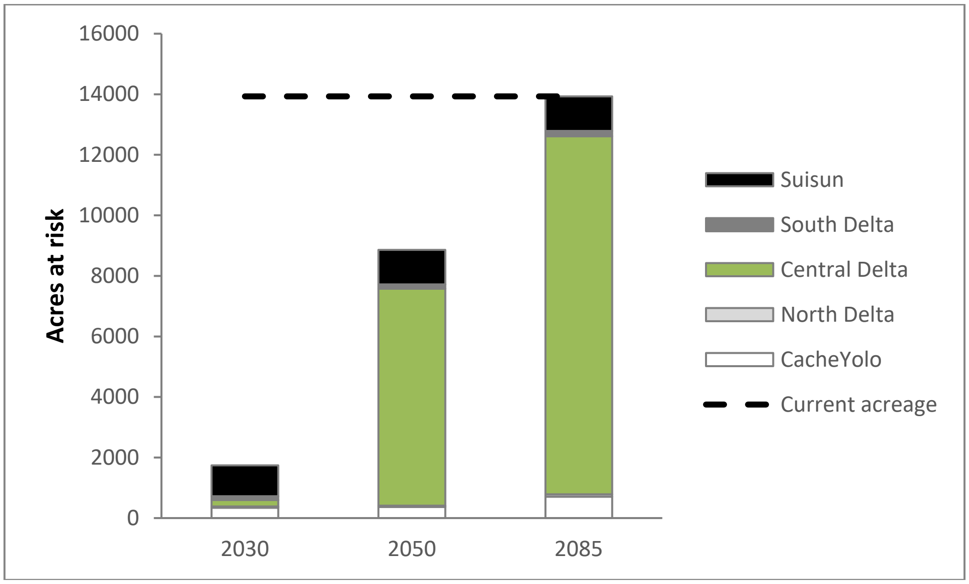


Figure 17. Number of acres of leveed wet meadow and seasonal wetland ecosystems at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of leveed wet meadow ecosystems.

Alkali Seasonal Wetlands

Leveed alkali seasonal wetland complexes in the Delta and Suisun Marsh are expected to have low exposure to moderate rates of SLR, with 38% at risk in 2085 with a medium probability of flooding (Table 9, Figure 18). Regionally, North Delta alkali seasonal wetlands are expected to have the lowest exposure, with no risk of loss, and South Delta alkali seasonal wetlands are expected to have the highest exposure, with 100% at risk; however, in the Cache-Yolo area the largest area of alkali seasonal wetlands (3,679 acres) are at risk.

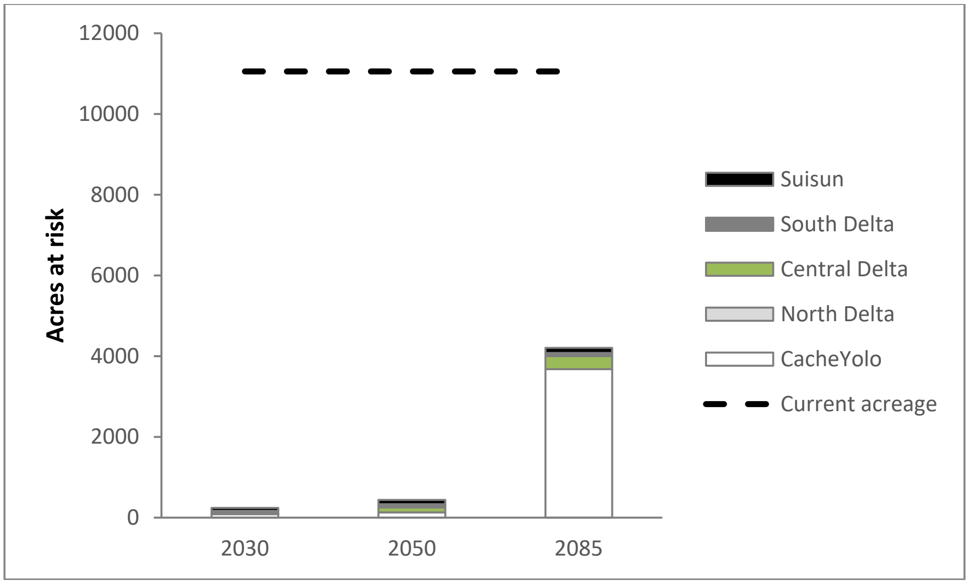


Figure 18. Number of acres of leveed alkali seasonal wetlands at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of leveed alkali seasonal wetlands.

Grassland

Leveed grassland ecosystems in the Delta and Suisun marsh are expected to have moderate exposure to moderate rates of SLR, 63% at risk in 2085 with a medium probability of flooding (Table 9, Figure 19). Regionally, North Delta grasslands are expected to have the lowest exposure, with 16% at risk, and Suisun grasslands are expected to have the highest exposure, with 90% at risk.

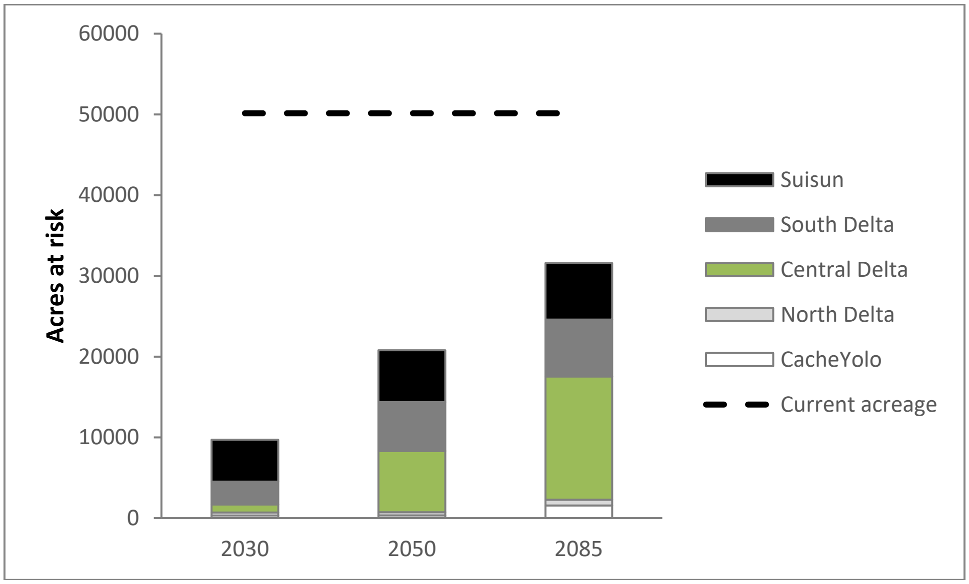


Figure 19. Number of acres of leveed grassland at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of leveed grassland.

Wildlife-associated Agriculture

Wildlife-associated agriculture in the Delta and Suisun Marsh has high exposure to moderate rates of SLR, with 68% of current total acres at risk (Table 9, Figure 20). Regionally, wildlife-associated agriculture in the North Delta is expected to have the lowest exposure, with 17% at risk, and agriculture in the South Delta is expected to have the highest exposure, with 85% at risk.

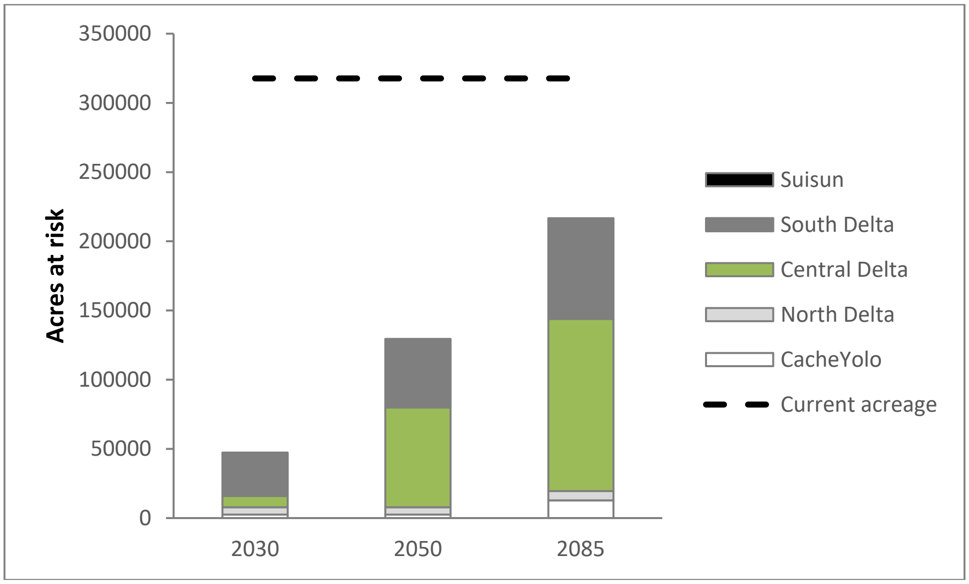


Figure 20. Number of acres of wildlife-associated agriculture in the Delta and Suisun Marsh at risk in 2030, 2050, and 2085 with a medium probability of flooding (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period). The dashed line indicates the current acreage of wildlife-associated agriculture in the Delta and Suisun Mars

Table 9. Acres at risk of flooding and percent (in parentheses) of current leveed ecosystem acreage at risk in 2030 at four levels of flood risk probability (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period).

Ecosystem Asset	**Region**	**Current Acres**	Acres at **low** risk of flooding	Acres at **medium** risk of flooding	Acres at **high** risk of flooding	Acres at **very high** risk of flooding
Nontidal Freshwater Wetlands	CacheYolo	725	33 (5%)	33 (5%)	33 (5%)	0
	North Delta	1430	1031 (72%)	1031 (72%)	1026 (72%)	0
	Central Delta	3511	386 (11%)	173 (5%)	137 (4%)	93 (3%)
	South Delta	265	165 (62%)	159 (60%)	0	0
	Total	5931	1614 (27%)	1396 (24%)	1196 (20%)	93 (2%)
Managed Wetland	**Total**	30738	29514 (96%)	29228 (95%)	29011 (94%)	27123 (88%)
Riparian/ Willow Ecosystems	CacheYolo	314	121 (39%)	121 (39%)	121 (39%)	0
	North Delta	3894	773 (20%)	773 (20%)	379 (10%)	0
	Central Delta	5917	266 (4%)	147 (2%)	125 (2%)	105 (2%)
	South Delta	1495	896 (60%)	782 (52%)	0	0
	Suisun	269	234 (87%)	234 (87%)	232 (86%)	226 (84%)
	Total	11890	2290 (19%)	2057 (17%)	856 (7%)	331 (3%)
Wet Meadow and Seasonal Wetland	CacheYolo	1996	344 (17%)	344 (17%)	344 (17%)	0
	North Delta	1214	42 (3%)	42 (3%)	16 (1%)	0
	Central Delta	12580	289 (2%)	207 (2%)	198 (2%)	186 (1%)
	South Delta	184	128 (70%)	126 (69%)	0	0
	Suisun	1141	1037 (91%)	1021 (89%)	1019 (89%)	917 (80%)
	Total	17115	1841 (11%)	1741 (11%)	1577 (9%)	1103 (6%)
Alkali Seasonal Wetland	CacheYolo	7606	86 (1%)	86 (1%)	86 (1%)	0
	North Delta	1893	0	0	0	0
	Central Delta	1308	50 (4%)	1	1	0
	South Delta	79	79 (100%)	79 (100%)	0	0
	Suisun	168	76 (45%)	76 (45%)	76 (45%)	76 (45%)
	Total	11054	290 (3%)	242 (2%)	162 (1%)	76 (1%)
Grassland	CacheYolo	3625	305 (8%)	305 (8%)	305 (8%)	0
	North Delta	4540	387 (9%)	386 (9%)	135 (3%)	0
	Central Delta	24099	1496 (6%)	997 (4%)	978 (4%)	297 (1%)
	South Delta	10080	3028 (30%)	2828 (28%)	0	0

	Suisun	7800	5356 (69%)	5178 (66%)	4769 (61%)	4243 (54%)
	Total	50144	10572 (21%)	9695 (19%)	6187 (12%)	4540 (9%)
Wildlife-associated Agriculture	CacheYolo	36378	2533 (7%)	2533 (7%)	2533 (7%)	0
	North Delta	38986	5316 (14%)	5316 (14%)	1891 (5%)	0
	Central Delta	156901	11949 (8%)	8020 (5%)	8020 (5%)	7711 (5%)
	South Delta	85417	33920 (40%)	31422 (37%)	0	0
	Total	317682	53718 (17%)	47292 (15%)	12444 (4%)	7711 (2%)

Table 10. Acres at risk of flooding and percent (in parentheses) of current leveed ecosystems at risk in 2050 at four levels of flood risk probability (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period).

Ecosystem Asset	**Region**	**Current Acres**	Acres at **low** risk of flooding	Acres at **medium** risk of flooding	Acres at **high** risk of flooding	Acres at **very high** risk of flooding
Nontidal Freshwater Wetlands	CacheYolo	725	37 (5%)	36 (5%)	34 (5%)	33 (5%)
	North Delta	1430	1040 (73%)	1031 (72%)	1031 (72%)	1013 (71%)
	Central Delta	3511	2553 (73%)	2385 (68%)	1723 (49%)	173 (5%)
	South Delta	265	202 (76%)	181 (68%)	173 (65%)	0
	Total	5931	3831 (65%)	3633 (61%)	2960 (50%)	1219 (21%)
Managed Wetland	**Total**	30738	30649 (100%)	30640 (100%)	30633 (100%)	29228 (95%)
Riparian/ Willow Ecosystems	CacheYolo	314	138 (44%)	134 (43%)	129 (41%)	117 (37%)
	North Delta	3894	829 (21%)	773 (20%)	773 (20%)	224 (6%)
	Central Delta	5917	3537 (60%)	2959 (50%)	1939 (33%)	147 (2%)
	South Delta	1495	1282 (86%)	1184 (79%)	1069 (71%)	0
	Suisun	269	257 (96%)	257 (96%)	256 (95%)	234 (87%)
	Total	11890	6042 (51%)	5307 (45%)	4167 (35%)	722 (6%)
Wet Meadow and Seasonal Wetland	CacheYolo	1996	382 (19%)	371 (19%)	355 (18%)	326 (16%)
	North Delta	1214	75 (6%)	42 (3%)	42 (3%)	6 (1%)
	Central Delta	12580	9264 (74%)	7166 (57%)	3923 (31%)	207 (2%)
	South Delta	184	147 (80%)	140 (76%)	132 (71%)	0
	Suisun	1141	1139 (100%)	1139 (100%)	1139 (100%)	1021 (89%)
	Total	17115	11008 (64%)	8858 (52%)	5591 (33%)	1560 (9%)

Alkali Seasonal Wetland	CacheYolo	7606	151 (2%)	130 (2%)	108 (1%)	52 (1%)
	North Delta	1893	0	0	0	0
	Central Delta	1308	271 (21%)	122 (9%)	96 (7%)	1 (0%)
	South Delta	79	79 (100%)	79 (100%)	79 (100%)	0
	Suisun	168	116 (69%)	108 (64%)	108 (64%)	76 (45%)
	Total	11054	617 (6%)	439 (4%)	392 (4%)	129 (1%)
Grassland	CacheYolo	3625	361 (10%)	337 (9%)	319 (9%)	291 (8%)
	North Delta	4540	474 (10%)	388 (9%)	388 (9%)	117 (3%)
	Central Delta	24099	9304 (39%)	7581 (31%)	4242 (18%)	997 (4%)
	South Delta	10080	6484 (64%)	6064 (60%)	3520 (35%)	0
	Suisun	7800	6479 (83%)	6417 (82%)	6375 (82%)	5178 (66%)
	Total	50144	23102 (46%)	20787 (41%)	14845 (30%)	6584 (13%)
Wildlife-associated Agriculture	CacheYolo	36378	2539 (7%)	2538 (7%)	2536 (7%)	2527 (7%)
	North Delta	38986	6464 (17%)	5316 (14%)	5316 (14%)	453 (1%)
	Central Delta	156901	94976 (61%)	72076 (46%)	42149 (27%)	8020 (5%)
	South Delta	85417	54697 (64%)	49578 (58%)	45371 (53%)	0
	Suisun	0	0	0	0	0
	Total	317682	158676 (50%)	129509 (41%)	95372 (30%)	11001 (3%)

Table 11. Acres at risk of flooding and percent (in parentheses) of current leveed ecosystems at risk in 2085 at four levels of flood risk probability (1-2% Equivalent Annual Probability of Exceedance, which equals a 50-100-year return period).

Ecosystem Asset	**Region**	**Current Acres**	Acres at **low** risk of flooding	Acres at **medium** risk of flooding	Acres at **high** risk of flooding	Acres at **very high** risk of flooding
Nontidal Freshwater Wetlands	CacheYolo	725	450 (62%)	382 (53%)	37 (5%)	0
	North Delta	1430	1057 (74%)	1040 (73%)	1040 (73%)	0

	Central Delta	3511	3143 (90%)	3137 (89%)	3132 (89%)	93 (3%)
	South Delta	265	213 (80%)	213 (80%)	210 (79%)	0
	Total	5931	4863 (82%)	4772 (80%)	4419 (75%)	93 (2%)
Managed Wetland	**Total**	30738	30703 (100%)	30700 (100%)	30698 (100%)	27123 (88%)
Riparian/ Willow Ecosystems	CacheYolo	314	187 (60%)	181 (58%)	138 (44%)	0
	North Delta	3894	1225 (31%)	864 (22%)	829 (21%)	0
	Central Delta	5917	5068 (86%)	4851 (82%)	4823 (82%)	105 (2%)
	South Delta	1495	1462 (98%)	1462 (98%)	1430 (96%)	0
	Suisun	269	265 (99%)	265 (99%)	265 (99%)	226 (84%)
	Total	11890	8206 (69%)	7622 (64%)	7485 (63%)	331 (3%)
Wet Meadow and Seasonal Wetland	CacheYolo	1996	724 (36%)	708 (36%)	382 (19%)	0
	North Delta	1214	124 (10%)	75 (6%)	75 (6%)	0
	Central Delta	12580	11884 (94%)	11828 (94%)	11826 (94%)	186 (1%)
	South Delta	184	178 (97%)	178 (97%)	177 (96%)	0
	Suisun	1141	1140 (100%)	1140 (100%)	1140 (100%)	917 (80%)
	Total	17115	14050 (82%)	13930 (81%)	13600 (79%)	1103 (6%)
Alkali Seasonal Wetland	CacheYolo	7606	3954 (52%)	3679 (48%)	151 (2%)	0
	North Delta	1893	0 *0*	0 *0*	0 *0*	0 *0*
	Central Delta	1308	328 (25%)	319 (24%)	308 (24%)	0
	South Delta	79	79 (100%)	79 (100%)	79 (100%)	0
	Suisun	168	129 (77%)	129 (77%)	125 (75%)	76 (45%)
	Total	11054	4491 (41%)	4207 (38%)	663 (6%)	76 (1%)
Grassland	CacheYolo	3625	1957 (54%)	1563 (43%)	361 (10%)	0
	North Delta	4540	1253 (28%)	711 (16%)	474 (10%)	0
	Central Delta	24099	15649 (65%)	15259 (63%)	15032 (62%)	297 (1%)
	South Delta	10080	7172 (71%)	7061 (70%)	6659 (66%)	0
	Suisun	7800	7098 (91%)	6996 (90%)	6957 (89%)	4243 (54%)
	Total	50144	33128 (66%)	31589 (63%)	29484 (59%)	4540 (9%)

Wildlife-associated Agriculture	CacheYolo	36378	13753 (38%)	12852 (35%)	2539 (7%)	0
	North Delta	38986	8817 (23%)	6638 (17%)	6464 (17%)	0
	Central Delta	156901	125650 (80%)	124431 (79%)	123182 (79%)	7711 (5%)
	South Delta	85417	73543 (86%)	72772 (85%)	61322 (72%)	0
	Suisun	0	0	0	0	0
	Total	317682	221763 (70%)	216693 (68%)	193508 (61%)	7711 (2%)

2.2 Sensitivity

The sensitivity analysis evaluates the degree to which an ecosystem asset is sensitive to a particular climate stressor. For the following sensitivity matrix (Table 12), primary climate stressors were evaluated and include: Air Temperature, Local Precipitation, and SLR.

For all climate stressors Air Temperature and Local Precipitation the sensitivity matrix synthesizes the results of both exposure and sensitivity. Due to the spatially explicit quantitative results available for exposure and sensitivity, these were analyzed separately for the climate stressor SLR, except for tidal freshwater and brackish wetlands, where modeling results that incorporate sensitivity were included as part of the exposure analysis.

Sensitivity to SLR of leveed ecosystems is determined by levee height, levee condition, and subsided land elevation. Ecosystem sensitivity therefore varies between Delta islands, however, it is beyond the scope of this study to assess levee condition. Dominant vegetation communities and physical processes of leveed ecosystems were evaluated as highly sensitive to SLR, because most islands are subsided and ecosystems would shift to open water habitat if islands flood (Durand 2017). The response of fish and wildlife species was evaluated in a more differentiated manner. In general, permanent flooding of terrestrial island ecosystems will increase fish habitat, but the quality and type of habitat will vary across Delta regions and risk (Durand 2017). Avian species will likely be able to adapt to some changes in ecosystems configuration due to their mobility (Dybala et al. 2020). Terrestrial species like salt marsh harvest mice and giant garter snakes may be less sensitive to gradual changes in SLR, but highly sensitive to episodic flooding events (e.g., Smith et al. 2020). Due to the diversity of climate change impacts on fish and wildlife species, we have attempted to highlight the relevant impacts to the extent possible, but responses are likely to be highly species specific.

Sensitivity of un-leveed ecosystems to SLR is ultimately determined by the current elevation, the ability to accrete surface elevation in place, and the ability to move upland.

Due to the use of the WARMER model to project tidal wetland surface elevations for the exposure section, some aspects of sensitivity are already incorporated into the analysis for these ecosystems, which factored into the sensitivity rankings for freshwater and brackish tidal marshes. The ability of tidal wetlands to move upland was assessed by qualitatively by examining the adjacency of existing tidal wetlands identified by VegCAMP to upland transition zone as mapped by Siegel and Gillenwater 2020. This demonstrated that the opportunity for tidal wetlands to move to adjacent upland accommodation space is highly limited in the Delta. This is particularly true in the Central Delta, where the accretion potential is the highest, which makes tidal freshwater ecosystems across the Delta highly sensitive to sea level rise. More potential for upland accommodation exists in the Suisun Marsh, which was identified by Schile et al. 2014 as critical for increasing tidal marsh sustainability at Rush Ranch. However, upland transition area for tidal brackish wetland does not occur everywhere in the Suisun Marsh. In addition to the impacts of SLR or marsh surface elevations, brackish tidal wetlands in Suisun Marsh may also be impacted by changes in salinity. Increasing salinity will change species composition, lower organic productivity, and subsequently lower the ability of tidal wetlands to keep pace with SLR.

Table 12. Sensitivity Matrix of Delta ecosystems and sensitivity to each of the three primary climate stressors on a scale of 1 (low sensitivity) to 3 (high sensitivity)

Ecosystem Type	Ecosystem Components	Sensitivity of each ecosystem component to **sea level rise**	Sensitivity of overall ecosystem to **sea level rise**	Sensitivity of ecosystem component to **air temperature**	Sensitivity of ecosystem to **air temperature**	Sensitivity of ecosystem component to **local precipitation**	Sensitivity of ecosystem to **local precipitation**
Tidal Freshwater Emergent Wetland	Dominant Vegetation Communities	3	high	1	Low	1	low
	Fish and Wildlife Species	3		1		1	
	Physical Processes	2		1		1	
Non-tidal Freshwater Emergent Wetland	Dominant Vegetation Communities	3	high	1	moderate	1	moderate
	Fish and Wildlife Species	2		2		2	
	Physical Processes	3		1		1	
Tidal Brackish Emergent Wetland (Un-leveed)	Dominant Vegetation Communities	3	high	1	low	1	low
	Fish and Wildlife Species	3		1		1	
	Physical Processes	2		1		1	

Ecosystem Type	Ecosystem Components	Sensitivity of each ecosystem component to **sea level rise**	Sensitivity of overall ecosystem to **sea level rise**	Sensitivity of ecosystem component to **air temperature**	Sensitivity of ecosystem to **air temperature**	Sensitivity of ecosystem component to **local precipitation**	Sensitivity of ecosystem to **local precipitation**
Managed Wetland (leveed)	Dominant Vegetation Communities	3	high	1	low	1	low
	Fish and Wildlife Species	2		1		1	
	Physical Processes	3		1		1	
Riparian/Willow Ecosystems (un-leveed)	Dominant Vegetation Communities	1	low	2	moderate	2	moderate
	Fish and Wildlife Species	1		2		2	
	Physical Processes	1		2		2	
Riparian/Willow Ecosystems (leveed)	Dominant Vegetation Communities	3	high	2	moderate	2	moderate
	Fish and Wildlife Species	2		2		2	
	Physical Processes	3		2		2	

Ecosystem Type	Ecosystem Components	Sensitivity of each ecosystem component to **sea level rise**	Sensitivity of overall ecosystem to **sea level rise**	Sensitivity of ecosystem component to **air temperature**	Sensitivity of ecosystem to **air temperature**	Sensitivity of ecosystem component to **local precipitation**	Sensitivity of ecosystem to **local precipitation**
Wet Meadow and Seasonal Wetland (leveed)	Dominant Vegetation Communities	3	high	3	high	3	high
	Fish and Wildlife Species	3		3		3	
	Physical Processes	3		3		3	
Alkali Seasonal Wetland Complex (leveed)	Dominant Vegetation Communities	3	high	3	high	3	high
	Fish and Wildlife Species	3		3		3	
	Physical Processes	3		3		3	
Grassland (un-leveed)	Dominant Vegetation Communities	2	moderate	2	moderate	2	moderate
	Fish and Wildlife Species	1		2		2	
	Physical Processes	2		2		2	

Ecosystem Type	Ecosystem Components	Sensitivity of each ecosystem component to **sea level rise**	Sensitivity of overall ecosystem to **sea level rise**	Sensitivity of ecosystem component to **air temperature**	Sensitivity of ecosystem to **air temperature**	Sensitivity of ecosystem component to **local precipitation**	Sensitivity of ecosystem to **local precipitation**
Grassland (leveed)	Dominant Vegetation Communities	3	high	2	moderate	2	moderate
	Fish and Wildlife Species	2		2		2	
	Physical Processes	3		2		2	
Wildlife-associated Agriculture (leveed)	Dominant Vegetation Communities	3	high	1	low	1	low
	Fish and Wildlife Species	2		1		1	
	Physical Processes	3		1		1	

2.2.1 Tidal Freshwater Emergent Wetland

2.2.1.1 Air Temperature

Tidal freshwater emergent wetlands were rated low for sensitivity to increases in air temperature. Increased air temperatures will likely lead to increased local water temperatures which could adversely affect the distribution of aquatic species within this habitat (Durand 2008, 2015; Schoellhamer et al. 2016). However, as these systems are largely influenced by tidal action, the incoming cooler oceanic waters may ameliorate the stress of increased air temperatures on this ecosystem type (Dettinger and Cayan 1995; Kimmerer 2004; Lebassi et al. 2009). Since these ecosystems are associated with a higher water content when compared to upland areas, they have the ability to absorb more heat and buffer organisms against rising temperatures (Naiman et al. 2000).

2.2.1.2 Precipitation

Tidal freshwater emergent wetlands were rated low for sensitivity to changes in precipitation. These tidal systems are less dependent on local precipitation. Similarly, emergent vegetation, wildlife and aquatic species are adapted to the daily fluctuations in water availability and periods of desiccation (Kimmerer 2002). Salinity levels will change with wet or dry periods; however, plant and wildlife species are adapted to these fluctuations (Glibert et al. 2014; Brown et al. 2016). Further, water system operations to maintain the hydraulic salinity barrier (see Water Management chapter) are likely to prevent salinity intrusion, even during droughts.

2.2.1.3 Sea Level Rise

Tidal freshwater emergent wetlands were rated moderate for sensitivity to SLR.

Dominant Vegetative Communities

Organic and mineral accretion allow these ecosystems to keep pace with moderate rates of SLR (Thorne et al., Swanson et al. 2015, Schile et al. 2014, this study). However, under 2 feet of SLR 47% of freshwater tidal wetlands are projected to transition from high to low marsh. Under 6 feet of SLR, 47% of freshwater tidal wetlands will have drowned, and 53% will transition to low marsh. Further, upland transition accommodation space for tidal freshwater wetlands is limited in the Delta, preventing existing tidal wetlands from migrating upland. Therefore, sensitivity was rated high for dominant vegetative communities of tidal freshwater emergent wetland.

Fish and Wildlife Species

Sensitivity of fish and wildlife species in tidal freshwater emergent wetlands to SLR is high. As high marsh habitats transition to low marsh primary productivity decreases, which will have implications for both aquatic and terrestrial species. Under SLR rates of 6 feet and above, substantial areas of fish and wildlife habitat are likely to disappear. In addition, high water storm and king tide events are likely to impact resident species in acute events beyond the chronic changes reflected in this analysis, particularly where upland transition and high tide refugia are not available (SFEI and SPUR 2019). Therefore, sensitivity was rated high for fish and wildlife species.

Future assessments of sensitivity should determine the extent of upland transition under more extreme sea level rise scenarios to discern the full impact on wildlife species.

Physical Processes

Tidal freshwater marshes generally persist between mean lower low water and mean higher high water (Schile et al. 2014; Swanson et al. 2015). Biophysical feedbacks between vegetation primary productivity (above and belowground) and mineral sediment allow wetlands to keep pace with moderate levels of SLR. The modeling performed for this effort indicates that the physical processes needed for tidal wetland persistence are likely to be retained through 3.5 feet of SLR by 2085. However, if island breaches change the hydrodynamics of the system, local water levels may be impacted. Further, SLR in the long term may lead to increases in salinity, reducing organic matter production and lowering rates of accretion, putting the persistence of these ecosystems at risk (Swanson et al. 2015). Sensitivity of physical processes to SLR was rated moderate.

Site-Level and Regional Wetland Sensitivity to Sea Level Rise

The sensitivity of un-leveed ecosystems to SLR is determined by the current elevation, the ability to move upland, and the ability to accrete surface elevation in place.

Because a vegetation-corrected DEM does not exist for the Delta, a single initial elevation value reflecting the median value of high/mid marsh (30 cm in the Delta based on Swanson et al. 2015; 60 cm in Suisun Marsh based on Buffington et al. 2019) was used for each patch of tidal wetland, effectively removing site-level variation from the model results. Thus, transitions to low marsh are considered at the site level. Freshwater wetland species are able to persist in areas that are continuously inundated (Sloey et al. 2015, 2016).

2.2.2 Non-Tidal Freshwater Wetland

2.2.2.1 Air Temperature

Non-tidal freshwater wetlands were rated moderate for sensitivity to increases in air temperature.

Dominant Vegetative Communities

It is expected that warming temperatures will increase evapotranspiration rates causing stress on vegetation communities (Anderson et al. 2008). However, as these habitats are permanently saturated due to management and high water table levels, effects of warming temperatures will likely be buffered by inundation (Naiman et al. 2000). Additionally, emergent vegetation such as bulrushes, tule and cattails are adapted to seasonally dry conditions (Whipple et al.

2012). Therefore, dominant vegetation communities were ranked as having a low sensitivity to changes in air temperature.

Fish and Wildlife

Fish and wildlife species were ranked as having a moderate sensitivity to changes in air temperature within non-tidal freshwater wetlands. Increasing air temperatures will result in warming waters and reduced inundation extent (Durand 2008, 2015). These changes could negatively impact aquatic species reliant on specified temperature thresholds for physiological processes (Wagner et al. 2011) and sustained inundation. Other wildlife may be less impacted as dominant vegetation communities will still provide adequate habitat and some level of shading (DeHaven 1989).

Physical Processes

With increasing temperatures, non-tidal wetlands will likely be more vulnerable to desiccation and water stress due to increased evapotranspiration (Mauger et al. 2015). But as these habitats are indirectly influenced by the tides that maintain high water table levels, the impacts of higher temperatures are minimized (Naiman et al. 2000). Therefore, physical processes of non-tidal freshwater wetlands were ranked as having a low sensitivity to changes in air temperature.

2.2.2.2 Precipitation

Non-tidal freshwater wetlands were rated moderate sensitivity to change in precipitation.

Dominant Vegetative Communities

Changes to seasonal precipitation patterns, especially decreases in the fall and spring, could place undue stress on vegetation communities found in non-tidal freshwater wetlands (Diffenbaugh 2015; Dettinger et al. 2016). However, as these habitats are permanently saturated due to higher water table levels, effects of decreased seasonal precipitation will likely be buffered. Additionally, common plant species within this habitat are adapted to seasonal fluctuations in precipitation (Whipple et al. 2012). Therefore, dominant vegetation communities were ranked as having a low sensitivity to changes in precipitation.

Fish and Wildlife

Reduced spring and fall precipitation coupled with increasing temperatures could increase amphibian and reptile vulnerability to impacts of climate change. Although there may be adequate ponding throughout the year, there could be a mismatch between habitat availability and species needs, inhibiting completion of life history cycles (Mauger et al. 2015; Cloern et al. 2011). As a result, fish and wildlife species were ranked as having a moderate sensitivity to shifts in precipitation patterns.

Physical Processes

With changes in precipitation, non-tidal wetlands will likely be more vulnerable to desiccation and evapotranspiration (Anderson et al. 2008; Mauger et al. 2015). But as these habitats are indirectly influenced by the tides that maintain high water table levels, the impacts of stochastic precipitation patterns are likely buffered. Therefore, physical processes of non-tidal freshwater wetlands were ranked as having a low sensitivity to changes in precipitation.

2.2.2.3 Sea Level Rise

Fish and Wildlife

The extent of freshwater emergent wetland has decreased by 98% in the modern Delta (without Suisun Marsh; Robinson et al. 2014). Any further losses due to climate change would mean a significant loss of habitat of species dependent on these ecosystems. Therefore, fish and wildlife associated with non-tidal freshwater wetlands were ranked as highly sensitive to SLR.

2.2.3 Tidal Brackish Emergent

2.2.3.1 Air Temperature

Tidal brackish wetlands were rated low sensitivity to increases in air temperature. Increased air temperatures will likely lead to increased water temperatures, adversely affecting the distribution of aquatic species within this habitat (Durand 2008, 2015; Cloern et al. 2016). However, as these systems are largely influenced by tidal action, incoming cooler oceanic waters may ameliorate the stressors of increased air temperatures (Dettinger and Cayan 1995; Lebassi et al. 2009).

2.2.3.2 Precipitation

Tidal brackish emergent wetlands were rated low sensitivity to changes in precipitation. As they are tidally influenced, they have a low reliance on direct rainfall. Similarly, emergent vegetation, wildlife and aquatic species in tidal brackish marshes are adapted to daily fluctuations in water availability and periods of desiccation (Mauger et al. 2015; Cloern et al. 2016; Schoellhamer et al. 2016). Consequently, these habitats are fairly resilient to periods of drought and storm events (Diffenbaugh 2015; Dettinger et al. 2016).

2.2.3.3 Sea Level Rise

Dominant Vegetative Communities

Tidal brackish marshes generally persist between mean lower low water and mean higher high water, and were rated high sensitivity to SLR. Biophysical feedbacks between vegetation primary productivity (above and belowground) and mineral sediment allow wetlands to keep pace with moderate rates of SLR (Thorne et al., Swanson et al. 2015, Schile et al. 2014), but all high marsh is likely to transition to low marsh by 3.5 feet SLR.

Fish and Wildlife

While sensitivity of fish and wildlife species in tidal brackish emergent wetlands to moderate levels of SLR is low, it is likely to increase under SLR rates of 3.5 feet and above. In addition, high water storm and king tide events are likely to impact resident species, particularly where upland transition and high tide refugia are not available (SFEI and SPUR 2019). Salt marsh harvest mice are common in tidal brackish marshes, and will be sensitive to both long-term changes in sea level and acute high water events (Rosencranz et al. 2019). Tidal brackish marshes in Suisun, particularly in the Rush Ranch area, have some upland transition zones that will allow for high-tide refuge and the potential for marshes to move upland, but not all areas have this potential (Schile et al. 2014). Further, brackish marsh wildlife are highly dependent on high marsh, and thus will be highly sensitive to transitions to low marsh (Rosencranz et al. 2019). Therefore, sensitivity was rated high for fish and wildlife species.

Future assessments of sensitivity should determine the extent of upland transition under more extreme sea level rise scenarios to discern the full impact on wildlife species.

Physical Processes

Physical properties were ranked as moderate sensitivity to SLR, as the modeling performed for this effort indicates that the physical processes needed for tidal brackish wetland persistent are likely to be retained through 2 feet of SLR, and some upland accommodation space available. Increased sediment availability may be a result of climate change, which would help these ecosystems maintain their elevation. However, if island breaches change the hydrodynamics of the system, local water levels may be impacted, increasing the risk of altering physical processes. Increases in salinity may shift species composition towards a lower productivity saline marsh structure that could reduce the organic accretion rate (Schile et al. 2014).

2.2.4 Managed Wetlands

2.2.4.1 Air Temperature

Managed wetlands were ranked as having a low sensitivity to increases in temperature.

These systems are heavily managed for waterfowl and hunting purposes within the Delta (SFEI-ASC 2014). As a result, managed flooding will keep vegetation buffered from increasing temperatures and will continue to provide adequate habitat for associated species.

2.2.4.2 Precipitation

Managed wetlands were ranked as having a low sensitivity to changes in precipitation. As these systems are actively managed, vegetation and wildlife can be buffered from seasonal precipitation reductions by increasing water flow within these habitats (SFEI-ASC 2014).

2.2.4.3 Sea Level Rise

Fish and Wildlife

Fish and wildlife in managed wetlands were ranked to have moderate sensitivity to SLR. Levee overtopping may change the character of the wetland but associated fish and wildlife species may be able to adapt. However, some species may be more sensitive to the effects of SLR on managed wetlands. For example, salt marsh harvest mice require high-tide refuge from predators, which will be heavily compromised by increasing sea levels and resulting flooding in managed wetlands (Moyle et al. 2014). Waterfowl, the primary target of managed wetlands, may be negatively impacted if these areas transition to tidal open water. However, aquatic and tidal marsh species may benefit if these areas transition to tidal brackish wetland.

2.2.5 Riparian and Willow Ecosystems

2.2.5.1 Air Temperature

The riparian/willow ecosystems was rated moderately sensitive to increases in air temperature. Note that this ecosystem asset category includes linear habitat types with a diverse degree of tidal and other aquatic influence – those along stream/ river channels to those in valley foothill riparian areas further from water accessibility. As a result, this asset category was particularly challenging to score.

Dominant Vegetative Communities

Vegetative communities in riparian/willow ecosystems were ranked as having a moderate sensitivity to changes in air temperature. Increasing temperatures will likely lead to increased evapotranspiration rates that will decrease soil moisture content (Porporato et al. 2004; Anderson et al. 2008). Therefore, this will increase competition for freshwater sources, driving shifts in plant phenology and potentially altering species composition of riparian/willow ecosystems (Naiman et al. 2000; Hegland et al. 2009).

Fish and Wildlife

Rising air temperatures will warm surrounding waters of riparian/willow ecosystems. Higher water temperatures may exceed the thermal threshold of aquatic species associated with this habitat (Mauger et al. 2015; Cloern et al. 2011). However, riparian areas with thicker vegetation may still provide some level of shading to buffer increasing water temperatures and provide protection from predation for these aquatic species (DeHaven 1989). Fish and wildlife were ranked as having a moderate sensitivity to changes in air temperature in riparian/willow ecosystems.

Physical Processes

Physical processes were ranked as having a moderate sensitivity to changes in air temperature. With increasing temperatures, soil moisture content is likely to be reduced through evapotranspiration which may inhibit fall seedling establishment (Porporato et al. 2004). Additionally, there may be increased competition for groundwater resources if vegetation becomes stressed due to lack of water (Sridhar et al. 2004, Cassie 2006). These stressors will be higher in riparian/willow ecosystems that are disconnected from the Delta's hydrology.

2.2.5.2 Precipitation

The Riparian/Willow complex was rated moderate for sensitivity to changes in precipitation.

Dominant Vegetative Communities

Riparian vegetation communities were ranked as having a moderate sensitivity to changes in precipitation. Projected reductions in fall precipitation could impact fall seedling establishment, leading to phenological shifts and community composition changes (Porporato et al. 2004). Established vegetation in riparian/willow ecosystems connected to local water sources will likely not be as affected by precipitation changes as they can tap into groundwater sources (Seavey et al. 2009). However, riparian/willow ecosystems with lower water content and disconnected from rivers due to levees or those located in upland habitats will be more vulnerable to reduced precipitation as well as prolonged drought events (Naiman et al. 2000). In general, riparian/willow ecosystems are adapted to fluxes in precipitation and are resilient to storm events and short-term droughts.

Fish and Wildlife

Fish and Wildlife were ranked as having a moderate sensitivity to changes in precipitation. With projected reductions in spring and fall precipitation, intact riparian/willow ecosystems will provide suitable habitat for organisms looking to relocate for more reliable water sources, whereas isolated habitats will be less suited to provide adequate habitat for wildlife (Seavey et al. 2009). Furthermore, flooding events brought on by winter storms and atmospheric river events may have deleterious effects on water quality adding to impacts of aquatic species and other wildlife (Feyrer et al. 2011, MacWilliams et al. 2015, SWRCB 2010).

Physical Processes

Riparian/willow ecosystems can withstand, and are adapted, to major flashflood events brought on by atmospheric rivers. However, increased winter storm events are likely to negatively impact water quality (Seavey et al. 2009). This could have a disproportionate and negative effect on riparian/willow ecosystems connected to the Delta's hydrology compared to those habitats that are isolated from it. Physical processes were ranked as having a moderate sensitivity to changes in precipitation.

2.2.5.3 Sea Level Rise

Un-leveed Riparian/Willow Ecosystems

Dominant Vegetative Communities

The sensitivity to SLR of the dominant vegetation communities of un-leveed riparian/willow ecosystems is determined by accretion rates and elevation range. Because riparian and willow ecosystems can withstand periodic flooding and accretion likely occurs (although it has not been studied for these ecosystems in the Delta), they were ranked as having a low sensitivity to moderate changes in SLR.

Fish and Wildlife

Because riparian and willow vegetative communities have a low sensitivity to SLR with moderate levels of SLR, fish and wildlife species depending on these vegetation communities were also ranked to have a low sensitivity to SLR.

Physical Processes

Physical processes are expected to be unchanged by moderate levels of SLR, and accretion may counteract SLR (Stella et al. 2011). Physical processes were ranked as having a low sensitivity to changes in SLR.

Leveed Riparian/Willow Ecosystems

Fish and Wildlife

The extent of riparian/willow ecosystems has decreased by 66% in the modern Delta (Robinson et al. 2014). Further losses due to climate change would mean a considerable loss of habitat of species dependent on these ecosystems. In addition, terrestrial species dependent on riparian vegetation, such as the endangered riparian brush rabbit (*Sylvilagus bachmani riparius*), are likely to be highly impacted in the event of flooding (Williams et al. 2008). Therefore, fish and wildlife associated with leveed riparian/willow ecosystems were ranked as moderately sensitive to SLR.

2.2.6 Wet Meadows/Seasonal Wetlands

2.2.6.1 Air Temperature

Wet meadows and seasonal wetlands were rated high sensitivity to increases in air temperature.

Dominant Vegetative Communities

Vegetation communities were rated highly sensitive to increases in air temperature. Warming temperatures and increased evapotranspiration could cause seasonal wetlands to prematurely dry (Ordonez et al. 2014). This may result in amplified competition for limited water supply and could shift phenological responses thereby altering species composition to favor of more robust and heat tolerant, or non-native species (Hegland et al. 2009).

Fish and Wildlife

Increasing air temperatures will also drive higher water temperatures within wet meadows and seasonal wetlands. Warming water temperatures may cause these temporary bodies of water to prematurely dry, impacting species such as invertebrates and amphibians who rely heavily on water presence for critical physiological processes such as reproduction and support of larval phases (Cloern et al. 2011; Mauger et al. 2015). Warmer water temperatures may also drive phenological shifts in species life history patterns. Food availability and resources may also be impacted, negatively affecting wildlife populations. Fish and wildlife species were rated high for sensitivity to increases in air temperature.

Physical Processes

Physical processes were subsequently rated high for sensitivity to air temperature increases. Increased evaporation will lead to decreases in soil moisture and could shift wet meadows and seasonal wetlands to become alkali meadows/wetlands. The clay-rich soils may be better adapted to hold more water, however, prolonged higher temperatures coupled with drought-like conditions could result in these water bodies and soils drying out (SFEI-ASC 2014). In the Delta, many wet meadows and seasonal wetlands are in poor shape as they are already heavily impacted by agriculture and levees (SFEI-ASC 2014). As these habitats are highly disturbed, they are increasingly susceptible to any additional disturbances and the impacts of climate change.

2.2.6.2 Precipitation

Wet meadows and seasonal wetlands were ranked as having a high vulnerability to changes in precipitation.

Dominant Vegetative Communities

The vulnerability of wetlands to climate change is directly related to their water source (Winter 2000). Wetlands that receive the majority of their water from sources other than direct rainfall such as tidal action or groundwater discharge are more buffered from the effects of climate change (Vaghti and Greco 2007; Grewell et al. 2007). Wet meadows and seasonal wetlands were rated highly sensitive to changes in precipitation as their water supply is directly related to rainfall. Consequently, these habitats are highly susceptible to drought conditions. Projected decreases in spring and fall precipitation can increase competition amongst vegetation for limited water supply and can negatively impact species composition favoring more drought-tolerant species (Mauger et al. 2015).

Fish and Wildlife

Shifts in wildlife habitat correspond to changes in hydrologic regimes and vegetative communities. Many amphibian species are already, and will continue to be, highly vulnerable to a combination of increasing temperatures, reduced spring and fall precipitation, and drought (McMenamin et al. 2008; Jeffries et al. 2016). Wetland desiccation and declines in suitable habitat can cause shifts in amphibious and fish species physiological processes, as available water dries out and increases competition between fish and amphibian species (Petranka et al. 2007; McMenamin et al. 2008) Fish and wildlife species are therefore ranked high for sensitivity to changes in precipitation in seasonal wetlands.

Physical Processes

Physical processes were ranked high for sensitivity to changes in precipitation. Higher precipitation during the winter months may help buffer decreased precipitation projections of spring and fall seasons. However, dry seasons coupled with warmer temperatures could cause these seasonal wetlands to dry out sooner (McMenamin et al. 2008; Diffenbaugh 2015; Dettinger et al. 2016).

2.2.6.3 Sea Level Rise

Fish and Wildlife

The extent of wet meadows and seasonal wetlands has decreased by 93% in the modern Delta (Robinson et al. 2014). Any further losses due to climate change would mean a significant loss of habitat of species dependent on these ecosystems. Therefore, wildlife in wet meadows and seasonal wetlands were ranked as having high sensitivity to SLR.

2.2.7 Alkali Seasonal Wetland Complex

2.2.7.1 Air Temperature

Alkali seasonal wetland complex were ranked as having a high sensitivity to increases in air temperature.

Dominant Vegetative Communities

Vegetation communities were ranked high for sensitivity to increases in air temperature. Higher temperatures can drive increased evapotranspiration which not only dries out seasonal ponds earlier in the year and may result in increased salt content in the soil more so than the vegetation communities are adapted to. As groundwater declines, alkali vegetation begins to lose contact with the water table, and total plant cover declines resulting in mortality (Elmore et al. 2006). These changes, along with decreases in soil moisture have the potential to shift phenology patterns for dominant plant species and alter overall species composition in this habitat type (Hegland et al. 2009). Shifts in vegetation community could have cascading impacts on fish and wildlife communities reliant upon this habitat.

Fish and Wildlife

Increasing temperatures will increase water temperatures and evaporation rates, negatively impacting already susceptible wildlife species such as invertebrates and amphibians (Durand 2008, 2015). Seasonal ponds with warmer water temperatures that evaporate prematurely will negatively impact species whose life history patterns are intimately tied with the presence of standing water and increase inter- and intra-species competition for the limited water resources (McMenamin et al. 2008). Additionally, there may also be shifts in the availability of food resources that can negatively affect species at the landscape scale. Fish and wildlife were ranked high for sensitivity to increases in air temperature.

Physical Processes

Physical processes were also rated high for sensitivity to air temperature increases. Increased evaporation will cause soils to desiccate (Porporato et al. 2004). Although the clay-rich soils are better adapted to hold more water, prolonged high temperatures coupled with drought conditions will eventually result in alkali wetlands to dry up and lead to soil with a higher salt content (SFEI-ASC 2014).

2.2.7.2 Precipitation

Alkali seasonal wetland complex were ranked as having a high sensitivity to changes in precipitation.

Dominant Vegetative Communities

Alkali wetlands are reliant upon rainfall and to some extent groundwater sources for their water supply. With periods of decreased rainfall in the spring and fall, competition for the limited water supply will increase or lead to total declines (Elmore et al. 2006). This may be ameliorated by winter storm events, however, during drought years, groundwater supply may be severely reduced due to groundwater overdraft, causing further stress on vegetation communities (Diffenbaugh 2015; Dettinger et al. 2016). Dry periods and drought years will also drive increased soil salinity and push the vegetation communities above their salt-tolerance threshold. It is likely that phenological responses will shift and alter species composition to include more drought-tolerant species. Vegetation communities were ranked high for sensitivity to changes in precipitation.

Fish and Wildlife

Shifts in wildlife habitat correspond to changes in hydrologic regimes and vegetative communities. Many aquatic species would be highly vulnerable to a combination of increasing temperatures and reduced spring and fall precipitation (McMenamin et al. 2008). Reduction in alkali ponding and water supply can shift species' physiological processes and make it difficult for them to complete critical life history phases (McMenamin et al. 2008). Increased salt content of the soil can also negatively impact wildlife and their food supply (Wang et al. 2017).

Fish and wildlife species are therefore ranked high for sensitivity to changes in precipitation in alkali wetlands.

Physical Processes

Physical processes were ranked high for sensitivity to changes in precipitation. Higher precipitation during the winter months may help buffer decreased precipitation projections of spring and fall seasons. However, dry seasons coupled with warmer temperatures could cause these seasonal alkali wetlands to dry out sooner, and possibly remain dry throughout the year until they can be replenished (Diffenbaugh 2015; Dettinger et al. 2016). This would decrease the availability of viable habitat and food resources for the species that depend upon alkali wetlands.

2.2.7.3 Sea Level Rise

Fish and Wildlife

The extent of alkali seasonal wetlands has decreased by 97% in the modern Delta (Robinson et al. 2014). Any further losses due to climate change would mean a significant loss of habitat of species dependent on these ecosystems. Therefore, fish and wildlife associated with alkali seasonal wetlands were ranked as having high sensitivity to SLR.

2.2.8 Grasslands

2.2.8.1 Air Temperature

Grasslands were ranked as having a moderate sensitivity to increases in temperature.

Dominant Vegetative Communities

Dominant vegetative communities in grasslands were ranked moderate for sensitivity to temperature increases. Grasslands in the Delta are already highly altered with almost 90% of the plant species comprising invasive species (SFEI-ASC 2014). It is expected that warming temperatures will drive increased evapotranspiration, leading to increased competition for freshwater resources (Anderson et al. 2008). These conditions will favor species that are more heat and drought tolerant and will likely lead to an increase in invasive species within these habitats (Sandel et al. 2012).

Fish and Wildlife

Increasing temperatures within grassland habitats will likely cause more heat-sensitive wildlife to relocate to adjacent cooler wetlands (Parmesan 2007). Consequently, fish and wildlife were ranked moderate for sensitivity to temperature increases.

Physical Processes

Physical processes were ranked moderate for sensitivity to temperature increases. Increased temperatures will lead to increased evaporation within this ecosystem and therefore less soil moisture (Anderson et al. 2008; Porporato et al. 2004). Increase of invasive species may also negatively impact critical carbon, water and energy cycles within grassland habitats (Li et al. 2017).

2.2.8.2 Precipitation

Grasslands were ranked as having a moderate sensitivity to changes in precipitation.

Dominant Vegetative Communities

Dominant vegetative communities in grasslands were ranked moderate for sensitivity to changes in precipitation. Increased winter rainfall will not likely affect these habitats, but little to no spring and fall precipitation reductions may be a limiting factor for grassland production and contribute to a shift in species composition exacerbating invasive species abundance (Harpole et al. 2007; Sandel et al. 2012).

Fish and Wildlife

Fish and wildlife scored moderate for sensitivity to changes in precipitation. With a reduction in spring and fall precipitation, wildlife will likely disperse and seek refuge in adjacent wetlands for water supply which will increase species competition in the adjacent wetland habitats (Parmesan 2007).

Physical Processes

Physical processes were ranked moderate for sensitivity to changes in precipitation. Reduced spring and fall rainfall regimes can shift species composition of grasslands negatively impacting key physical processes that take place within this habitat such as carbon, water and energy regimes (Li et al. 2017). Drier conditions coupled with higher temperatures may lead to lower soil moisture and make soils less resilient and adaptive to sudden flooding events during winter (Porporato et al. 2004; Diffenbaugh 2015; Dettinger et al. 2016). Additionally, drought-like conditions and higher temperatures may increase wildfire risk for grassland communities, though past studies have shown that grassland communities may have more adaptive capacity to extreme conditions including drought and wildfire (Craine et al. 2013).

2.2.8.3 Sea Level Rise

Un-leveed Grassland

Un-leveed grassland was rated moderately sensitive to SLR.

Dominant Vegetative Communities

Un-leveed grasslands occur at slightly higher elevations than wetlands and riparian/willow ecosystems. Accretion rates of grasslands have not been studies, but are likely to be lower than those of wetland and riparian/willow ecosystems. While they can withstand temporary flooding, the dominant vegetative communities will be sensitive to permanent flooding from SLR. Grassland vegetation communities were ranked as having a moderate sensitivity to moderate changes in SLR.

Fish and Wildlife

The extent of grasslands has increased by 30% in the modern Delta (Robinson et al. 2014). Grasslands in the Delta are highly altered with almost 90% of the plant species comprising invasive species (SFEI-ASC 2014). Therefore, the sensitivity to SLR of wildlife species depending grasslands was ranked low.

Physical Processes

In grasslands at slightly higher elevation, physical processes are expected to be unchanged by moderate levels of SLR. If the water level rises, lower laying grasslands may convert to marsh or riparian ecosystems (Fagherazzi et al. 2019). Physical processes were ranked as having a moderate sensitivity to changes in SLR.

<u>Leveed Grassland</u>

Fish and Wildlife

The extent of grasslands has increased by 30% in the modern Delta (Robinson et al. 2014). While many of the plant species of grasslands in the Delta and Suisun Marsh are non-native, there are grassland-dependent wildlife species. Given the mobility of avian species, they are likely to adapt to changes in ecosystem distribution across the landscape. Terrestrial species dependent on grassland vegetation are likely to be highly impacted in the event of flooding. The loss of over 30,000 acres of grasslands would affect population sizes, decreasing grassland-dependent species but increasing species thriving in the aquatic ecosystems that would arise where grasslands were permanently flooded. Fish and wildlife in grassland ecosystems were ranked as having low sensitivity to SLR.

2.2.9 Agricultural Lands

2.2.9.1 Air Temperature

Agricultural lands were ranked as having a low sensitivity to increases in temperature. Warming temperatures will likely increase evapotranspiration rates thereby decreasing soil moisture content putting undue stress on croplands and associated wildlife species (Schlenker et al. 2007). However, as these areas are heavily managed, increased irrigation will likely offset these stressors (Schlenker et al. 2007). Due to the managed nature of these systems, they have the potential to be more flexible and adaptable to consequences of climate change and can continue to act as a refugia for associated and nearby wildlife such as waterfowl and birds (SFEI-ASC 2014).

2.2.9.2 Precipitation

Agricultural lands were ranked as having a low sensitivity to changes in precipitation.

Projected reduced precipitation rates for spring and fall seasons will be ameliorated by increased irrigation activities maintaining the cropland resources and its habitat value (Schlenker et al. 2007).

During drought years, however, irrigation rates will become more variable and contingent on what farmers have available and can afford. During these dry years some fields may need to be fallowed which can negatively impact croplands and associated wildlife species. Fallowed fields are prone to increased soil erosion during flashy, winter storm events. Consequently, agricultural fields are more vulnerable to the impacts of extreme drought events. Ruderal lands, frequently found in close proximity to agricultural lands, are predominantly comprised of non-native species that are highly tolerant of hot and dry conditions (SFEI-ASC 2014). During drought years vegetation communities may provide an increased fuel source during wildfire season.

2.2.9.3 Sea Level Rise

As agricultural crops rapidly change location and extent across the Delta in response to market conditions, we have not performed regional analyses for this land cover type.

Fish and Wildlife

Fish and wildlife like sandhill cranes and Canada geese that use agricultural areas will be negatively impacted if islands flood permanently. Because the area of wildlife-associated agricultural lands is large in the Central Valley, the sensitivity of wildlife to SLR was ranked as moderate.

2.3 Adaptive Capacity

2.3.1 Inherent Adaptive Capacity

The inherent ability of organisms to respond to increasing air temperatures and changes in precipitation is dependent upon many factors, and individual species will respond differently to the effects of climate change. While some species are expected to adapt in place (e.g., some marsh wildlife and native fish), others will need to relocate to more suitable areas or become extirpated (Beller et al. 2015). Some species have much more narrow thermal envelopes or are not adapted to extreme hydrologic patterns making it more difficult to adapt to increased temperatures, prolonged exposure to extreme heat wave events, flooding and drought events.

Species with higher genetic diversity and larger geographic extents are likely to have higher adaptive capacity (CVLCP 2017).

2.3.2 Institutional Adaptive Capacity

The institutional adaptive capacity of the Delta is dependent upon current and future legislation, regional management decisions, adaptive management activities, and society's ability to curb greenhouse gas emissions. Currently, there several policies specific to the Delta address climate change. The Delta Reform Act was passed by the California Legislature in 2009 and mandates the consideration of "the future impact of climate change and sea level rise" in restoration planning. It identifies a restoration timeline horizon of 2100. The Delta Plan was adopted by the Delta Stewardship Council in 2013 and serves to support the coequal goals of a reliable statewide water supply and a resilient Delta ecosystem. It is one of the requirements of the Delta Reform Act. The ecosystem chapter is currently undergoing a proposed amendment to reflect the latest science on climate change. Executive Order B-30-15 was signed by Governor Brown in 2015 requires California state agencies to incorporate climate change into planning and investment decisions. It also mandates agencies to prioritize natural infrastructure over built infrastructure, and requires actions toward climate preparedness being taken in the most vulnerable populations.

In addition to existing policies, multiple interagency efforts are ongoing to coordinate thinking about and planning for climate change and adaptive management, and to inform policy makers. Activities include developing conceptual models, synthesizing data and published studies, convening workshops, and preparing communication materials for policy makers. Another important body is the Delta Plan Interagency Implementation Committee which comprises the highest-ranking members of 18 state, federal, and regional agencies. This committee is a venue for decision makers to align on priorities, including climate change, around land, wildlife, and water resources. Regulatory authority comes from the Delta Stewardship Council which implements the Delta Reform Act, can make policy decisions, and can require that best available science and adaptive management with regard to climate change are considered for projects planned in the legal Delta.

Suisun Marsh is also subject to regulation under the Bay Plan, which covers the lower estuary. Because many land use decisions are made at local or regional levels, aligning these decisions and actions to address climate change in the entire San Francisco Estuary is necessary. Funding of climate change adaptation actions is a major component of political adaptive capacity—without effective leveraging of resources at the policy level, high-cost adaptation measures will not be feasible.

2.3.3 Sea Level Rise

2.3.3.1 Un-leveed Ecosystems

In the Delta, remnant un-leveed ecosystems occur discontinuously along waterways where geomorphic processes have allowed for their persistence. Natural adaptive capacity to SLR lies in the potential for ecosystems to shift to higher elevations. Although likely severely limited due to levees and development that cut off the landward connection of un-leveed ecosystems, adaptive capacity was estimated by the amount of available area for un-leveed ecosystems to migrate upland.

Restoration projects, particularly when involving tidal wetlands, are key opportunities where thoughtful site design can increase adaptive capacity. By accounting for climate change (for example, creating the opportunity for upland migration via ecological transition zone space), restoration projects can reduce the risks associated with climate change.

Identifying opportunities to use dredge material may be another approach to increase adaptive capacity, especially in the brackish wetlands of Suisun Marsh (Raposa et al. 2020). However, the literature indicates possible detrimental effects on freshwater wetland vegetation including

- a reduction in germination and recruitment from seed banks,
- a reduction of rhizome productivity and hypoxic effects on roots and rhizomes,
- seedling burial and reduction in seedling productivity,
- a reduction in mature plant productivity, and
- changes in vegetation population (Deverel and Finlay 2007).

A study conducted on Twitchell Island that applied sediment layers to wetland mesocosms supports these findings. Detrimental effects of sediment application on biomass accumulation were observed. Sediment application also caused the soil bulk density to increase in the recently deposited sediments by 26 to 48 %.

Another consideration is timing of dredge material availability. Dredging is not permitted after November and during the wetland dormant season when application would have less effect on plant productivity. Therefore, to apply dredge material during the dormant season would require stockpiling. Application during the wetland growing season is not recommended based on the detrimental effect on wetland vegetation.

2.3.3.2 Leveed Ecosystems

For leveed ecosystems, institutional adaptive capacity is likely to be higher than for un-leveed ecosystems. The risk of levee overtopping means a risk of ecosystem loss through deep and permanent flooding. Delta Adapts modeling results show that many levees, under current conditions, would overtop even with only 1 ft SLR, causing the islands to flood. However, Delta islands are heavily managed with a range of motivations for maintenance. Many Delta islands are productive farmland, are home to communities, contain infrastructure such as highways, train tracks, electrical power transmission lines, and pipelines, and are key to maintaining the hydraulic salinity barrier that allows for the State and Federal Water Projects and other in-Delta water diversions to continue. Ongoing investments in Delta levees are highly likely, meaning that current levee conditions will be improved, thus lowering the risk of overtopping. For high-priority islands, there is also a high likelihood that breached levees would be repaired and floodwaters pumped out. Therefore, adaptive capacity of leveed ecosystems is mainly determined by institutional factors such as the motivation to maintain levees. Here we assume a high adaptive capacity for leveed ecosystems in the Delta.

The levees protecting the managed wetlands in Suisun Marsh and maintaining the hydraulic salinity barrier that allows for the State and Federal Water Projects and other in-Delta water diversions to continue are often not maintained to the same levels as the levees protecting wetlands and agricultural lands in the legal Delta. If Suisun Marsh levees are overtopped but not breached with significant damage, water control infrastructure currently used to maintain managed wetland water levels will facilitate tidal drainage. If these flooding events persist for an extended period of time or occur from storm events such as atmospheric rivers that damage levees, the managed wetland habitats and wildlife populations dependent upon them can be negatively impacted. As MSL and storm event frequency increases, flooding events are likely to become more common, putting strain on the levee systems in these areas. Because there currently is no state or federal funding for a majority of the levee maintenance expenses in the Suisun Marsh, the adaptive capacity of managed wetlands was ranked as moderate.

2.3.3.3 Accommodation Space

The 2020 Draft Amendment to the Ecosystem Chapter of the Delta Plan (Chapter 4) mapped potential accommodation space for intertidal ecosystems to move into what are currently upland areas under different climate change scenarios (Figure 17). The data underlying the maps were used to explore the amount of potential accommodation space across three categories of SLR ranges in each Delta region and Suisun Marsh. The results show that potential accommodation space exists throughout the Delta (Figure 21 and Figure 22, Table 12), but that these areas may not have adequate tidal, floodplain, or riverine connection to function as accommodation space. Notably, the Central Delta, where wetland accretion is predicted to be the highest, is almost completely devoid of upland transition zones adjacent to existing wetlands, which are adjacent to deeply subsided islands (Figure 22). In the Cache Slough region, extensive wetlands on Liberty Island have minimal connections to upland transition zones. Lindsey Slough and adjacent areas have more potential, but fewer contemporary wetlands (Figure 22). Unlike leveed ecosystems, where levee repair may have multiple institutional aspects motivating investments in repairing levee failures, tidal systems may not have technical or institutional capacity to create upland accommodation space for existing wetlands. Thus tidal wetland restoration projects are key locations on the landscape where adaptive capacity can be vastly increased by incorporating sea level rise accommodation space into project implementation. Additional research could illustrate where accommodation space has adequate connectivity to function as desired.

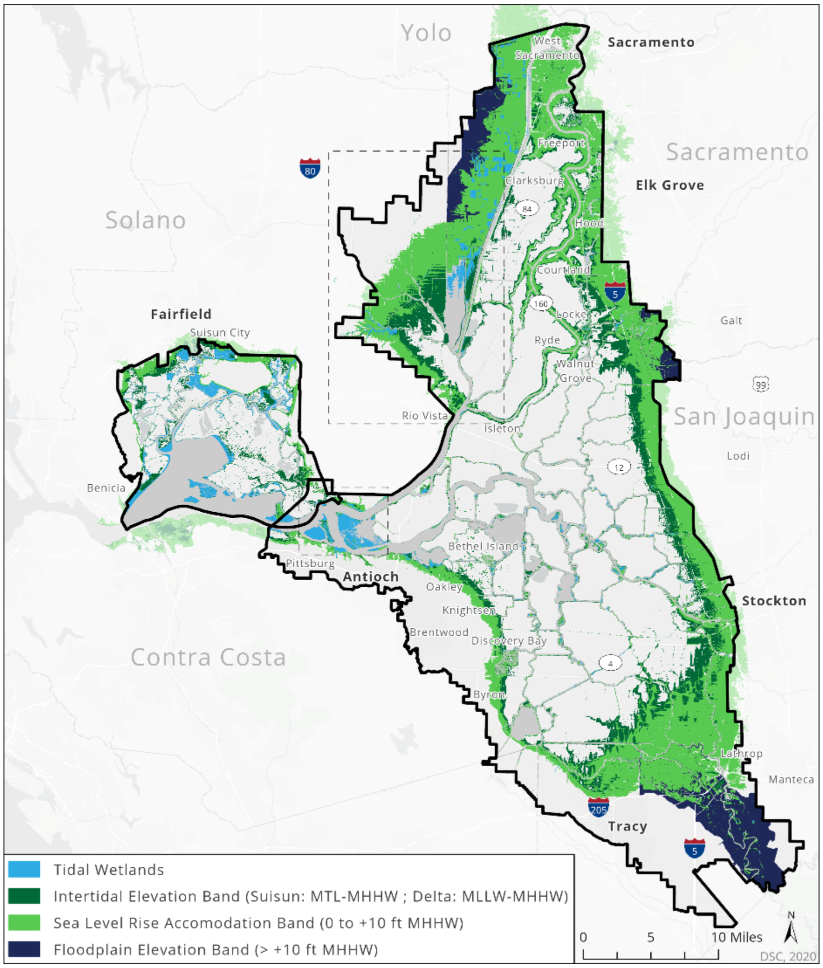


Figure 21. Map of SLR accommodation space categories in the Delta (DSC 2020). Figure 22 shows detailed maps of the inset boxes.

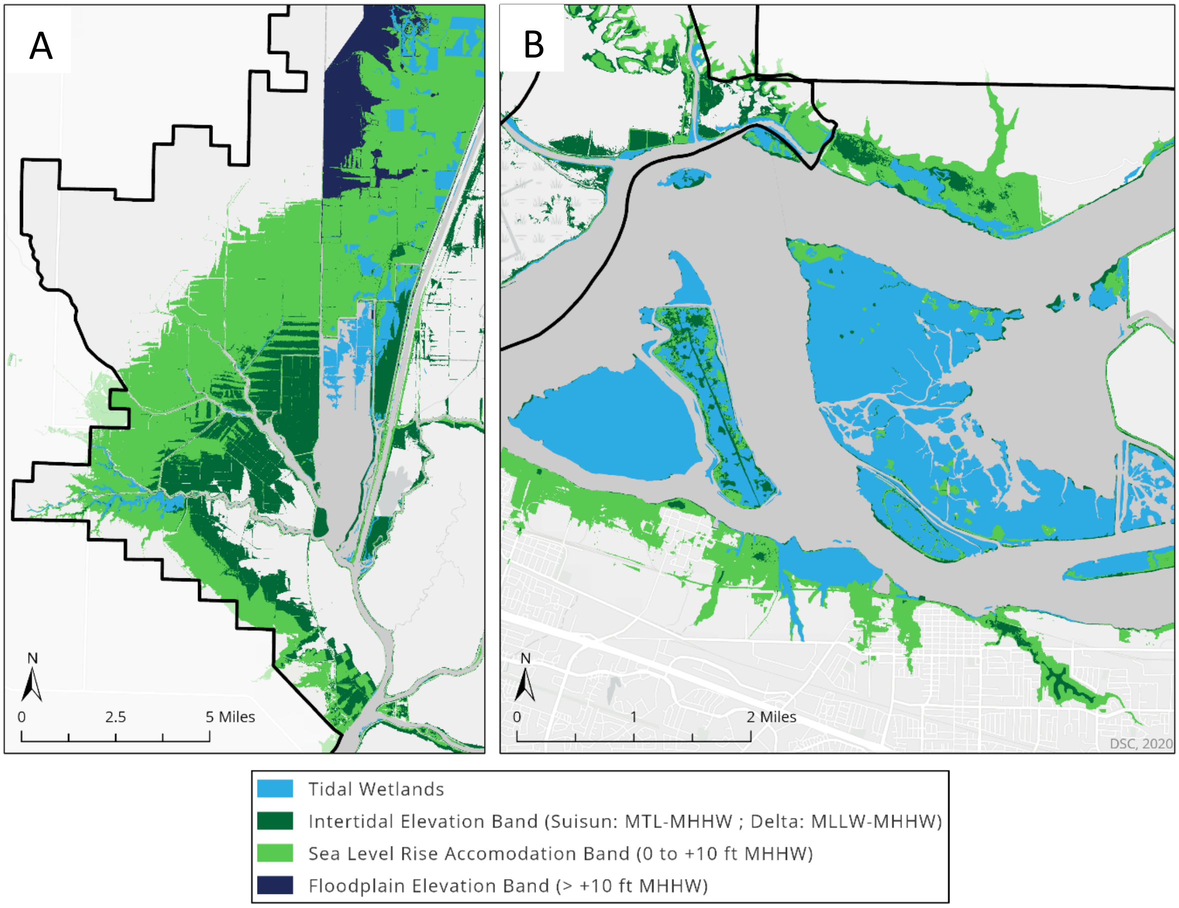


Figure 22. Sea level rise accommodation space for tidal wetlands is present in the Cache Slough Complex tidal freshwater wetlands (A), but absent in Central Delta tidal wetlands (Browns Island, Winter Island, and Sherman Lake) (B).

2.3.3.4 Restoration and climate change

The analyses performed for this effort do not include land slated for future restoration or restoration projects currently under construction. The majority of planned restoration in the Delta is occurring under the EcoRestore program, which includes levee setbacks, fish passage improvements, subsidence reversal, and restoration of tidal wetlands, floodplains, and riparian/willow ecosystems. To date, 1,900 acres of tidal wetlands and 1,700 acres of non-tidal projects have been restored, and are included in this analysis. In the fall of 2020, projects were under construction on 3,700 acres, and slated for near-term implementation on 3,900 additional acres. Restoration of over 38,500 acres are projected as part of the program (EcoRestore 2020).

Because the Delta Plan requires projects to consider climate change in the planning process, the individual projects will largely be resilient to climate change. As all of the EcoRestore projects and others are completed, they will expand the total area covered by natural ecosystems and increase the resilience of the landscape to climate change.

2.4 Other Ecological Assets

This section looks at floodplains and cold-water pool management. These assets are not possible to analyze in the same manner as the ecosystem assets mapped by VegCamp, so qualitative analyses based on literature review are included below.

2.4.1 Floodplains

Floodplains are defined as a landscape feature that is periodically inundated by water from an adjacent river (Opperman et al. 2010). They have a high value to society, because they provide many ecosystem services, including attenuation of flood flows thereby reducing flood risk, filtration of surface water, recreation, provision of protein (fisheries) and fiber, and groundwater recharge which contributes to more-sustained and cooler dry-season flows (Opperman et al. 2010). Floodplains also have a high value to biodiversity. As sites of high productivity they support high biodiversity (Corline, Sommer, and Katz 2017), are a nursery for many fish species (Corline et al. 2017), provide food in the form of plankton and insects for juvenile salmon migrating to the ocean (Jeffres, 2008), and export plankton into the adjacent streams, thereby adding to the river's foodweb (Lehmann et al. 2008).

The Yolo Bypass in the northern portion of the Delta is the primary remaining floodplain of the estuary (Frantzich et al. 2018). Despite substantial alteration, it retains different ecosystem types including multiple channel sizes, broad shoals, tidal marsh, tidal sloughs, and dead-end sloughs (SFEI 2014; Sommer et al., 2005, Goertler et al. 2017). While local tributaries flood the Yolo Bypass in most years, the Sacramento River flows into the Yolo Bypass at the Fremont and Sacramento Weirs in 60% of years (Frantzich et al. 2018). It is used for agriculture from spring through early autumn, but managed as a floodplain in the winter (Corline et al. 2017). The inundation frequency and duration varies with patterns of precipitation. The planned Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project will construct a gated notch at Fremont Weir that will allow a controlled flow from the Sacramento River into the Yolo Bypass to increase the frequency and duration of seasonal flooding.

There are also sizable floodplains along the Cosumnes River which lacks major dams and thus retains a relatively natural hydrology (Jeffres et al. 2008). This river system is rain dominated, because most of the watershed lies below the snow line. A small spring snowmelt signature however is present. In dry years, flow ceases by the end of the summer in the lower river reaches, which is exacerbated by severe declines in regional groundwater levels (Whipple et al. 2016. Intentional levee breaches have restored former farmland to floodplain habitats (Jeffres et al. 2008). This has resulted in sediment deposition, greater topographic complexity, riparian forest establishment and succession, increased productivity, and provision of new spawning and rearing habitat for native fish (Whipple et al. 2016).

Given the importance of Yolo Bypass flooding, understanding the influence of climate change on the frequency, magnitude, duration and timing of flooding is critical for understanding future value of the bypass to the Bay-Delta ecosystem.

2.4.1.1 Exposure

The projected increase in drought will negatively alter the existing Delta floodplain ecosystems by depriving them of riverine inundation. At the same time, floods in the Delta are likely to increase in frequency and intensity of peak flows, but decrease in duration. Understanding the influence of the gated notch and climate change on the frequency, magnitude, duration and timing of flooding is critical for understanding future value of the bypass to the Bay-Delta ecosystem.

Work is in progress to calculate flood metrics for the Yolo Bypass including magnitude, duration, frequency, and timing of floods using model outputs from the CASCADE 2 project (Marissa Wulff, USGS, per. comm.). Model output under 20 climate change scenarios with and without the notch will be examined. Flood metrics will include the start- and end date of each flood event, the average, maximum, and minimum amount of water of each flood event, the total, average, and maximum duration of flood events, and the total number of flood events that will last over 30 days. These results will be interpreted with respect to habitat needs of native fishes and other ecosystem benefits of Yolo Bypass flooding.

2.4.1.2 Sensitivity

Floodplains are highly sensitive to the effects of climate change including extended drought periods and changing flood patterns. Floodplain forests along the Cosumnes River are sensitive to low groundwater levels that are likely to be caused by a combination of extended drought cycles and increased groundwater extraction (Dettinger et al. 2016, Skiadaresis et al. 2019). Droughts may also increase the sensitivity to non-native fish species, because native species tend to reproduce on the floodplains in isolation from non-native species (Dettinger et al. 2016). As winter floods increase and less precipitation falls as snow in Sierra Nevada, winter inundations of floodplains will become most frequent. The predicted increase in frequency of atmospheric rivers will likely exacerbate extreme inundations and damaging floods may become more frequent (Florsheim and Dettinger 2015). These events can increase the potential of juvenile salmon being washed downstream losing the benefit of raising in the floodplains (TNC: Climate Change Impacts on Puget Sound Floodplains).

2.4.1.3 Adaptive Capacity

Because the Yolo Bypass is a tightly managed system, its adaptive capacity is quite high. Weirs and river flows can be modified and managed to increase the frequency and duration of floodplain inundations. The planned gated notch in the Fremont Weir will be instrumental in this respect. However, to account for the effects of increased variability on floodplain inundation, other types of habitat with tidal and riverine connection that do not depend on seasonal flooding should continue to be expanded across the landscape to provide food and habitat for target species.

The adaptive capacity of the floodplains along the Cosumnes River are moderate, because floodplains are naturally adapted to variation in inundation pattern (Florsheim & Dettinger

2015), but longer drought cycles and decreasing ground water levels may affect the floodplain ecosystems beyond their adaptive capacity. Also, under climate change, infrastructure and reservoir management policies to accommodate increased winter flows (and reduced spring and summer flows) and decisions about timing, magnitude, and duration of flow releases from upstream reservoirs are likely to determine the form of those geomorphic responses can influence the adaptive capacity of the floodplains (Florsheim & Dettinger 2015). Unintentional levee breaks which in the past have often occurred as a result of atmospheric river storms and flooding may re-establish functioning floodplain ecosystems (Florsheim & Dettinger 2015).

2.4.2 Cold-water Pools

Currently, reservoirs are managed to provide cold-water releases for salmon and other species, which depend on particular temperatures to complete their life cycles. Extended droughts put this ecosystem management approach at risk (Durand 2020; Zarri et al. 2019).

Management of the state and federal water projects during the last drought required considerable intervention to maintain water supply reliability (Kimmerer et al. 2019; Durand 2020). As droughts become more common, dam releases will become increasingly important for maintaining the location of the 2 ppt low salinity zone (referred to as X2) needed for state and federal water project operations, which will limit the ability to provide cold-water releases for fish species (Durand 2020; Stacey et al. 2015). With low reservoir levels during droughts, a conflict between ecosystem management (cold-water releases) and water supply (water releases maintain the hydraulic salinity barrier) may arise (Dettinger et al. 2016, Durand et al. 2020).

In addition, different species and seasonal runs of anadromous species like salmon have different cold-water requirements at different times of the year, which means that tradeoffs between species needs will be inevitable when system flexibility decreases (Durand 2020; NMFS 2016). Innovative management of dam releases is a potential solution that has been demonstrated at the Shasta Dam (Zarri et al. 2019). The continued use of cold-water pools for in-stream temperature management will depend on the severity and length of future droughts, state-wide water management initiatives including groundwater management, and the need to control X2.

2.5 Secondary Climate Stressors

2.5.1 Wind

Due to the Delta's close proximity to the Pacific Ocean – connected via the San Francisco and Suisun Bays – the region receives more coastal winds than the San Joaquin and Sacramento Valleys. This has been observed to offset historical maximum daily temperatures and has the ability to offset increasing air temperatures that are projected for the region as a factor of climatic change (Lebassi et al. 2009).

California's summer climate is dominated by complex large-scale atmospheric and oceanic patterns, including the coastal ocean and continental weather patterns. Small changes in these patterns can create large variations in the coastal climate, especially when considering climate change stressors, such as increasing air temperature.

The Central Valley of California is surrounded by mountain ranges—Klamath to the northwest, Cascades to the northeast, Sierra Nevada to the east, and the Coastal Range to the west. Low elevation inlets from the ocean into the Sacramento Valley allow for a channeling of cool, marine airflow, otherwise known as a westerly jet, which passes through the Golden Gate Gap—a passage from the San Francisco Bay east into the Delta. Once this cool air enters the Delta, it splits north to the Sacramento Valley and south to the San Joaquin Valley, resulting in enhanced daytime onshore winds caused by the temperature differential between cool coastal air and warm inland valley areas. The reverse process occurs in the evening, resulting from offshore land-breezes that occur when the land cools quicker than the sea (Lebassi et al. 2009).

Studies indicate that projected warming of summer air temperatures in the inland valleys may produce enhanced cool-air sea breeze activity due to a large temperature gradient between the land-sea interface. This enhanced wind effect may have the ability to offset localized summer temperatures in the Delta (Lebassi et al. 2009).

2.5.2 Water Temperature

Increasing air temperatures have direct consequences on water temperatures in the greater Delta watershed. Water temperatures at a specific location are dependent on the interplay of atmospheric forcing, riverine flows, and tidal dispersion – all of which are projected to be impacted by climate change. Warming water temperatures will vary spatially in the system and have even been projected to level off at some threshold due to evaporative cooling. These shifts will impact dissolved oxygen levels, species-specific thermal thresholds, ecological function, predator-prey dynamics, and more (Wagner et al. 2011; DSC 2018a).

Warming water temperatures will similarly impact the quality of aquatic habitats and the ability of native amphibious populations to adapt to new environmental factors. Potential phenological mismatch between the timing of spawning and prey availability is likely to be triggered by the increased stress of warmer waters (Moyle et al. 2013; DSC 2018a).

Fifty percent of California's native fish are already critically or highly vulnerable to extinction, and those species that require cold water (below 71.6°F) have been identified as more likely to become extinct. By the mid-21st century, juvenile salmonids' weights are expected to be lower in the California Central Valley as stream temperature and flow influence egg development and juvenile growth (Beer and Anderson 2013). By the end of the century, the Sacramento River water temperatures could warm as much as 5.4 to 10.8°F (Wagner et al. 2011).

Further, the effects of climate change are likely to alter the hydrologic forces in the Delta's watershed, affecting operational flows, those managed to meet water quality criteria and exports, for the State Water Project, Central Valley Project, and to meet Bay-Delta water quality criteria. While these operations are not directly tied to climate change effects, as they are human-managed, operations will likely need to be adaptively managed and modified to accommodate factors that are affected by climate change. These include tradeoffs in reservoir level, flood management and water supply, and cold-pool flow releases to manage water temperatures, and other environmental demands (DSC 2018a).

2.6 Ecosystem Asset Vulnerability

Based on the exposure, sensitivity, and adaptive capacity ratings for ecosystems with respect to SLR, the vulnerability of the different ecosystem assets was calculated (Table x).

Table 13. Ecosystem asset vulnerability ratings to sea level rise are derived using the formula Vulnerability = Exposure + Sensitivity – Adaptive Capacity.

Ecosystem Asset	Exposure Rating	Sensitivity Rating	Adaptive Capacity Rating	Vulnerability Rating	Vulnerability Rating
Tidal Freshwater Wetland	High 3	High 3	Low 1	5	High
Non-tidal Freshwater Wetlands	High 3	High 3	High 3	3	Moderate
Tidal Brackish Wetland	High 3	High 3	Moderate 2	4	High
Managed Wetland	High 3	High 3	Moderate 2	4	High
Un-leveed Riparian and Willow Ecosystems	Low 1	Low 1	Low 1	1	Low
Leveed Riparian and Willow Ecosystems	Moderate 2	High 3	High 3	2	Moderate
Wet Meadow/ Seasonal Wetland	High 3	High 3	High 3	3	Moderate
Alkali Seasonal Wetland	Low 1	High 3	High 3	1	Low
Un-leveed Grassland	Low 1	Moderate 2	Low 1	2	Moderate
Leveed Grassland	Moderate 2	High 3	High 3	2	Moderate
Wildlife-associated Agriculture	High 3	High 3	High 3	3	Moderate

* Please note that, unlike in the exposure and sensitivity matrices, high ratings are positive and marked in yellow, and low ratings are negative and marked in red.

Table 14. Ecosystem asset vulnerability ratings by primary climate driver

Ecosystem Asset	Un/ Leveed	Air Temperature	Precipitation	Sea Level Rise
Tidal Freshwater Emergent Wetlands	Un-leveed	low	low	high
Non-Tidal Freshwater Emergent Wetland	Leveed	moderate	moderate	moderate
Tidal Brackish Water Emergent Wetland	Un-leveed	low	low	high
Managed Wetlands	Leveed	low	low	high
Riparian/Willow Ecosystems	Un-leveed	moderate	moderate	low
Riparian/Willow Ecosystems	Leveed	moderate	moderate	moderate
Wet Meadows/Seasonal Wetlands	Leveed	high	high	moderate
Alkali Seasonal Wetland Complex	Leveed	high	high	low
Grasslands	Un-leveed	moderate	moderate	moderate
Grasslands	Leveed	moderate	moderate	moderate
Wildlife-associated agriculture	Leveed	low	low	moderate

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CHAPTER 3. KEY FINDINGS
(VA SECTION 7.2 RESTORE DELTA ECOSYSTEMS)

3.1 Management Implications

Key findings of this vulnerability assessment (1) highlight the ecosystem assets that scored moderate and greater and (2) identify how those particular ecosystem assets could be managed into the future in order to reduce vulnerability to climate drivers.

Ecosystems that scored as highly vulnerable include the following:

- Tidal Freshwater Wetland, Brackish Wetland, and Managed Wetland—high vulnerability to SLR
- Non-tidal Freshwater Wetlands, managed wetlands, and grasslands – high vulnerability to increasing air temperature
- Wet meadow/Seasonal Wetlands– high vulnerability to increasing air temperature and changes in precipitation
- Alkali Seasonal Wetlands – high vulnerability to changes in precipitation

Ecosystems that scored as moderately vulnerable include:

- Tidal Freshwater Emergent Wetlands – moderate vulnerability to increasing air temperature
- Non-Tidal Freshwater Emergent Wetlands – moderate vulnerability to changes in precipitation, and SLR
- Grasslands – moderate vulnerability to SLR
- Leveed Riparian and associated ecosystems – moderate vulnerability to increasing air temperature, changes in precipitation, and, in leveed areas, SLR
- Wet meadow – high vulnerability to air temperature, precipitation, and SLR
- Alkali Seasonal Wetland Complex – moderate vulnerability to SLR
- Grasslands – moderate vulnerability to increasing air temperature, changes in precipitation, and SLR
- Agricultural -- moderate vulnerability to increasing SLR

Tidal wetlands were ranked highly vulnerable to SLR, with risk increasing considerably under the 6 foot SLR scenarios added for the ecosystem chapter. Across California and Oregon, near complete loss of tidal wetlands by 2110 was projected by Thorne et al. (2018). Three key issues with managing existing wetland sustainability in the context of SLR are: 1) the logistical issues with and limited efficacy of adding sediment to wetlands to increase marsh surface elevations

(Deverel and Finlay 2007); 2) the decline of sediment supply in recent decades (Moftakhari et al. 2015) and uncertainty in future sediment supply from the Delta watershed (Stern et al. 2020); and 3) the limited upland accommodation space connections of existing tidal wetlands that increase resilience to SLR (Schile et. al 2014, Thorne et. al 2018).

The results of this study indicate that rapid action to restore tidal wetlands in the Delta and Suisun Marsh is likely to create ecosystems that will be able to develop the biophysical feedbacks required to keep pace with moderate rates of SLR in coming decades (SFEI and SPUR 2019; Swanson et al. 2015; Schile et al 2014). However, planning projects with substantial connections to upland accommodation space is critical for creating tidal wetland investments that will persist past 2100. The Delta Plan and other guiding documents require proactive integration of climate change projections into project planning, which should include considerations that, unlike built infrastructure, tidal wetland restoration can take decades to develop the processes that will allow for SLR resilience. Thus, the sooner projects can be implemented, the better their chances of long-term success (SFEI and SPUR 2019).

For leveed ecosystems, SLR has different management implications. While exposure and risk are high, numerous technical opportunities exist for protecting leveed areas. Setback levees can increase levee strength while creating in-channel marshes and riparian habitat. On heavily subsided islands, transitions to managed subsidence reversal wetlands can reduce the risk of levee failure while creating extensive habitat for avian and other species.

Wet meadows, seasonal wetlands and alkali seasonal wetlands are already heavily impacted ecosystems within the Delta and Suisun Marsh. Land use extent for alkali seasonal wetlands has declined 95% compared with historical acreage, and wet meadows/seasonal wetlands have declined by 91% (DSC 2018b). These sharp declines have been due to a culmination of factors, including the alteration of land for agriculture and urban development. The remaining wet meadows, seasonal wetlands, and alkali wetlands are small in size, fragmented, and impacted by human stressors not associated with climate change (DSC 2018b). Increased pressure from climate drivers may push these ecosystems to collapse, unless adaptive management, restoration, and conservation measures are implemented.

Managed wetlands are highly likely to flood even under base conditions, which contributes to their high vulnerability to SLR. However, they are currently managed for waterfowl, and will likely transition to tidal mudflat or wetland. This may mean that a loss of managed wetlands could lead to the creation of productive aquatic or intertidal ecosystems.

Ecosystems likely to be moderately impacted by increasing air temperature and local precipitation changes include non-tidal freshwater emergent wetlands, riparian/willow ecosystems, and grasslands. Non-tidal freshwater emergent wetlands are likely to experience increased evapotranspiration rates, leading to an increase in remnant water temperatures, which will cause stress on plant and wildlife communities and the potential for further fragmentation of this ecosystem type within the Delta.

Riparian/willow ecosystems will vary in their exposure, sensitivity and ability to adapt to climate stressors/hazards based on the proximity to water sources and also elevation. Shading provided by the trees may increase adaptive capacity of fish and wildlife species that depend on cooler water temperatures. In the present landscape, most riparian/willow ecosystem patches are very narrow and small, restoring larger riparian forests and wider riparian areas lining rivers and sloughs with minimal gaps would improve their ecological function.

The majority of grasslands in the Delta is currently is located on artificial levees or in subsided areas behind levees (Robinson et al. 2016). Non-native species are common, but some levees are managed for native grass species (Tuel 2017). In the short term, these areas are important for supporting wildlife, such as lizards and snakes, grassland dependent bird species such as white-tailed kites, Swainson's Hawks, and western burrowing owls, and insects including pollinators. Because of the risk of island flooding with SLR, in the long term, grassland restoration should focus on the transition zone between aquatic and terrestrial ecosystems around the periphery of the Delta. Flooding of islands as a result of SLR and levee failure may result in grasslands transitioning to riparian or wetland areas which should be supported by managing for native species.

3.1.1 Targeting Resilience within the Delta

Understanding which ecosystem assets within the Delta are most vulnerable to particular climate parameters is important for future management actions, adaptation strategies, and restoration practices to lessen projected impacts. Increasing ecosystem resilience within the Delta at a landscape level is a critical conservation target that requires collaboration across sectors and considerations of connectivity, complexity, redundancy, and scale (DSC 2018b).

California EcoRestore, a restoration initiative led by the California Natural Resources Agency, has been in operation since 2015 with a mission to restore 30,000 acres of critical habitat in the Delta, Suisun Marsh, and Yolo Bypass (DWR 2020). The project employs a diversity of restoration strategies:

- Breaching levees to allow river water to flow up into the banks of the Delta with the tides, allowing fish to access more food.
- Inserting underwater passages in flood-control weirs to reopen floodplains for fish access.
- Inundating Delta islands to sequester atmospheric carbon and reverse subsidence.
- Installing setback levees to protect communities from flooding and restore ecosystems
- Spurring the production of zooplankton, or small bugs eaten by fish, by managing flows of river water into new areas.

Implementation of restoration actions such as these that reconnect tidal wetlands and flood plains, remove aquatic barriers, reverse subsidence, create marsh migration space, and that re-establish native plant and animal communities is important to the future of the Delta and will provide species with better opportunity to adapt to climate change.

This section summarizes the implications for the protection, restoration, and management of the Delta ecosystem (DSC 2018b):

1. The Delta is unique and of global ecological importance as an estuary.
2. Restoration potential varies sub-regionally within the Delta.
3. Lands with suitable elevations should be prioritized for hydrologic reconnection and restoration of natural vegetation communities.
4. Reversing subsidence is critical to reducing the risk of levee failures leading to undesirable ecosystem conditions, and in protecting opportunities for restoration in the Delta.
5. Recovery of native species populations within the Delta will require targeting re-establishment of vegetation communities that represent the historical species composition, structure, and function.
6. Re-establishing food web function and increasing species habitat requires restoring multiple aspects of connectivity and native vegetation community distribution.
7. Water quality impairs the food web function and species habitat conditions within an already limited footprint.
8. Impaired water quality has compounding effects on other ecosystem stressors such as non-native species and harmful algal blooms.
9. Improving the health of the Delta ecosystem will require actions that address multiple primary stressors.
10. Adoption of best management practices on agricultural lands that reduce impacts to native species or create analogue habitat resources could help mitigate ecosystem stressors.

3.1.2 Next steps

The management implications discussed herein will be developed into a subsequent Climate Adaptation Plan, which will outline step-wise, specific goals and objectives for the entirety of the Delta and will draw on the key findings within this chapter to create ecosystem-based adaptation strategies and specific solution to reduce vulnerability and enhance resilience under future climate scenarios.

3.1.3 Knowledge Gaps

3.1.3.1 Model limitations

- Vulnerability is assessed for individual climate parameters; however, the variables are not truly independent of one another. Accounting for cumulative or interactive effects would be much more complex to assess for the Delta Region.

- Human stressors impact the adaptability and resilience of ecosystems within the Delta, as it is already highly altered and managed.
- SLR modeling does not take into account potential changes to the landscape, including future levee improvements or levee failures.

3.1.3.2 Data Gaps

- Precipitation projections exemplify a lot less certainty, and do not show consistent trends compared with the model predictions for air temperature and SLR.
- Much of the available climate data for air temperature and local precipitation are based off a coarse scale (typically 1/16 degree, or about 6 km grid size). This coarse resolution was necessary to provide readily available depictions of general regional areas that face the greatest climate change vulnerability; however, these data would be much more useful if developed specifically for the scale of the Delta and associated watershed areas.
- The Delta DEM is not corrected for wetland vegetation. A vegetation corrected DEM would allow for more fine scale exploration of SLR impacts on tidal wetlands.

3.1.3.3 Future Research Opportunities

- The true resiliency of native ecosystems is not fully known. Further research is needed to understand how ecosystems may respond to increased frequency and intensity of perturbations or disturbances.
- Ensure future restoration and conservation projects within the Delta incorporate multiple ecosystem services and co-benefits to simultaneously benefit local communities, enhance ecological function, and improve ecosystem quality.

3.1.3.4 Further climate adaptation research to address gaps

- Increase understanding of the effects of SLR on un-leveed riparian/willow ecosystems in the Delta by studying accretion rates.
- Additional research could illustrate where accommodation space is functionally connected to areas that will flood with SLR, and where connectivity can be restored.

Social science research to determine potential human-dimensions topics related to ecosystem climate adaptation.

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CHAPTER 4. REFERENCES (VA SECTION 9 REFERENCES)

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