Appendix 5.A.1

Climate Change Implications for Natural Communities and Terrestrial Species

Appendix 5.A.1
Climate Change Implications for Natural Communities and Terrestrial Species

5.A.1.0 Executive Summary

This appendix summarizes the effects of climate change in California and the Plan Area that are relevant to Bay Delta Conservation Plan (BDCP) natural communities and terrestrial (non-fish) covered species. The purpose of this appendix is to provide the scientific background on the effects of climate change on natural communities and terrestrial species and descriptions of how the BDCP has taken into account many of these expected changes in the design of the conservation strategy in Chapter 3, *Conservation Strategy.* The assumptions made in the BDCP regarding climate change modeling for aquatic covered species are presented in the Appendix 5.A.2, *Climate Change Approach and Implications for Aquatic Species*.

Following are examples of potential effects of climate change on natural communities and terrestrial species in the Plan Area.

- Higher temperatures and earlier spring conditions may disrupt environmental cues that many terrestrial plant and animal species rely on to initiate critical life history events such as migration (Parmesan 2006; Parmesan and Yohe 2003; Penuelas and Filella 2003; Forest and Miller-Rushing 2010; Miller-Rushing et al. 2010; Ibáñez et al. 2010).
- Higher temperatures may exceed the thermal tolerances of some species, which may displace species or reduce growth and survival (Parmesan 2007; Albright et al. 2010; Perry et al. 2012).
- Higher temperatures already are resulting in more winter precipitation falling as rain and earlier snowmelt, which has increased the risk of winter flooding of terrestrial habitats and reduced water availability for terrestrial plants and animals in late summer (Knowles and Cayan 2004).
- An increase in heat waves and a greater likelihood of prolonged drought will reduce the growth and survival of vegetation and the survival of terrestrial wildlife in summer (Gershunov et al. 2009; Mastrandrea et al. 2009).
- Warmer spring and summer temperatures, combined with reduced precipitation as a result of reduced snowpack and earlier spring snowmelts, increase the risk of wildland fires and wildfire-related deaths of terrestrial wildlife and damage to terrestrial habitats (Westerling et al. 2006).
- Reduced precipitation and runoff volumes may reduce the extent of water-dependent habitats such as vernal pools (Pyke 2004).
- Sea level rise, increased storm surge, and heavy winter rains will increase the risk of catastrophic flooding of wetland and riparian habitats in winter (Parker et al. 2011).
- Rising seas will increase water depths of wetlands and likely increase salinity of those habitats, potentially favoring salt-tolerant invasive species (Parker et al. 2011).
- Sea level rise combined with ongoing subsidence, more winter storms and increased river flooding will increase the instability of the Sacramento–San Joaquin River Delta's (Delta's) levee

network, increasing the potential for unintentional flooding of managed wetlands and the risk of catastrophic flood events (Mount and Twiss 2005; Florsheim and Dettinger 2007).

The physical changes associated with climate change are expected to be widespread and long-lasting, even if meaningful reductions in greenhouse gas emissions (i.e., climate change mitigation) are made now (Solomon et al. 2009). The BDCP will not counter or reverse these physical trends. However, conservation measures will provide benefits to the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) ecosystem, natural communities, and covered terrestrial species that are expected to reduce their vulnerability to the adverse physical and biological effects of climate change. Table 5.A.1.0-1 provides examples of conservation measures that promote climate resilience, and Table 5.A.1.0-2 indicates some of the benefits of the conservation strategy for terrestrial ecosystem services.

Table 5.A.1.0-1. Conservation Measures to Increase Climate Resilience of Natural Communities and Terrestrial Species

Approaches for Increasing Resilience*	**Examples of Conservation Measures That Increase Resilience**
Reduce anthropogenic stressors	*CM11 Natural Communities Enhancement and Management* will include rapid response to contain and eradicate new occurrences of invasive nonnative species
Represent a portfolio" of variant forms of a species or ecosystem	*CM9 Vernal Pool and Alkali Seasonal Wetland Complex Restoration* will include a range of environmental conditions within large, interconnected or contiguous expanses of vernal pool communities. *CM7 Riparian Natural Community Restoration* will increase habitat complexity and wildlife diversity by maintaining late-successional vegetation in a number of locations and ensuring horizontal and vertical overlap among vegetation components.
Replicate to maintain more than one example of each ecosystem or population	*CM3 Natural Communities Protection and Restoration* will protect natural communities across a wide range of their occurrence in the Plan Area and will protect multiple populations of covered terrestrial species.
Restore or rehabilitate lost or degraded ecosystems	All conservation measures seek to recover ecological functions and habitat values (e.g., dispersal pathways, refugia). For example, *CM3 Natural Communities Protection and Restoration* and *CM4 Tidal Natural Communities Restoration* will restore environmental gradients (hydrology, elevation, soils, slope, aspect) that will allow wetlands to migrate in response to rising sea levels.
Use refugia or less affected areas as sources of "seed" for recovery or destinations for migrants	*CM4 Tidal Natural Communities Restoration* will create upland refugia for terrestrial species. *CM5 Seasonally Inundated Floodplain Restoration* and *CM6 Channel Margin Enhancement* will allow natural flooding to create bare substrate for vegetation colonization.
Relocate or transplant organisms from one location to another in order to bypass a barrier	*CM11 Natural Communities Enhancement and Management* provides for translocation (e.g., if western pond turtle habitats are threatened by sea level rise, individuals could be moved to less vulnerable wetlands)
CM = Conservation Measure * Source: Julius et al. 2008	

Table 5.A.1.0-2. Benefits of Conservation Strategy for Ecosystem Services Provided by Wetlands Ecosystems

Ecosystem Service	Benefits
Protection from sea level rise	Increased wetland plant biomass, including belowground production, helps to promote accretion and the ability of the marsh to keep pace with sea level rise (Callaway et al. 2011; Parker et al. 2011). A wider and more extensive marsh plain in tidal wetlands and a wider floodplain in river systems increases protection of upland habitat and human structures from flooding and storm surges, which are predicted to worsen with climate change (Cayan et al. 2008).
Protection of migrating birds	The brackish marshes in the North Bay and Suisun Marsh provide an important resting place for birds along the Pacific Flyway. These birds will experience increasing loss of mudflats used for forage and resting during long-distance migration (Point Reyes Bird Observatory 2011). Riparian areas are the most critical habitat for neotropical migrants such as the western yellow-billed cuckoo, least Bell's vireo, and Swainson's hawk (Riparian Habitat Joint Venture 2004).
Increased upland transition zones	Tidal wetland restoration will include a wide upland transition area, providing refuge for wetland animals during extreme high tides (predicted to increase with climate change) and opportunities for wetland migration upslope in response to sea level rise (Callaway et al. 2011; Parker et al. 2011).
Reduction in risks of levee failure	When wetlands behind levees dry out, the organic matter in the soil oxidizes, which can increase subsidence. This can reduce the stability of levees and increase the risk of levee failure during flooding, resulting in saltwater intrusion into aquifers and farmlands (Mount and Twiss 2005). Restoration will help prevent wetlands from drying out and reduce subsidence.
Natural water management	Improved floodplain connections to rivers will restore the ability of floodplains to absorb flood flows and provide a reservoir of water to help species withstand droughts.
Increased habitat variability	Supports species diversity by providing a mosaic of habitats that can be used by different species that have evolved to use specific habitats.
Increased habitat patch size and connectivity	Protection and restoration of a variety of natural communities will increase the patch size and connectivity of these habitats. Increasing patch size will tend to increase population sizes of native species, which provides more resilience against a changing climate. Increasing connectivity allows more genetic exchange among populations and movement to more suitable habitats as environmental conditions change.
Carbon sequestration and climate change mitigation	Marsh grasses, microalgae, and phytoplankton remove carbon dioxide (CO_2) from the atmosphere and marsh soils store carbon from marsh organisms, helping to control CO_2 emissions that contribute to climate change (Marsh et al. 2005; Trulio et al. 2007).

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Acronyms and Abbreviations

°F	degrees Fahrenheit
Bay-Delta	San Francisco Bay/Sacramento–San Joaquin River Delta
BDCP	Bay-Delta Conservation Plan
CALFED	CALFED Bay-Delta Program
CM	Conservation Measure
CO_2	carbon dioxide
Delta	Sacramento–San Joaquin River Delta
DPS	distinct population segment
ENSO	El Niño Southern Oscillation
FR	*Federal Register*
MLLW	mean lower-low water
NWR	National Wildlife Refuge
ppt	parts per thousand
PRBO	Point Reyes Bird Observatory
ROA	restoration opportunity area

Appendix 5.A.1
Climate Change Implications for Natural Communities and Terrestrial Species

5.A.1.1 Introduction

This appendix is organized as follows. The effects of climate change on the physical environment and fire regimes are summarized first, followed by a discussion of potential and expected ecological responses to these changes. Next, the Bay Delta Conservation Plan (BDCP) reserve design process is described in the context of climate change adaptation. Each natural community then is evaluated qualitatively for expected changes in response to climate change in the Plan Area. Finally, a vulnerability assessment is applied to the covered terrestrial species to help assess the relative magnitude of potential effects on each species and species group from climate change. Examples are also provided of specific effects of climate change that might occur on the terrestrial covered species.

5.A.1.2 Climate Change Effects on the Physical Environment

Climate change results in both direct and indirect effects on the physical environment. These effects are summarized globally, in California, and in the Plan Area in Appendix 2.C, *Climate Change Implications and Assumptions*. The effects that have the most important implications for ecological responses to climate change are outlined below.

5.A.1.2.1 Temperature

Increased warming from ongoing climate change has many direct effects on species viability and natural community distribution and composition, as well as indirect effects on the amount and timing of precipitation, the accumulation and release of water in snowpack, and the frequency of severe weather and related disturbance events.

Higher air temperatures can cause early arrival of spring and delay of fall, altering species' migration and reproduction patterns (Walther et al. 2002; Parmesan 2006). Increased evapotranspiration can reduce soil moisture and the availability of water for terrestrial vegetation and can lead to earlier drawdown of vernal pools and other seasonal wetlands, thus affecting special-status wildlife using these areas.

Increased water temperatures can affect water supplies for waterfowl and reduce water quality (e.g., dissolved oxygen levels), impairing the developing eggs and larvae of invertebrates and amphibians in freshwater habitats. In addition, some species have developmental phases influenced by water temperatures that could be negatively affected by warmer water temperatures.

5.A.1.2.2 Precipitation

Climate projections oriented on Sacramento indicate that interannual-decadal variation in annual precipitation likely will increase over this century, and there will be a drying tendency, indicated by most simulations showing mid- and late 21st century 30-year averages with precipitation deficits of -5 to -15% of historical (1961 to 1990) climatology (Cayan et al. 2009).

Changes in precipitation can interfere with life cycle events that are tied to moisture conditions (Walther et al. 2002; Parmesan 2006) and the suitability of moisture-dependent habitats. In the Sierra Nevada, more precipitation is falling as rain instead of snow, increasing the risk of winter flooding and reducing the availability of water to support dry-season flows, a trend that is projected to continue over the permit term (Knowles and Cayan 2004; Knowles et al. 2006; Maurer et al. 2007; Moser et al. 2009; Cloern et al. 2011).

5.A.1.2.3 Sea Level Rise

Increasing sea level rise will increase saltwater intrusion into the Sacramento–San Joaquin River Delta (Delta), disrupting marsh and estuary ecosystems and reducing freshwater and terrestrial plant species habitat. Increased salinity also may increase mortality for species that are sensitive to salinity concentrations. Changes in salinity levels may place added stress on other species, reducing their ability to respond to disturbances. Increased frequency and severity of flood events combined with sea level rise can relocate species and damage or destroy species habitat. Lower ecosystem productivity from increased salinity will affect both phytoplankton-based and detritus-based foodwebs (Parker et al. 2011).

Sea level rise is predicted to be an especially significant factor in the Plan Area, where much of the land has subsided to below sea level and is protected from flooding by levees. In the Delta, sea level rise in combination with ongoing subsidence of Delta islands will increase the instability of the Delta's levee network, increasing the potential for island flooding and sudden landscape change in the Delta over the next 50 years (Mount and Twiss 2005). The current subsided island condition, combined with higher sea level, increased winter river flooding, and more intense winter storms, will significantly increase the hydraulic forces on the levees. With sea level rise exacerbating current conditions, a powerful earthquake in the region could collapse levees, leading to major seawater intrusion and flooding throughout the reclaimed lands of the Delta, altering the tidal prism, and causing substantial changes to the tidal perennial aquatic natural community (Mount and Twiss 2005; Florsheim and Dettinger 2007).

5.A.1.2.4 Snowpack and Runoff

Snowpack is projected to decline by 20 to 40% by the end of the century, depending on the emissions scenario. In addition, snowmelt is occurring earlier, changing the timing of freshwater inflows to the Delta (Knowles and Cayan 2002, 2004; Knowles et al. 2006; Maurer et al. 2007).

These changes will shift the freshwater-salinity mixing zone eastward, progressively encroaching on the Delta and increasing the salinity in the brackish regions of the Napa River and Suisun Bay, and potentially the western Delta. Because of the shift in the timing of freshwater inflows to the Delta, Knowles and Cayan (2004) projected that inflows will increase by 20% from October through February and decrease by 20% from March through September.

Reduced precipitation and runoff volumes can reduce floodplain habitat and vegetation growth. Changes in snowmelt timing, and associated changes in runoff timing, can impede riparian vegetation establishment and survival. Increased evaporation will likely affect the amount of freshwater habitat such as vernal pools, other seasonal wetlands, and ponds that are habitat for several special-status wildlife species. Loss of watershed vegetative cover and reduced soil moisture during droughts will reduce soil stability and increase erosion potential.

5.A.1.2.5 Extreme Events

The frequency and magnitude of both high maximum and high minimum temperatures are projected to increase in California (Bell et al. 2004; Mastrandrea et al. 2009, 2011). Climate modeling of a low emissions scenario projects a tenfold increase in extreme temperatures that currently occur only once every 100 years; under a high emissions scenario, these extremes could occur every year (Mastrandrea et al. 2009, 2011). The frequency of heat waves is increasing already, and it is generally becoming more humid (Gershunov et al. 2009).

In both the Sacramento and San Joaquin basins there has been an increase in the frequency of extreme wet and dry years since the mid-1970s (Bureau of Reclamation 2011). Climate model projections of precipitation extremes are highly variable, depending on the model and downscaling method used. However, in general, projections indicate that longer dry spells will become more common, punctuated by occasional intense rainfall events (Mastrandrea et al. 2009, 2011). In the Sierra Nevada, extreme precipitation events are projected to increase in the winter (Leung et al. 2004). Heavy rains in winter or sudden melting of snowpack will increase the risk of flooding of downstream habitats. Increased occurrence or severity of droughts will reduce species' water supplies and food resources, as well as vegetative cover and soil moisture. Reductions in soil moisture, along with high temperatures, will create erodible soil conditions, increasing the potential for high-intensity runoff events triggered by heavy precipitation.

Extremes in coastal storm surge and floods due to high runoff levels in California rivers often coincide, and storm surges can exacerbate Delta flooding. Bromirski and Flick (2008) demonstrated that extreme sea-level events in the ocean near San Francisco propagate to the Delta. The combination of higher sea levels and larger precipitation events has increased the frequency of extreme tidal flows in the Delta.

5.A.1.3 Fire

California could experience a 55% increase in wildfire risk by mid-century (Luers et al. 2006). Many factors influence the likelihood of wildland fires, including precipitation, winds, temperature, and vegetation. For some locations, increasing precipitation and temperature may stimulate increased vegetation growth through a portion of the year, creating more fuel to burn later; other locations may experience decreasing precipitation and increasing temperature, creating dry vegetation that can burn easily (Luers et al. 2006). Drier and warmer conditions increase evapotranspiration, leading to a reduction in soil moisture and an increase in the likelihood of fire. Simulations indicate that increased temperatures increase large fire frequency in wetter, forested areas because of the effects of warmer temperatures on fuel flammability (Westerling and Bryant 2008). However, simulations also indicate that reduced moisture availability because of lower precipitation and higher temperatures may lead to reduced fire risks in locations where fuel flammability is less important than the availability of fine fuels (Westerling and Bryant 2008). Long-term records indicate that over the last three decades the wildfire season in the western United States has increased by 78 days, and burn durations of fires over 1,000 hectares have increased from 7.5 to 37.1 days, indicating that climate change is contributing to the increase in wildfires (Westerling et al. 2006). In response to longer dry seasons, wildfires in California have been increasing in frequency, duration, and size (Moser et al. 2009).

5.A.1.4 Ecological Responses to Climate Change

Increased air and water temperatures, greater variability in precipitation, early snowmelt, increased winter flooding, prolonged drought, more heat waves, accelerated sea level rise, increased Delta salinity, greater erosion, and changes in fire regimes may affect species and natural communities in the Plan Area in a number of ways. Information on potential ecological responses to the direct and indirect effects of climate change is summarized below. In considering this information, it is important to recognize that ecological responses to environmental change are often more complex than the available literature may imply. In many situations, response curves may not be linear or even unique, and step changes are likely to cause responses different from changes that occur gradually.

5.A.1.4.1 Phenology

There is substantial evidence of phenological changes among species from all taxa and regions of the world (Penuelas and Filella 2003; Parmesan 2006; Forest and Miller-Rushing 2010; Miller-Rushing et al. 2010; Ibáñez et al. 2010). A review of 1,598 species found that nearly 60% showed changes in phenology and/or distributions in recent decades (Parmesan and Yohe 2003). Phenological events are occurring 2 to 3 days earlier per decade across a range of species (Parmesan and Yohe 2003) and 5.1 days earlier per decade for those species showing the greatest changes (Root 2003). In lowland California, 70% of 23 butterfly species advanced the date of first spring flights by an average of 24 days between 1972 and 2002 (Forister and Shapiro 2003). A study analyzing spring and fall phenology of migratory songbirds moving through California found that species sensitive to changes in climate changed their migratory arrival in spring, though not their fall phenology. They tended to arrive earlier in spring in association with warmer local temperatures and periodic large-scale changes in weather such as a strong El-Niño Southern Oscillation (ENSO) event (MacMynowski and Root 2007). Migratory bird species that do not show a phenological response to climate change experience population declines (Møller et al. 2008). Long-distance migrating birds have shown declines in western Europe (Both and Visser 2001), and some species are reducing migration distances (Visser et al. 2009).

5.A.1.4.2 Physiological Tolerances

Species differ in their sensitivity to temperature, precipitation, moisture, and weather extremes. Species with narrow physiological tolerances or that live close to ecological or physiological thresholds are more likely to exceed their tolerance limits as climate changes.

Climate change can affect terrestrial vegetation communities in a number of ways. High temperatures increase evaporative demand and reduce soil moisture and plant water availability. Variation in the duration, timing, and amount of precipitation affects the vertical distribution of water in the soil profile. The combination of higher temperatures and reduced precipitation favors species that are relatively tolerant of heat and dry conditions. Species that lack these traits may decrease in abundance or experience high mortality in response to prolonged droughts. Although increased carbon dioxide (CO_2) tends to increase photosynthesis and growth in riparian plant species such as cottonwood, higher maximum temperatures resulting from climate change will increase riparian plant heat stress and reduce growth. Plant species currently restricted to relatively low elevations (e.g., Fremont cottonwood) may expand upstream. Species currently at the upper limits of river basins may disappear (Perry et al. 2012).

The evidence is accumulating that extreme events often have a greater influence on species than average conditions (Jentsch et al. 2007; Intergovernmental Panel on Climate Change 2012). Local population extinctions of Edith's checkerspot butterfly correlate with extreme climatic events such as drought (Parmesan 2007). As high temperature events become more common, bird species with narrow temperature tolerances will experience more frequent episodes of thermal stress (Point Reyes Bird Observatory 2011). There is evidence that thermal tolerance is a strong predictor of population resilience to climate warming (Jiguet et al. 2006). Drought is associated with decreased habitat quality for birds, greater bird mortality, reduced reproductive effort, and a decrease in the abundance and diversity of avian communities (Albright et al. 2010). A recent study reports "catastrophic" avian mortality during extreme heat waves (McKechnie and Wolf 2010). The co-occurrence of heat waves and drought is particularly stressful, with bird species' responses varying depending on ecoregion, migratory strategy, and functional traits such as body size (Albright et al. 2010).

5.A.1.4.3 Range Shifts

There have been numerous observations of changes in species' distributions in response to climatic changes. Both plant and animal species that are able to track temperature changes have shifted their distributions toward higher elevations and latitudes (Parmesan et al. 1999; Parmesan 1996; Wilson et al. 2005; Lawler et al. 2009). There is also evidence that the dispersal of montane species may be hindered by declines in the quantity and quality of habitat as they move up in elevation, resulting in range contractions, especially if lower elevation refugia exist (Morelli et al. 2012).

In California's Yosemite National Park, half of 28 species of monitored small mammals showed substantial upward changes in elevation (averaging 500 meters [1,640 feet]), consistent with an increase in minimum temperatures (Moritz et al. 2008). Recently, Peterson and Martinez-Meyer (2009) showed population-level shifts northward in the abundance of large numbers of North American bird species, which are expected to result in species' geographic range shifts in coming years. The northern boundary of one butterfly species expanded from California to Washington (420 miles) in just 35 years; during a year of extreme heat, the species moved 75 miles northward in a single year.

Both empirical observations and simulations under assumed climate change indicate range shifts among a variety of plant species. A modeling study of 80 tree species in eastern North America indicated range expansions for about 30 species and an equal number of range contractions (Iverson et al. 1998). Analysis of vegetation types in California in response to projected climate change indicated a reduction in coniferous forest in the northwestern part of the state and increases in broadleaf vegetation (Lenihan et al. 2003). Loarie and coauthors (2008) projected that up to 66% of California's endemic plants will experience at least an 80% reduction in range size during this century as a result of projected changes in temperature and precipitation.

Some marine species are shifting both location and depth. In the northeast, two-thirds of 36 examined fish stocks shifted northward and/or to deeper depths over a 40-year time period in response to consistently warm waters (Nye et al. 2009). In the California Current System, shifts in spatial distribution were more pronounced in species that were commercially exploited (Hsieh et al. 2008).

A recent meta-analysis of available studies for a range of taxonomic groups found that the rate of change in elevation and latitude is two to three times faster than previously reported (Chen et al. 2011). The median rate of movement to higher elevations is 11.0 meters (36 feet) per decade, and to higher latitudes it is 16.9 kilometers (10.5 miles) per decade.

Some species' ranges may expand rapidly during favorable conditions and contract during unfavorable periods (Walther et al. 2002). Successful dispersal also depends upon a species' ability to withstand rapid fluctuations in climate that may occur over decadal time scales in the course of a longer-term migration (Early and Sax 2011).

5.A.1.4.4 Ecological Interactions

Different species are responding differently to changes in climate, leading to decoupling of important ecological interactions (Walther 2010). Interactions among species, such as predator-prey or pollinator-plant relationships, may be disrupted by climate change if conditions reverse (e.g., Suttle et al. 2007) or the interaction is decoupled (e.g., Visser and Holleman 2001). This could lead to the decline or loss of a resource or alter synchronization in phenology, such as when migration occurs after the time when food resources are available (Parmesan 2006). There are indications that asynchrony may be associated with reduced fitness (Visser and Both 2005). Phenological changes in Edith's checkerspot butterfly have led to mismatches with host plants for caterpillars and nectar sources for adult butterflies (Parmesan 2006). Lizards and owls declined during a period when their prey species experienced unfavorable climatic conditions (Brown et al. 1997). Differential species' responses to the direct and indirect effects of climate change will influence the likelihood, rate, and pattern of spread of nonnative species (Walther et al. 2009) and pests (Pounds et al. 2006).

5.A.1.4.5 Nonnative Invasive Species

The San Francisco estuary has a long history of nonnative species introductions (Cohen and Carlton 1998). Many of these species have successfully invaded the aquatic fauna in the Plan Area, often with adverse consequences on native species and ecosystem processes (e.g., Kimmerer et al. 1994). Nonnative invasive species interact with native species through competition, predation, hybridization, disease, and alteration of habitat, all of which can be influenced by climate change (Dukes and Mooney 1999; Thuiller et al. 2007; Walther et al. 2009). When native and nonnative invasive species respond differently to climate change, the outcome of these interactions can be altered or reversed (Suttle et al. 2007; Bradley and Wilcove 2009; Bradley et al. 2009).

Nonnative competitors may be favored when changes in climatic variables such as temperature and precipitation reduce the growth, reproduction, and/or survival of native species or the ability of native species to disperse to suitable habitat in new locations (Thuiller et al. 2007; Walther et al. 2009). On the other hand, climate change may reduce the competiveness of invasives in some situations. Where this occurs, the retreat of invasive species can provide opportunities for restoration of currently invaded areas (Bradley et al. 2009; Bradley and Wilcove 2009).

A number of nonnative invasive species in the Plan Area may benefit from climate change and therefore potentially increase their adverse effects on ecosystems and native species. The invasive smooth cord grass (*Spartina alterniflora*) outcompetes the native Pacific cord grass, altering the vegetative structure and habitat for the California clapper rail, a covered species. With progressive increases in sea level in the San Francisco estuary, smooth cord grass may ultimately replace Pacific cord grass because it has a high tolerance for the water logging and hypersalinity that develop in the lower marsh as sea levels rise (Goals Project 1999). This also makes it possible for smooth cord grass to spread to tidal flats, which will reduce the exchange of sediment from tidal flats to tidal marshes, inhibiting accretion and impeding the migration of the marsh in response to sea level rise (California Department of Natural Resources 2009; San Francisco Bay Conservation and Development Commission 2011).

Yellow starthistle (*Centaurea solstitialis*) provides another example of an invasion by a nonnative that is facilitated by climate change. Yellow starthistle has been invading California grasslands over the past 50 years. Because yellow starthistle grows better than native grassland species when water is available in late spring, it is thought that climate change will increase the success of this invader. Yellow starthistle is considered undesirable in grasslands because it outcompetes native species, increases water consumption, increases fire vulnerability, and reduces available forage for livestock (Dukes and Shaw 2007). Simulations of a bioclimatic model by Bradley and coauthors (2009) indicate that the distribution of yellow star thistle may expand in the future into northern California, Oregon, Washington, and Nevada.

Aquatic invaders are also a concern. The invasion of two nonnative crab species in the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta), the green crab and Chinese mitten crab, has contributed to erosion and loss of marsh habitat through burrowing in tidal channels (Dittel and Epifanio 2009). Invasive clams have fundamentally altered the Delta's aquatic foodweb (Kimmerer et al. 1994). If climate change favors these species, their adverse impacts will increase. However, if climate change effects such as warmer water temperatures reduce the reproductive success of these species, it could help reverse their damaging effects.

5.A.1.4.6 Demography

Severe declines in species populations in numerous locations have been attributed to climate change (Parry et al. 2007). A recent global, multitaxa meta-analysis estimated a mean extinction probability of 10% by 2100 across studies that have made predictions of the future effects of climate change (Maclean and Wilson 2011). The analysis found that this is consistent with a mean probability of 14% based on empirical evidence of the realized effects of climate change.

Documented demographic changes include shifts in species density due to changes in resource availability and climatic gradients (Millar et al. 2006); decreases in species abundances due to increases in diseases and pests (Pounds et al. 2006); changes in body size, breeding season, and geographic distribution (Isaac 2009); and decreases in native species abundance due to increased competition from invasive species (Walther et al. 2009).

Local evolutionary adaptations to warming have occurred, and in some cases changes in resource use and dispersal have evolved rapidly (Parmesan and Yohe 2003). Most of the evidence for rapid adaptation to climate change is toward higher frequencies of heat-tolerant genotypes in the interior of species' ranges (Parmesan 2006). Although there is less evidence of adaptive evolution in response to climate change, Hairston and coauthors (2005) showed in studies of lizards that adaptive evolution can occur on ecological time scales.

5.A.1.5 Climate Change Considerations in Reserve Design

The conservation strategy includes numerous measures that will enhance the climate resilience of natural communities and covered species in the Plan Area. The U.S. Climate Change Science Program identified several adaptation approaches to maximize resilience to climate change (Julius et al. 2008), all of which are applied as part of the BDCP, as outlined below and discussed in more detail in subsequent sections and in Chapter 3, *Conservation Strategy*.

1. *Reduce anthropogenic stressors (e.g., pollution) that hinder the ability of species or ecosystems to withstand climatic events.*

   As described in Chapter 5, *Effects Analysis*, the conservation strategy will reduce a number of anthropogenic stressors that have degraded natural communities and reduced the viability of terrestrial covered species in the Plan Area for many years. For example, the abundance, biomass, extent, and adverse effects of nonnative invasive species will be reduced in the reserve system through improved and sustained management and monitoring for new infestations (which allows rapid response to contain and eradiate new colonists; see *CM11 Natural Communities Enhancement and Management*).

2. *Represent a "portfolio" of variant forms of a species or ecosystem so that, regardless of the climatic changes that occur, there will be areas that survive and provide a source for recovery.*

   CM9 Vernal Pool and Alkali Seasonal Wetland Complex Restoration will include a range of environmental conditions within large interconnected or contiguous expanses of vernal pool communities. This diversity of conditions will enhance habitat complexity and help ensure that some vernal pool communities and associated species will survive and provide a source for recovery regardless of the climate change impacts that may occur. Similarly, the creation of a mosaic of seral stages, age classes, plant zonation, and plant heights and layers under *CM7 Riparian Natural Community Restoration* will increase habitat complexity and wildlife diversity. Late-successional vegetation will be maintained in a number of locations. In addition, there will be horizontal and vertical overlap among vegetation components. All of these actions will help resilience to climate change effects and ensure the persistency of riparian natural communities in the Plan Area.

3. *Replicate to maintain more than one example of each ecosystem or population such that if one area is affected by a disturbance, replicates in another area provide insurance against extinction and a source for recolonization.*

   The reserve system (*CM3 Natural Communities Protection and Restoration*) is designed to protect natural communities across a wide range of their occurrence in the Plan Area. In many cases, land acquisition requirements are established in multiple Conservation Zones to ensure that protection is distributed across the range of each community in the Plan Area. This strategy ensures that there is replication within the reserve system and the connected network of other public lands. A similar approach is taken with the preservation of populations of covered species. For example, the Implementation Office will establish and protect at least two populations of currently unprotected Heckard's peppergrass and at least two currently unprotected populations of San Joaquin spearscale. This replication will help ensure that there is still a source for recolonization if one area is reduced or eliminated because of local hydrologic changes or other impacts of climate change. Multiple populations of covered wildlife species also are going to be protected; examples include giant garter snake, tricolored blackbird, and western burrowing owl.

4. *Restore or rehabilitate ecosystems that have been lost or compromised.*

   All of the conservation measures will contribute in some way to the restoration or rehabilitation of degraded ecosystems. Restoration in terrestrial ecosystems will increase climate resilience by recovering ecological functions and habitat values and by increasing the overall stability of natural communities through increases in native biodiversity and reductions in the diversity, density, and biomass of nonnative invasive species. Restoration also will provide dispersal pathways between populations to allow healthy gene flow, as well as avenues for escape during extreme events such as catastrophic floods, which are projected to increase with climate change.

5. *Use refugia or areas that are less affected by climate change*

   Habitat restoration will include the creation of habitat linkages and dispersal corridors and the protection of migratory pathways, providing multiple ways to access refugia. These areas can serve as recovery initiation points. For example, actions under *CM5 Seasonally Inundated Floodplain Restoration* and *CM6 Channel Margin Enhancement* will allow natural flooding to create bare substrate for vegetation colonization and deposit fine sands and silt for mudflat development. Similarly, in *CM4 Tidal Natural Communities Restoration*, restoration sites will include the creation and maintenance of upland refugia for salt marsh harvest mouse and Suisun shrew during extreme tidal events that will be essential to long-term survival as sea level rises.

6. *Relocate or transplant organisms from one location to another in order to bypass a barrier.*

   BDCP implementation actions will allow relocation or transplanting of covered species within the reserve system or to other protected areas inside or outside the Plan Area as needed to increase species' ability to respond to climate change. For example, if some restoration locations for western pond turtle are threatened by sea level rise, individuals could be translocated to more resilient wetland sites.

5.A.1.6 Potential Effects on Natural Communities

A natural community is characterized by similarities in vegetation and the natural ecological processes that dominate the community and give it its unique characteristics. The natural communities in the Plan Area are tidal perennial aquatic, tidal mudflat, tidal brackish emergent wetland, tidal freshwater emergent wetland, nontidal perennial aquatic, nontidal freshwater perennial emergent wetland, alkali seasonal wetland complex, vernal pool complex, managed wetland, other natural seasonal wetland, valley/foothill riparian, grassland, and inland dune scrub. The following sections describe the key features of these natural communities, some of the ways climate change may modify these communities, and examples of resilience measures included in the conservation strategy.

5.A.1.6.1 Tidal Perennial Aquatic

The tidal perennial aquatic natural community covers 10% of the Plan Area. It is defined as the deep-water aquatic zone (greater than 10 feet deep from mean lower low tide[1]) and shallow aquatic zone (less than or equal to 10 feet deep from mean lower low tide) of estuarine bays, river channels, and sloughs. Under present operations, the tidal perennial aquatic community in the Delta is mainly freshwater habitat, with brackish and saline conditions occurring in the western Delta at times of high tides and low flows into the western Delta. It is freshwater in the Yolo Bypass and mainly brackish and saline in Suisun Marsh. Shorebirds, wading birds, and waterfowl use the tidal perennial aquatic natural community for foraging, resting, and escape cover. The natural community contains structural elements such as woody debris that serve as basking sites for giant garter snakes and western pond turtles.

Tidal mudflats are part of the tidal perennial aquatic community. They are composed of sediments in the intertidal zone between the mean high tide and the mean lower low water (MLLW), and are exposed above water at low tide. At their upper edge, they are associated with tidal brackish or tidal freshwater emergent wetland. The extent of tidal mudflat has been substantially reduced in the Plan Area with the construction of levees and dikes, the channelization of waterways, and the conversion of tidal marshes to cultivation and other land uses. As of 1998, tidal mudflats in the Bay-Delta area had declined to approximately 53% of the historical extent present in 1800 (Goals Project 1999).

Climate change will affect the tidal perennial aquatic community in a number of ways. Ongoing sea level rise will inundate wetlands and alter the location of the estuary's low salinity zone. Although the amount of precipitation in the Plan Area is not expected to change markedly, the type and timing of precipitation are changing in significant ways. Seasonal and interannual variations in precipitation likely will increase, as observed over the past century (California Department of Water Resources 2006). More precipitation is falling as rain instead of snow during winter, and the snowpack is melting earlier, resulting in greater peak flows during the rainy season and lower flows during the dry season (Knowles and Cayan 2004). The risk of catastrophic floods is expected to increase because of the combined effects of sea level rise and greater storm surge during the rainy season. Changes in flows and water temperatures may disrupt environmental cues that many species rely on for initiating critical life history events, such as migration and spawning, with potential impacts on the growth, production, and survival of affected species (Parmesan 2006).

Implementation of conservation measures will enhance the climate resilience of this community in a number of ways. Under *CM4 Tidal Natural Communities Restoration* at least 10,000 acres of this community will be restored or created in the restoration opportunity areas (ROAs). *CM3 Natural Communities Protection and Restoration* will protect and enhance tidal perennial aquatic habitat as part of a reserve system. CM3 and CM4 will develop environmental gradients (hydrology, elevation, soils, slope, aspect) that will allow wetlands to migrate in response to rising sea levels. These conservation measures also will ensure that there are sufficient upland transitional areas adjacent to restored areas to permit the future upslope establishment of tidal wetland communities. Additional uncultivated upland also will provide habitat and high-tide refugia for native wildlife. In addition, CM3 and CM4 will provide corridors for covered terrestrial species to move to new locations of suitable habitat. In the West Delta ROA, actions under CM4 will provide tidal marsh plains in the anticipated future eastward position of the low salinity zone of the estuary.

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[1] Mean lower-low tide is the 19-year average of the lowest of the two low tides during the daily tidal cycle.

Actions under *CM5 Seasonally Inundated Floodplain Restoration* and *CM6 Channel Margin Enhancement* will allow natural flooding to promote fluvial processes, creating bare mineral soils for vegetation colonization and fresh deposits of fine sands and silt for mudflat development.

CM11 Natural Communities Enhancement and Management will control invasive wetland plants and nonnative wildlife species that otherwise could be favored by changing climatic conditions.

5.A.1.6.2 Tidal Brackish Emergent Wetland

The tidal brackish emergent wetland natural community is found in 1% of the Plan Area. It is a transitional community between tidal perennial aquatic and terrestrial upland communities. In the Plan Area, it exists in the saltwater/freshwater mixing zone that extends from Collinsville westward to the Carquinez Strait, and is most extensive in undiked areas of Suisun Marsh, along undiked shorelines on the south shore of Suisun Bay, and on undiked in-channel islands such as Browns Island.

Channels in the tidal brackish emergent wetland are either flooded or exposed, depending on tidal stage. The marsh plain is usually free of standing water but may be flooded at very high tides. The plant community is characterized by tall herbaceous wetland plant species that line the channels down to the MLLW depth. The high marsh zone and marsh plain are dominated by saltgrass and pickleweed (Culberson et al. 2004).

The tidal brackish emergent wetlands in the Plan Area provide habitat for a number of covered terrestrial species, including the salt marsh harvest mouse, Suisun shrew, California black rail, California clapper rail, Suisun song sparrow, tricolored blackbird, delta mudwort, Delta tule pea, Mason's lilaeopsis, soft bird's beak, and Suisun Marsh aster.

In order to persist as sea levels rise, the tidal brackish emergent wetland natural community must be able to accrete at a rate that is high enough to keep the surface intertidal (Watson and Byrne 2009). Culberson and coauthors (2004) showed that sediment alone is insufficient to build surface elevation in these marshes within the San Francisco estuary. Substantial root material is added to the soil profile during seasonal plant growth, and this additional material makes an important contribution to surface elevation. Higher frequency and duration of inundation result in lower marsh productivity, reducing this source of organic material for building the marsh surface (Culberson et al. 2004). Therefore, the rate of accretion in tidal brackish emergent wetland in response to climate change is likely to depend on how changing salinity and inundation duration affect the production of belowground biomass (Culberson et al. 2004) as well as the species composition of the vegetation (Watson and Byrne 2009).

Implementation of the BDCP will help promote the resilience of the tidal brackish emergent wetland to climate change. Under *CM4 Tidal Natural Communities Restoration* at least 4,800 acres of this community will be restored or created in the ROAs. CM3 *Natural Communities Protection and Restoration* will protect and enhance tidal brackish emergent wetland as part of a reserve system. As sea levels rise and managed wetlands in Suisun Marsh become flooded, new areas of tidal brackish emergent marsh will help maintain suitable habitat for covered terrestrial species, including salt marsh harvest mouse, Suisun shrew, California clapper rail, California black rail, and covered endemic plant species such as the Suisun thistle, Suisun Marsh aster, and soft bird's-beak, in addition to a diversity of other plant and wildlife species.

Both CM3 and CM4 will develop environmental gradients (hydrology, elevation, soils, slope, aspect) to achieve a range habitats, from shallow subtidal aquatic to mudflat, emergent marsh plain, riparian, and transitional uplands. This will include brackish channel margin habitat with tall bulrushes, tules, and cattails; a brackish transition zone with species-rich vegetation containing a diversity of structural habitats; and a marsh plain that is dominated by low-stature salt-tolerant species such as pickleweed and saltgrass. By providing elevation gradients, CM3 and CM4 will make it possible for tidal brackish emergent wetlands to expand as sea level rises and will ensure that tidal mudflat will develop between shallow subtidal aquatic areas and emergent marsh plains. Mudflats have a number of ecological values, including as foraging habitat for migrating shorebirds.

CM3 and CM4 also will contribute to the overall stability of this natural community by ensuring that a diversity of habitats is maintained to support greater biodiversity. This will further enhance the community's climate resilience. In addition, CM3 and CM4 will provide dispersal pathways between populations in these habitats, allowing healthy gene flow, as well as avenues for escape during catastrophic flood events, which are projected to increase with climate change. Actions under *CM5 Seasonally Inundated Floodplain Restoration* and *CM6 Channel Margin Enhancement* will allow natural flooding to promote fluvial processes, creating bare mineral soils for vegetation colonization and fresh deposits of fine sands and silt for mudflat development.

Under *CM11 Natural Communities Enhancement and Management,* invasive wetland plants and nonnative wildlife species will be monitored and controlled if they pose a threat to covered species populations or native biodiversity in the tidal brackish emergent wetland community. Control of red fox and Norway rat will benefit nesting rails and song sparrows in this community, enhancing their ability to withstand climate changes. CM11 will improve nesting habitat for tricolored blackbirds, helping to promote their reproductive success and increasing their climate resilience.

5.A.1.6.3 Tidal Freshwater Emergent Wetland

The tidal freshwater emergent wetland natural community covers 1% of the Plan Area. Although greatly reduced in extent from historical conditions, the remaining tidal freshwater emergent wetland community retains a high degree of ecological function and value. It is typically a transitional community between tidal perennial aquatic and valley/foothill riparian or terrestrial upland. In the Plan Area, the tidal freshwater emergent wetland community often occurs at the shallow, slow-moving or stagnant edges of freshwater waterways or ponds in the intertidal zone, where it is subject to frequent long-duration flooding. Covered terrestrial species in this community include California black rail, Suisun song sparrow, tricolored blackbird, giant garter snake, western pond turtle, California red-legged frog, delta mudwort, Delta tule pea, Mason's lilaeopsis, Suisun Marsh aster, and Suisun thistle.

Tidal freshwater emergent wetland is regularly flooded tidal marshland with very low levels of soil salinity. These communities can be categorized based on their frequency of inundation and distinctive vegetation. The low-elevation tidal freshwater emergent wetland is influenced by the daily tides and is flooded more times than not. It is highly productive but supports few species other than tules that tolerate deep, prolonged tidal flooding. Middle-elevation tidal freshwater emergent wetland is regularly flooded, but the soil is exposed above the water level for many hours each day. The middle-elevation zone grades into the uppermost end of tidal freshwater marsh. The high-elevation tidal freshwater emergent wetland is occasionally flooded by tides or flood events but includes depressions that remain flooded after tides recede. High marsh may naturally grade into low-elevation grasslands or seasonal wetland transition zones, or it may end abruptly at the edges of steep levees or eroded riverbanks.

Higher sea level will relocate tidal freshwater emergent wetland to higher elevations in the Delta. Tidally influenced waterways would be relocated upstream, thus shifting the tidal freshwater emergent wetland natural community farther upstream. Because much of the Delta is armored with levees, the sea level–driven relocation of the intertidal zone would be primarily vertical and not horizontal, likely resulting in a reduction in the extent of the tidal freshwater emergent wetland natural community. Adjacent to steep-sided levees, the community would be replaced by deepwater habitat (i.e., tidal perennial aquatic natural community) (Parker et al. 2011).

In order for the area of tidal freshwater emergent wetland to remain constant in the face of rising sea levels, wetlands must accrete sediments, including both influxes of mineral sediments and local accumulations of peat, at a rate high enough to keep the lowest surface of the wetland above an elevation of 18 inches below MLLW (Simenstad et al. 2000; Kneib et al. 2008). Increasing salinity levels can shift the species composition from highly productive freshwater-adapted plants to much less productive saltwater-adapted plants (Byrne et al. 2001; Boul and Keeler-Wolf 2008; Watson and Byrne 2009), influencing the rate of peat bed development and the elevation of the marsh surface above sea level (Culberson et al. 2004). As the Bay-Delta increases in salinity and plant productivity declines, greater rates of mineral sediment inputs will be required for wetlands to remain stable with sea level rise (Parker et al. 2011). Sediment yields have declined by about 50% over the past half century (Ganju and Schoellhamer 2010; Schoellhamer 2011), and, as a result, current sediment loads may be insufficient to support a rate of accretion that will keep pace with projected sea level rise. To compensate for the decline in sediments, belowground plant productivity must show large increases in biomass production. Otherwise, an increase in the frequency and duration of tidal inundation would occur, and existing low marsh would be converted to mudflats (Parker et al. 2011).

A number of conservation measures will help address the conditions needed to sustain the tidal freshwater emergent wetland natural community in the face of sea level rise. Under *CM4 Tidal Natural Communities Restoration* at least 13,900 acres of this community will be restored or created in the ROAs. *CM3 Natural Communities Protection and Restoration* will protect and enhance tidal freshwater emergent wetland as part of a reserve system. Both CM3 and CM4 will develop environmental gradients (hydrology, elevation, soils, slope, aspect) to achieve a range habitats, from shallow subtidal aquatic to mudflat, emergent marsh plain, riparian, and transitional uplands. Incorporating upland transition zones adjacent to restored freshwater tidal marshes ensures that tidal freshwater emergent wetlands are sustainable with progressive sea level rise. Without upland transition zones with shoreline gradients allowing expansion of shallow water zones, water levels at both existing emergent wetlands and future wetlands would become too deep to support emergent vegetation. Additional uncultivated upland will provide wildlife with high-tide refugia from floods, which are expected to increase because of increased coastal storms, sea level rise, and greater storm surge. CM4 will restore and sustain a diversity of marsh vegetation reflecting historical species composition and high structural complexity. High plant diversity and vegetation structure create a variety of ecological niches to support high wildlife diversity. This will contribute to the overall stability of the tidal freshwater emergent wetland community and enhance the community's climate resilience. In addition, CM3 will provide dispersal pathways between populations in these habitats, allowing healthy gene flow, as well as avenues for escape during catastrophic flood events.

Actions under *CM5 Seasonally Inundated Floodplain Restoration* and CM6 *Channel Margin Enhancement* will allow natural flooding to promote fluvial processes that will create bare mineral soils for vegetation colonization and fresh deposits of fine sands and silt for mudflat development.

Under *CM11 Natural Communities Enhancement and Management,* invasive wetland plants and nonnative wildlife species will be monitored and controlled if they pose a threat to covered species populations or native biodiversity.

5.A.1.6.4 Valley/Foothill Riparian

The valley/foothill riparian natural community is found in about 2% of the Plan Area, representing only a small portion of its historical extent. Graber (1996) estimated that as many as 25% of the species dependent upon riparian habitats in the region are at risk of extinction.

Broadly defined, the valley/foothill riparian community is a transition zone between aquatic and upland terrestrial habitat. In the Plan Area, riparian forest and woodland communities are now limited to narrow bands along sloughs, channels, rivers, and other freshwater features. There are remnant patches of tall riparian trees, such as Fremont cottonwood, western sycamore, and black willow, often with an understory of woody riparian shrubs such as blackberries and buttonbush forming dense thickets (Bay Institute 1998).

The riparian community provides cover, shade, water, and food resources for migrating and resident bird species and terrestrial vertebrates. Covered terrestrial species in this natural community include western yellow-billed cuckoo, white-tailed kite, yellow-breasted chat, western pond turtle, California red-legged frog, valley elderberry longhorn beetle, delta button celery, delta mudwort, Delta tule pea, Mason’s lilaeopsis, side-flowering skullcap, slough thistle, and Suisun Marsh aster.

Climate change will have a number of effects on this natural community. Climate warming likely will advance the spring phenology of riparian plants, increasing the growing season (Menzel et al. 2006; Parmesan 2007). At the same time, higher maximum temperatures may increase plant heat stress and reduce growth (Perry et al. 2012). Plant species currently restricted to relatively low elevations (e.g., Fremont cottonwood) may expand upstream, but riparian species at the upper limits of river basins may disappear.

Rising sea level will affect the location, extent, and composition of riparian vegetation as a result of increased water elevation and increased saltwater intrusion. As water levels rise, riparian plants at the water’s edge will become flooded more frequently, and many species intolerant of this longer inundation will migrate upslope if suitable habitat and hydrologic regimes are present. Future vegetation composition also will depend on the tolerance levels of individual plant species to higher salinity.

Climate warming is reducing the amount and timing of snowmelt runoff, reducing late-spring and summer flows. Lower summer and base flows, combined with increased drought frequency and severity, will contribute to decreased water availability, increasing the vulnerability of riparian communities to climate change. Both drier conditions and the increased frequency of extreme precipitation events are likely to result in changes to the existing vegetation. Reduced water availability and changes in vegetative composition would reduce habitat quality (e.g., cover, shade, food availability) for riparian animal species. Climate change also could raise water temperatures, increasing the chance of establishment by more temperature-tolerant nonnative species (Perry et al. 2012).

Climate change is expected to alter riparian hydrology substantially (Barnett et al. 2008).Many dominant riparian species (e.g., cottonwoods, willows) are pioneer species that require bare, moist substrates created by floods for seed germination and specific hydrologic conditions for seedling establishment (Auble et al. 1994; Scott et al. 1996; Poff et al. 1997; Merritt et al. 2010). Earlier spring floods may reduce riparian tree recruitment by de-synchronizing the spring flow peak and seed release (Rood et al. 2008). In general, lower late-spring and summer flows reduce survival and growth of shallow-rooted plants such as seedlings and juvenile trees (Perry et al. 2012). However, in the Sacramento River, successful recruitment has been observed on point bars (Tansey pers. comm.). Cottonwoods and willows are relatively intolerant of dry soils and may be particularly vulnerable to lower groundwater tables during more frequent or intense droughts (Perry et al. 2012).

Under *CM7 Riparian Natural Community Restoration,* the Implementation Office will restore 5,000 acres of riparian forest and scrub in association with *CM4 Tidal Natural Communities Restoration*, *CM5 Seasonally Inundated Floodplain Restoration*, and *CM6 Channel Margin Enhancement*. These conservation measures will enhance the climate resilience of this natural community by increasing the protection, extent, and connectivity of riparian areas, restoring processes necessary to sustain the community, and creating important structural conditions that provide habitat for a diversity of wildlife. By providing habitat conditions that will help sustain native riparian species, CM7 will increase the ability of these species to withstand climatic changes. For example, CM7 will ensure that suitable habitat is available for future growth and expansion of populations of riparian bush rabbit, riparian woodrat, valley elderberry longhorn beetle, and other covered animal species. “Scaffolding” plants can help allow climbing plants to move above flood levels. The creation of a mosaic of seral stages, age classes, plant zonation and plant heights and layers will increase habitat complexity and wildlife diversity. Combined with horizontal and vertical overlap among vegetation components, this will help create a portfolio of variant forms so that there will be some vegetation patches that will survive and provide a source for recovery regardless of the climate change impacts that may occur. For example, late-successional vegetation will be maintained in a number of locations throughout Conservation Zones 5 and 7. Active restoration involving site preparation and planting of native vegetation in large patches will be implemented as needed to ensure establishment and to enhance flood control. The development of habitat linkages and large patches of interconnected valley/foothill riparian forest will help enhance the capacity for movement of native species and genetic exchange among populations that otherwise could become fragmented and isolated because of climate-related extreme events such as heavy flooding.

5.A.1.6.5 Nontidal Perennial Aquatic

The nontidal perennial aquatic natural community is less than 1% of the Plan Area. In the Delta, this natural community can range in size from small ponds in uplands to large lakes, such as North and South Stone Lakes. The nontidal perennial aquatic natural community can be found in association with any terrestrial habitat and can transition into nontidal freshwater perennial emergent wetland and valley/foothill riparian. This natural community is differentiated from the tidal perennial aquatic natural community described above by a physical separation from the tidally influenced sloughs and channels in the Delta.

Covered terrestrial species associated with the nontidal perennial aquatic natural community are giant garter snake, western pond turtle, California red-legged frog, and California tiger salamander. No covered plant species are associated with the nontidal perennial aquatic natural community.

The nontidal perennial aquatic natural community is vulnerable to sea level rise and changes to hydrology and water availability associated with climate change. Where this community exists in flooded depressions in upland areas, it will remain protected from progressive sea level rise. However, at elevations at or below current sea level, rising sea levels will alter its location, extent, and composition and potentially result in increased saltwater intrusion.

CM10 Nontidal Marsh Restoration will ensure, through ongoing adaptive management, that appropriate water availability and hydrologic processes are maintained as climatic conditions change. This may include site grading and creation of depressions to hold water. In addition, community resilience will be enhanced by creating a mosaic of nontidal perennial aquatic habitats, including habitat components to support giant garter snake, western pond turtle, California red-legged frog, and California tiger salamander; waterfowl foraging, resting and brood habitat; and shorebird foraging and roosting habitat. Currently, nontidal marsh in the Plan Area occurs only as small, highly fragmented patches, limiting ecological functions and habitat values. Enhancing habitat for covered species in this community, taking into account progressive sea level rise and changes in hydrology, will help maintain sustainable populations in the face of climate change.

5.A.1.6.6 Nontidal Freshwater Perennial Emergent Wetland

Nontidal freshwater perennial emergent wetland is found in less than 1% of the Plan Area. The extent of this community has declined dramatically over the past century because of reclamation and conversion of the habitat to other uses, primarily agriculture. It is composed of permanently saturated wetlands, including meadows, dominated by emergent plant species that do not tolerate permanent saline or brackish conditions (CALFED Bay-Delta Program 2000). It occurs in small fragments along the edges of the nontidal perennial aquatic and valley/foothill riparian natural communities. These emergent wetlands typically occur on the land side of the Delta levees. Emergent wetlands along the edges of the low-flow channel and in backwaters and sloughs can be extensive in downstream areas.

The nontidal freshwater perennial emergent wetland natural community is among the most productive wildlife habitats in California (California Department of Fish and Game 2005). It provides food, cover, and water for numerous mammals, reptiles, amphibians, and birds. Some species use the habitat primarily for breeding (e.g., California red-legged frog), feeding and hunting (e.g., bald eagle), or foraging and loafing habitat (e.g., migrating waterfowl). However, in the Plan Area, the ecological functions provided by nontidal freshwater perennial emergent wetlands in support of wildlife are very limited because this community is highly fragmented and occurs in small patches. Covered wildlife species that may use nontidal freshwater perennial emergent wetlands include the California black rail, tricolored blackbird, giant garter snake, western pond turtle, and California red-legged frog. No covered plant species are associated with nontidal freshwater perennial emergent wetlands.

Nontidal freshwater perennial emergent wetland is distinguished by environmental conditions that support erect, rooted herbaceous plant species that can tolerate long inundation periods. This plant community frequently includes tules, bulrushes, sedges, rushes, and other emergent plant species. Shallow emergent wetlands, found in water less than 3 feet deep, are dominated by thick, tall, highly productive stands of tules and cattails. Disturbed nontidal freshwater perennial emergent wetlands that occur in ditches support a higher proportion of cattails than stable nontidal freshwater marshes. Broad, deeply flooded areas that support open water most of the year and develop emergent mud beds late in the growing season effectively alternate between seasonal ponds and freshwater marshes. The higher elevation edges of freshwater marsh gradients may be characterized by abrupt transitions to terrestrial vegetation, or they transition into vegetation of alkali seasonal wetlands, riparian woodland, or riparian scrub.

Sea level rise will affect the location, extent, and composition of this community in places where it exists at or below current sea level because of increased water elevation, increased saltwater intrusion, and changes in the tidal hydrologic regime. Nontidal freshwater perennial emergent wetland locations that exist at the water's edge will become more deeply immersed or, in the case of overtopped levees, deeply flooded.

CM10 Nontidal Marsh Restoration will include restoration and protection of transitional upland habitat consisting of grasslands adjacent to restored freshwater emergent wetland to provide upland habitat for giant garter snake and wetland pond turtle.

CM11 Natural Communities Enhancement and Management will improve nesting habitat for tricolored blackbirds by promoting the development of lush stands of bulrush/cattail emergent vegetation. Nesting habitat will be managed through mechanical clearing and burning, as needed. By enhancing nesting habitat, CM11 will help promote the reproductive success of tricolored blackbirds in the Plan Area, increasing their resilience to climatic changes. Other actions will increase habitat values for the western pond turtle and giant garter snake. If necessary, management actions also may include species' translocation to more resilient wetland sites.

5.A.1.6.7 Alkali Seasonal Wetland Complex

Alkali seasonal wetland complex covers less than 1% of the Plan Area. This wetland type occurs on fine-textured soils that contain a relatively high concentration of dissolved salts. The vernal pool complex natural community is sometimes interspersed within the alkali seasonal wetlands. The vegetation of alkaline seasonal wetlands is composed of salt-tolerant plant species adapted to wetland conditions and high salinity levels. This natural community complex includes both seasonally ponded and saturated wetlands and the surrounding matrix of grassland.

Alkali seasonal wetlands in the Central Valley have been subject to fragmentation, hydrologic alteration, and invasion by nonnative species. The decline in the extent, distribution, and condition of alkali seasonal wetland complex has reduced the diversity of native plant species uniquely associated with alkali soils, as well as habitat for associated wildlife. The remaining alkali seasonal wetland complexes support many native, endemic, and rare species. Saltgrass-dominated grassland supports breeding and/or foraging habitat for the San Joaquin kit fox, greater sandhill crane, Swainson's hawk, tricolored blackbird, western burrowing owl, white-tailed kite, California red-legged frog, and California tiger salamander. Covered plant species that occur in this community include brittlescale and heartscale growing in alkaline drainages, Carquinez goldenbush, delta button celery growing on alluvium in the Discovery Bay area, and San Joaquin spearscale on basin rims.

The primary impacts of climate change on this community are expected to be driven by changes in the hydrologic regime due to increased variability in precipitation, leading to a more variable wet season and changes in the inundation period. In addition, rising average temperatures could result in increased evapotranspiration rates and therefore more extended dry periods, with adverse effects on the plant community. All of these impacts will occur in a community that is already subject to a number of ongoing stressors, and therefore reduction in these stressors will help promote the climate resilience of this community. *CM11 Natural Communities Enhancement and Management* will help control invasive nonnative species. Furthermore, increasing the cover of native alkali seasonal wetland plants relative to invasive nonnative species will minimize competition posed by invasive plants and improve overall habitat suitability for native wildlife. CM11 also will include measures to ensure that appropriate seasonal flooding and other hydrologic conditions are maintained, including seasonal flooding with overland flow and some ephemeral ponding. *CM3 Natural Communities Protection and Restoration* will protect alkali seasonal wetlands within a large, interconnected reserve system that will prevent further habitat fragmentation that can disrupt hydrologic processes and gene flow. The size and connectivity of the reserve system are also important in order to provide sufficient upland habitat for the protection of plant pollinators, provide for the dispersal of alkali seasonal wetland-associated plants and animals, and sustain important predators of herbivores such as rodents and rabbits (U.S. Fish and Wildlife Service 2005). All of these actions will help to increase community stability in the face of climatic changes.

5.A.1.6.8 Vernal Pool Complex

The vernal pool complex is located on less than 1% of the Plan Area. This community is characterized by interconnected and isolated groups of vernal pools and seasonal swales that are generally within a matrix of either grassland or alkali seasonal wetland vegetation. Grasslands with vernal pools support high levels of endemic biodiversity in the Central Valley.

Covered vernal pool plants include alkali milk-vetch, Boggs Lake hedge-hyssop, brittlescale, delta button celery, dwarf downingia, heartscale, Heckard's pepper-grass, legenere, and San Joaquin spearscale.

This habitat type occurs in the northeast and southwest areas of the Plan Area. The vernal pool landscape in the northeast Plan Area has been affected by leveling for agricultural land uses. The alkali grassland that supports vernal pools in the southwest Plan Area has been fragmented by agricultural and residential development and by water management projects. Only limited habitat remains for vernal pool species, such as fairy shrimp and native plants.

The vernal pool complex is governed by a hydrologic regime of standing water in winter and spring and desiccated soils in summer. The hydrologic regime depends on the source of water, the duration of the inundated and the waterlogged soil phases, and the seasonal timing of these phases. These characteristics make the community highly vulnerable to increased precipitation variability and extended droughts resulting from climate change (Pyke 2004, 2005a, 2005b).

CM9 Vernal Pool and Alkali Seasonal Wetland Complex Restoration will include restoration of vernal pools and swales within a larger matrix of grasslands. Large, interconnected or contiguous expanses of vernal pool habitat will be created in the Plan Area to represent a range of environmental conditions within a large reserve system. This will help ensure that some vernal pool habitat and associated species will survive and provide a source for recovery regardless of the climate change impacts that may occur. Establishment of a large reserve system will prevent further habitat fragmentation that can otherwise disrupt hydrologic processes and gene flow, reducing climate resilience. CM9 will establish and protect at least two populations of Heckard's peppergrass and at least two populations of San Joaquin spearscale. This replication will provide a source for recolonization if one area is reduced or eliminated because of local hydrologic changes due to climate change.

5.A.1.6.9 Managed Wetland

Managed wetlands make up 7.6% of the Plan Area. These areas are intentionally flooded and managed during specific seasonal periods to enhance habitat values for specific wildlife species and migratory birds (CALFED Bay-Delta Program 2000). The Plan Area includes a central portion of the Pacific Flyway and continues to provide vital migratory, wintering, and breeding habitat for migratory birds, especially in designated wildlife management areas (e.g., Suisun Marsh Yolo Bypass), where habitat management is optimized for managed species, including waterfowl, shorebirds, and wading birds. Although waterfowl have been reduced in numbers, the Delta still provides habitat for 26 species of wintering waterfowl (Bay Institute 1998). The Pacific Flyway is also particularly important for shorebirds and neotropical migrants.

The water level in these wetlands is managed by levees, dikes, ditches, and drains. The typical hydrologic management regime includes flooding during the winter arrival of migratory birds, followed by a slow drawdown to manage plant seed production and to control mosquito populations. Summer irrigation may be conducted. The management of Suisun Marsh is unique because water salinity is a significant management issue, and water use is carefully regulated (Suisun Ecological Workgroup 1997).

The managed wetland community is characterized by robust, perennial emergent vegetation, annual moist-soil grasses and forbs in freshwater areas, and often by pickleweed and brass buttons in brackish water areas (Hickson and Keeler-Wolf 2007). During periods when water is drained from the habitat, a wide variety of annual grasses and forbs germinate and grow beneath and within the space around clumping emergent plants such as cattails and tules (Hickson and Keeler-Wolf 2007).

The managed wetland community is particularly sensitive to climate change. The subsided condition of some of these wetlands, combined with higher sea level, increased winter river flooding, more intense winter storms, and difficulty maintaining levees, will significantly increase the hydraulic forces on the levees that currently provide protection from flooding (Mount and Twiss 2005). As sea levels rise and levee instability increases, the managed wetlands in Suisun Marsh are susceptible to unintentional flooding, which is less desirable for wildlife (U.S. Fish and Wildlife Service 2010). In Suisun Marsh, *CM4 Tidal Natural Communities Restoration* will replace managed wetlands with tidal brackish emergent wetland, which over time will provide benefits to many terrestrial species by providing a more natural transition between terrestrial and aquatic environments and the ecology supported by it.

5.A.1.6.10Other Natural Seasonal Wetlands

Other natural seasonal wetlands make up less than 1% of the Plan Area. This community type encompasses all of the remaining natural (not managed) seasonal wetland communities that are not part of the vernal pool complex and alkali seasonal wetland complex natural communities. Vegetation consists of a mixture of exotic and native perennial forbs, grasses, sedges, and rushes tolerant of temporary flooding and ponding or soil saturation during winter and spring months. The covered species that use this natural community include greater sandhill crane, Swainson's hawk, tricolored blackbird, western burrowing owl, and white-tailed kite.

This community type will have sensitivities to climate change similar to those for other wetlands. The primary climate drivers will be precipitation variability and variable runoff through the Central Valley. The pattern of precipitation and runoff will determine the relative abundances of plant species, with some conditions favoring increases in invasive species, which can increase populations relatively rapidly under a range of soil moisture conditions. As outlined in Section 5.A.1.5, *Climate Change Considerations in Reserve Design*, the conservation strategy includes numerous measures that will help enhance the climate resilience of natural seasonal wetlands and other natural communities in the Plan Area.

5.A.1.6.11Grassland

Grasslands are found in 7% of the Plan Area. Grasslands with vernal pools support high levels of endemic biodiversity in the Central Valley. This habitat type occurs in the northeast and southwest areas of the Delta. Grasslands often are found adjacent to wetland and riparian habitats and are the dominant community on managed levees in the Delta. In some areas of the Delta, the grassland community is interspersed with vernal pool complex, alkali seasonal wetland complex, and other natural seasonal wetland natural community types (Hickson and Keeler-Wolf 2007).

The grassland natural community provides habitat for the salt marsh harvest mouse, San Joaquin kit fox, greater sandhill crane, Swainson's hawk, tricolored blackbird, western burrowing owl, white-tailed kite, giant garter snake, western pond turtle, California red-legged frog, California tiger salamander (Central Valley distinct population segment [DPS]), valley elderberry longhorn beetle, alkali milk-vetch, brittlescale, Carquinez goldenbush, delta button celery, heartscale, Heckard's peppergrass, and San Joaquin spearscale.

The grassland community designation has been applied to areas that have been cleared of their natural vegetation cover, such as levee faces and edges of agricultural fields and roads. Vegetation in these areas is best characterized as ruderal. Ruderal vegetation is dominated by herbaceous, nonnative, weedy species and may support stands of noxious weeds. Ruderal vegetation on maintained levees throughout the Delta can be a persistent source of seeds of weedy and invasive plants. Ruderal and grassland communities provide some foraging, breeding, and cover habitat for wildlife species. However, because nonnative annual grasslands are dominated by exotic plant species, they may provide fewer habitat values than native grasslands.

Recent projections indicate that grasslands in the Sacramento Valley region could decline by about 20% by 2070 as a result of climate change (Point Reyes Bird Observatory 2011). The primary impact of climate change on this community is likely to be driven by the increased variability in precipitation. An increase in late spring precipitation or a decrease in the length of summer drought in the Central Valley is likely to favor herbaceous and woody perennial species and promote the invasions of nonnative species. (Dukes and Shaw 2007). Increasing temperatures are likely to affect the productivity and composition of grasslands because net primary production increases with temperature, and soil warming promotes nitrogen availability (Dukes and Shaw 2007).

CM8 Grassland Natural Community Restoration will increase the extent, distribution, and density of native perennial grasses by converting non-grassland areas into grassland and restoring native grassland in areas that are degraded and dominated by exotic species. Grassland planting and seeding will create a mosaic of grassland vegetation alliances, ensuring that different species are supported by variations in water availability, soil moisture, disturbance regimes, and other conditions potentially affected by climate change. CM8 also will increase habitat linkages for species that use grasslands by locating restoration projects between existing grasslands and by connecting fragmented patches of grassland. Grasslands will be restored along upper margins of restored floodplains to provide upland refugia for riparian brush rabbit. Grasslands also will be restored adjacent to tidal marsh to provide upland flood refugia for salt marsh harvest mouse and other wildlife. These actions will help ensure that there will be grassland areas and grassland-associated wildlife that survive and provide a source for recovery regardless of the climatic changes that occur.

CM11 Natural Communities Enhancement and Management will help control the spread of invasive grassland species, reducing a significant stressor on native grasslands and further enhancing their climate resilience of this community. At the same time, grazing management, prescribed burns, reseeding, and other grassland management techniques will help promote native perennial grasses. This will optimize conditions for burrowing mammals. Thatch will be controlled to facilitate movement by amphibians and other native wildlife.

5.A.1.6.12Inland Dune Scrub

Inland dune scrub makes up <0.1% of the Plan Area. Inland dune scrub is a dense to open shrub and sub-shrub dominated community of remnant dune soils with a unique mix of rare, endemic species of plants and insects. Inland dune scrub occurs only on the disturbed remnants of the former dune that existed along the southern shore of the San Joaquin River, immediately east of the city of Antioch. This natural community transitions into the tidal brackish emergent wetland natural community along its border with the San Joaquin River.

Only two patches of this natural community currently exist because of severe degradation from a century of sand mining. One vegetation type consists of a broadleaf shrubland that was classified as the *Lupinus albifrons* Antioch Dunes alliance (5 acres), and the other is a dwarf shrub vegetation type classified as the *Lotus scoparius* Antioch Dunes alliance (15 acres). Currently, the degraded remnants of the community are being managed within the Antioch Dunes National Wildlife Refuge (NWR). The community will be relatively less vulnerable to climate change because of its sandy soils, low water requirements, and elevation above areas subject to inundation.

5.A.1.6.13Cultivated Lands

About two thirds of the Plan Area is in agricultural use. Major crops and cover types include small grains (wheat and barley), field crops (corn, sorghum, and safflower), truck crops (tomatoes and sugar beets), forage crops (hay and alfalfa), pastures, orchards, and vineyards. The largest portion of the Plan Area includes many annually cultivated irrigated croplands (e.g., corn, wheat, tomatoes) that are seasonally or annually rotated to conserve soil nutrients and maintain soil productivity (Table 2-18 in Chapter 2, *Existing Ecological Conditions*; sources for spatial data are given in Table 2-1). This portion of the landscape, which includes most field, truck, and grain crops, changes seasonally as crops grow and are harvested, and with the rotational sequence of different crop types. Other cover types, such as orchards, vineyards, rice, and irrigated pasture, may remain uncultivated for many years and are considered perennial crop types because they do not seasonally or annually rotate to other crop or cover types. Still other crops, particularly alfalfa and other hay crops, while regularly harvested, may remain uncultivated for multiple years but eventually are rotated to other uses and thus are referred to as semiperennial crop types (Rosenstock et al. 2006; Jackson et al. 2012).

The distribution of seasonal crops varies annually, depending on factors such as crop-rotation patterns, water availability, and market forces (Jackson et al. 2012). These changes influence the value and use of cultivated habitats to covered wildlife species on a seasonal basis. While planting timeframes vary, most annually cultivated croplands are planted in spring and harvested in late summer or early fall. General cropping practices result in monotypic stands of vegetation for the growing season and bare ground in fall and winter. Cultivated lands in the Plan Area support abundant wildlife and provide essential breeding, foraging, and roosting habitat for many resident and migrant wildlife species, particularly birds.

5.A.1.6.13.1 Alfalfa

Alfalfa is an irrigated, intensively mowed, leguminous crop that constitutes a dynamic habitat. Vegetation structure varies with the growing, harvesting, and fallowing cycles. Alfalfa is rotated periodically with other crops, such as vegetables and cereal grains. It is a very productive crop that does not require frequent tilling, so it can support large populations. As a result, it provides high-quality foraging habitat for wildlife, including wading birds, shorebirds, sparrows, and hawks. Some of these species, such as shorebirds, use the fields when they are periodically flood-irrigated. Alfalfa can be particularly important to Swainson's hawk, white-tailed kite, and other raptor species, which capitalize on high prey densities and cycles of increased prey availability when the fields are being irrigated and mowed.

5.A.1.6.13.2 Irrigated Pasture

Pastures are managed grasslands that are not typically tilled or disturbed frequently. They are usually managed with a low structure of native herbaceous plants, cultivated species, or a mixture of both. Pastures provide breeding opportunities for ground-nesting birds (e.g., burrowing owl, northern harrier, western meadowlark) and burrowing animals (e.g., California ground squirrel, Botta's pocket gopher). The open structure of pastures provides foraging habitat for grassland-foraging wildlife, such as red-tailed hawk, American kestrel, and coyote.

5.A.1.6.13.3 Rice

Rice is a flood-irrigated crop of seed-producing annual grasses. It is maintained in a flooded state until near maturation. Rice is usually grown in areas that previously supported natural wetlands, and many wetland wildlife species use rice fields, especially waterfowl and shorebirds. Waste grain, the dry protective casings around the ripe seeds of cereals such as rice and wheat that are inedible to humans, also provides food for species such as ring-necked pheasant and sandhill crane. Other wildlife that use rice fields include giant garter snake, bullfrog, and wading birds that forage on aquatic invertebrates and small vertebrates such as crayfish and small fishes.

5.A.1.6.13.4 Grain and Seed Crops

Grain and seed crops are annual grasses that are grown in dense stands and include corn, wheat, and barley. Because the dense growth makes it difficult to move through these fields, most of the wildlife values are derived following the harvest, when waste grain is accessible to waterfowl and other birds, such as sandhill cranes. In some areas of the Delta, grain fields support a substantial proportion of the sandhill crane population that winters in California.

5.A.1.6.13.5 Orchards

Orchards are habitats dominated by a single tree species. Trees are usually kept fairly low and bushy, with a mostly closed canopy and an open understory. Orchard habitats are used by several common woodland-associated species, such as western gray squirrel, American robin, red-tailed hawk, bats, and the nonnative black rat.

5.A.1.6.13.6 Vineyards

Vineyards usually are grown on fertile land that formerly supported diverse and productive natural habitats and wildlife. Vineyard acreage has expanded in recent years. Except for some common species, such as mourning dove, and raptors that use perches and nest boxes installed to attract raptors to control pest species, vineyards provide little wildlife habitat.

5.A.1.6.13.7 Potential Climate-Induced Changes in Crop Allocations

In the Delta and Central Valley, climate warming has increased late-winter and early-spring air temperatures, resulting in a decline in the number of chill hours for fruit and nut crops in winter. Though current summertime warming is dampened somewhat by the cooling effect of widespread irrigation, ongoing increases in summertime temperatures are expected to overwhelm this effect in the near future. Higher temperatures increase evaporative water loss from vegetation. In the Sierra Nevada, the ratio of rainfall to snowmelt has increased and snowpack has declined. Lower winter precipitation and earlier spring snowmelt deplete the moisture in soils and vegetation, and also result in earlier low-flow conditions, reducing water availability during the summer growing season (Moser et al. 2009).

Research suggests that higher temperatures, fewer chill hours, and less available water will interact with biological and socioeconomic factors to produce changes in the Delta's cultivated lands. Results of a study based on historical relationships between crop types and climate change indicate that projected increases in winter temperatures (2035–2050) could increase cultivation of alfalfa and decrease acreage in wheat. Almond cultivation was projected to increase slightly, while walnut acreage was projected to decline slightly. By 2050, modeling projected an increase in tomato cultivation, but only a moderate change in tree and vine crops (Rosenstock et al. 2006; Jackson et al. 2012).

Other climate changes could have different implications for crop selection. For example, the water needs of different crop types may also strongly influence future planting decisions, because, without adaptation, the decline in snowpack would potentially reduce the water available for irrigating crops (Chung et al. 2009). Thus, although warmer winter temperatures may tend to increase alfalfa acreage and decrease wheat acreage, declines in water availability could have the opposite effect because of the high water demand of alfalfa (Jackson et al. 2012). Estimates of the water needs of the main irrigated crops in the Delta are provided in Table 5.A.1.6-1.

Table 5.A.1.6-1. Water Needs of Delta Crop Types

Crop	Liters of Water Needed per Kilogram of Yield
Alfalfa	1,100
Rice	1,080
Wheat	900
Corn	650
Source: Kraft et al. 2012.	

Sea level rise will also influence the future conditions of cultivated lands. As seas rise, salinity levels in the Delta are increasing, creating more saline soils and degrading water quality. If flows are sufficiently low, a powerful earthquake in the region could collapse levees, leading to major saltwater intrusion and flooding throughout the Delta (Mount and Twiss 2005). Areas within levees that are farmed would be affected by the floodwaters. While rice may not be particularly vulnerable to levee breach, damage to corn and wheat crops could be substantial. A decline in the availability of harvested corn fields would strongly affect the thousands of greater sandhill crane overwintering in the Delta. As outlined in Section 5.A.1.5, *Climate Change Considerations in Reserve Design*, the conservation strategy includes numerous measures that will help enhance the climate resilience of covered species and natural communities in the Plan Area.

5.A.1.7 Vulnerability of Species Groups

To consider the implications of projected climate change on terrestrial species, covered species have been grouped by taxon. The analysis discusses the life history, behavioral characteristics, and habitat requirements that predispose certain covered species within these groups to be particularly susceptible to climate change. For more details on the ecology, distribution, and abundance of the covered species, see Appendix 2.A, *Covered Species Accounts*. For a discussion of the effects of climate change on covered fish, see Appendix 5.A.2, *Climate Change Approach and Implications for Aquatic Species*.

5.A.1.7.1 Plants

Covered plant species include alkali milk-vetch, Boggs Lake hedge-hyssop, brittlescale, Carquinez goldenbush, delta button celery, delta mudwort, Delta tule pea, dwarf downingia, heartscale, Heckard's peppergrass, Mason's lilaeopsis, San Joaquin spearscale, side-flowering skullcap, slough thistle, soft bird's-beak, Suisun Marsh aster, and Suisun thistle.

Climate change can affect terrestrial plant species in several ways. For example, high temperatures increase evaporative water loss from vegetation, while lower winter precipitation and earlier spring snowmelt deplete the moisture in soils and vegetation (Moser et al. 2009). Variation in the duration, timing, and amount of precipitation affect the vertical distribution of water in the soil profile. The combination of higher temperatures and reduced water availability in the dry season favors species that are relatively tolerant of heat and dry conditions. Species that lack these traits may decrease in abundance or experience high mortality in response to prolonged droughts. Future changes in the summer dry period are likely to have significant impacts on plant growth (Moser et al. 2009).

Many covered endemic plant species also are sensitive to climate-related alterations in the hydrologic regime and water salinity. For example, the delta mudwort shows reduced flowering and seed germination in salinity concentrations near or greater than 7 parts per thousand (ppt). Increased precipitation variability combined with changes to the hydrologic regime could lead to a shorter, more variable wet season. Increased warming could increase evapotranspiration rates and extend dry periods. Both situations would reduce habitat suitability for covered plant species of alkali seasonal wetlands such as alkali milk-vetch, brittle scale, and heartscale. On the other hand, habitat suitability for species such as delta button celery depends largely on the degree and frequency of flooding (California Department of Fish and Game 2008). To the extent that climate change reduces seasonal floods, delta button celery and other flood-dependent species will see a reduction in habitat suitability.

Wetland plant species in the Plan Area include Mason's lilaeopsis, Delta tule pea, Suisun Marsh aster, and Delta mudwort. Mason's lilaeopsis prefers relatively unvegetated areas in brackish or fresh water habitats that are periodically inundated by waves or tides (Golden and Fiedler 1991; Fiedler and Zebell 1993; California Department of Fish and Game 2000; California Native Plant Society 2008). It is a colonizing species that establishes on newly deposited or exposed sediments (California Native Plant Society 2008) and has a preference for tidal flats. Delta tule pea is found immediately above the tidal zone in marshes and along rivers and streams (Grewell et al. 2007; California Native Plant Society 2008). Suisun Marsh aster is found at the upper margin and immediately above the tidal zones of fresh and brackish marshes and along rivers and creeks. Delta mudwort is found with Mason's lilaeopsis, and immediately below the tidal elevation where delta tule pea and Suisun Marsh aster are commonly found.

Diked marshes generally lack rare tidal marsh plant species such as Suisun Marsh aster. Instead, it is believed that the conditions brought about by dikes favor robust generalist species that can better tolerate the extremes of inundation and dryness in diked wetlands (Goals Project 2000). Climate change may exacerbate these extreme conditions. Restoration of tidal fresh and brackish marshes under the BDCP will promote reestablishment of Suisun Marsh aster and will enhance its resilience in the face of climate-induced changes to inundation regimes and increased drought.

5.A.1.7.2 Invertebrates

Covered invertebrate species include valley elderberry longhorn beetle and vernal pool crustaceans: California linderiella, Conservancy fairy shrimp, longhorn fairy shrimp, midvalley fairy shrimp, vernal pool fairy shrimp, and vernal pool tadpole shrimp.

The habitat and resource needs of valley elderberry longhorn beetle include clumps of elderberry shrubs with a basal diameter over 1 inch. *CM7 Riparian Natural Community Restoration* and *CM5 Seasonally Inundated Floodplain Restoration* will enhance the climate resilience of valley elderberry longhorn beetle by supporting conditions that will promote the growth and survival of elderberry shrubs.

Pyke (2005a) explored the potential impacts of projected changes in climate and land use for the hydrologic regime experienced by five fairy shrimp species endemic to vernal pools in California's Central Valley. Pyke (2005a) found that projected changes in precipitation consistently overrode changes in evapotranspiration resulting from temperature changes, and dominated vernal pool water balance. As a result, warmer, higher precipitation conditions during winter resulted in longer, more frequent periods of inundation, whereas cooler, lower precipitation conditions resulted in shorter, less frequent inundations. *CM9 Vernal Pool and Alkali Seasonal Wetland Complex Restoration* will provide large, interconnected expanses of vernal pool habitat to represent a range of environmental conditions. This will benefit the vernal pool crustacean community by ensuring that some vernal pool habitat will persist to provide a site for recovery regardless of the particular climate change impacts that may occur.

5.A.1.7.3 Amphibians

Covered amphibian species include California red-legged frog and California tiger salamander (Central Valley DPS).

Many amphibian species are undergoing dramatic population declines, and a recent review by Wake (2007) concluded that climate change has played an important role, even though other factors can be important, such as habitat loss (Cushman 2006) and exposure to ultraviolet-B radiation (Carey and Alexander 2003). There is evidence of long-term declines linked to climate-driven changes in habitat quality (Whitfield 2007), while other observations indicate that some amphibian species show susceptibility to diseases influenced by climate change (Pounds et al. 2006). California is considered a hotspot of amphibian decline, with many species experiencing dramatic range contractions. In the Sierra Nevada, more than half of the region's 29 native species of amphibians are at risk of extinction (Jennings 1996).

Most amphibians in temperate climates can tolerate wide variations in temperature, but their dependence on aquatic environments for reproductive success could be compromised by changes in seasonal and regional climatic patterns. Decreases in precipitation or shifts in the timing of precipitation would have an effect on reproductive success and adult survivorship because of increased risk of desiccation, reduced food supply, and increased predation due to reduced habitat availability. Such changes could lead to alterations in distribution and abundance.

Vernal pools and other seasonal rain pools are the primary breeding habitat of California tiger salamanders in the Plan Area (Barry and Shaffer 1994; 68 *Federal Register* [FR] 13498). However, because the species requires at least 10 weeks of pool inundation in order to complete metamorphosis of larvae (Anderson 1968; Feaver 1971), California tiger salamanders usually are found in only the largest vernal pools (Laabs et al. 2001). The species therefore is highly vulnerable to drying conditions with climate change.

The climate resilience of amphibian species of vernal pools will be enhanced by *CM7 Riparian Natural Community Restoration* and *CM5 Seasonally Inundated Floodplain Restoration,* which will help protect and sustain vernal pool habitats in the face of ongoing climatic changes.

5.A.1.7.4 Reptiles

Covered reptiles include the giant garter snake and western pond turtle.

The potential effects of climate change on reptiles are less well-studied than its effects on amphibians. However, there are indications that some reptile species can be highly vulnerable to changes in temperature. For example, some reptiles exhibit temperature-dependent sex determination, whereby increased air temperatures skew the sex ratio to favor females over males (Janzen 1994).

The giant garter snake is endemic to wetlands in the Sacramento and San Joaquin Valleys and historically was distributed throughout the San Joaquin Valley. The species has specialized habitat requirements, including: adequate water during the snake's active season (early spring through mid-fall) to provide food and cover; emergent, herbaceous wetland vegetation, such as cattails and bulrushes, accompanied by vegetated banks for escape cover and foraging habitat during the active season; basking habitat of grassy banks and openings in waterside vegetation; and higher elevation uplands for cover and refuge from flood waters during the snake's dormant season in the winter (Hansen and Brode 1980; Brode and Hansen 1992; U.S. Fish and Wildlife Service 1999).

The fragmented populations and specialized habitat requirements of giant garter snake make the species particularly sensitive to climate change. Climate-related declines in snowpack, early snowmelt, and reduced water availability in summer and fall will reduce the availability of emergent wetland habitat and food and cover during the active season. Episodes of extreme winter flooding may reduce survival of the species during its dormant season if adequate upland refugia are not available.

Western pond turtle spends a considerable amount of time basking in order to thermoregulate. Western pond turtles are sensitive to body temperatures above their critical thermal maximum of 104 degrees Fahrenheit (°F) and therefore may be vulnerable to more frequent or prolonged droughts with climate change, especially in areas where movements to ponds and other refugia are restricted.

CM3 Natural Communities Protection and Restoration and *CM10 Nontidal Marsh Restoration* will provide nontidal marsh consisting of a mosaic of nontidal freshwater emergent perennial wetland and nontidal perennial aquatic natural communities, providing habitat that will help enhance the climate resilience of western pond turtle and giant garter snake. Where the floodplain is widened and restored, oxbows and slow-moving side channels will form, providing suitable aquatic habitat for western pond turtle (Bury and Germano 2008). Where riparian vegetation grows adjacent to slower-moving channels, sloughs, and ponds, downed trees can provide important basking and cover habitats for turtles. Protection of uplands, consisting primarily of grasslands adjacent to tidally restored areas and valley/foothill riparian natural community, will benefit the western pond turtle by providing nesting and overwintering habitat. Most of the upland natural communities that will be protected by implementation of the BDCP will provide dispersal habitat for western pond turtles, which travel over many different land cover types. Dispersal will allow the species to move between habitat areas and promote gene flow between populations. Fragmentation of western pond turtle populations is thought to be a factor contributing to lack of genetic variability for western pond turtles in Oregon and Washington (Gray 1995). Genetic variability is important for maintaining population stability and resilience.

5.A.1.7.5 Birds

Covered bird species include California black rail, California clapper rail, greater sandhill crane, least Bell’s vireo, Suisun song sparrow, Swainson’s hawk, tricolored blackbird, western burrowing owl, western yellow-billed cuckoo, white-tailed kite, and yellow-breasted chat.

A recent analysis by Gardali and coauthors (2012) found that more than 70% of the threatened and endangered bird species in California are vulnerable to climate change, with wetland bird species making up the most vulnerable group. It is estimated that California has lost more than 90% of its original wetlands, making wetland-associated species particularly susceptible to further habitat modification and loss resulting from climate change. Tidal wetlands in the Plan Area provide habitat for a number of covered bird species, including California black rail, California clapper rail, Suisun song sparrow, and tricolored blackbird.

Preferred nesting sites of rail species are in dense marsh vegetation near the upper limits of tidal flooding. Upland areas provide refuge during extreme high-tide events. The specialized nesting requirements of these species make them highly vulnerable to climate change. Water depth is an important parameter for successful nest sites as rising water levels can prevent nesting or flood nests and reduce access to low marsh foraging habitat (Eddleman et al. 1994). Too little water will lead to abandonment of the site until the water source is reestablished. Therefore, water level is an important determinant of reproductive success. Ongoing sea level rise, increases in precipitation variability, and the likelihood of enhanced winter flooding and coastal storm surge as a result of climate change increase the risk of nest failure and population declines. Already many tidal marshes in south San Francisco Bay are completely submerged during high tides, resulting in nest failure.

The Suisun song sparrow is endemic to the salt marshes of Suisun Bay. While dense vegetation is characteristic, exposed ground is important for foraging. The song sparrow is the only obligate ground-foraging bird in the tidal brackish marsh, and the species occupies an uncontested niche by foraging on the surface of the mud (Larsen 1989). This advantage is diminished; however, as increasing sea level rise inundates tidal flats with increasing frequency. It is thought that large areas of tidal marsh in Suisun Marsh could be inundated with progressive sea level rise, making these areas unsuitable for Suisun song sparrow. Moreover, existing habitat in Suisun Marsh has been reduced to small fragments that often are separated by various kinds of barriers, reducing dispersal, gene flow, and reproduction and consequently reducing the species' adaptive capacity (Spautz and Nur 2008).

Tricolored blackbirds form the largest breeding colonies of any North American passerine bird, and more than 75% of the breeding population is estimated to occur in California's Central Valley. However, the species has suffered drastic population declines in area in recent decades, largely as a result of habitat degradation and loss. Passerines are one of the avian orders that are most vulnerable to climate change in California (Gardali et al. 2012). Tricolored blackbirds require breeding sites with open, accessible water and a protected nesting substrate, including flooded, thorny, or spiny vegetation (Hamilton et al. 1995; Beedy and Hamilton 1999). Because these requirements are dependent on precipitation and hydrologic conditions, the species is potentially highly vulnerable to climate change. Protection, restoration, and enhancement of nesting and foraging habitat will help stabilize and increase depleted populations, helping to promote resilience to adverse effects of climate change.

Riparian bird species also are at risk from climate change (Gardali et al. 2012). The western yellow-billed cuckoo and yellow-breasted chat have experienced dramatic declines in willow-cottonwood riparian habitat in the Central Valley. Changes in the timing and amount of spring peak flows as a result of climate change may have important consequences for seedling establishment, which depends on moist substrate for seed germination (Scott et al. 1996). Declines in soil water recharge and changing flood regimes will combine with warmer and drier air conditions during the growing season to exacerbate other threats to native riparian vegetation (Stromberg et al. 2010).

The cultivated lands of the Central Valley are important habitats for a wide variety of bird species, including large concentrations of raptors such as white-tailed kite and Swainson's hawk that prey on the high numbers of rodents in these habitats. As discussed in Section 5.A.1.6.13, continued climate warming and drying may encourage farmers to switch from high water-use crops such as alfalfa, the highest value crop for both Swainson's hawk and white-tailed kite, to less water-intensive crops, adding to the loss of forage habitat for raptors. Conversion to orchards and vineyards, which do not support sufficient prey, is already a factor contributing to raptor declines in the Central Valley (J. A. Estep, in preparation). Greater sandhill cranes that overwinter in the Delta may experience reductions in both forage and roosting habitat as climate change proceeds. Throughout their wintering range in the Delta, cranes roost in shallow-flooding seasonal wetlands and forage in harvested fields of corn (Pogson and Lindstedt 1991; Littlefield and Ivey 2000). Water depth is important for the quality of roosting sites, which must have some water but also remain shallow. Littlefield (1993) reported cranes abandoning roosting sites when water depth reached 8 to 11 inches. Therefore, climate-related changes in the winter flooding regime are potentially critical: either too little or too much water may eliminate suitable roosting habitat. At the same time, the continued conversion of cropland to orchards and vineyards will reduce harvested cornfields and other high-quality forage. As outlined in Section 5.A.1.5, *Climate Change Considerations in Reserve Design*, the conservation strategy includes measures that will help enhance the climate resilience of these and other covered species in the Plan Area.

5.A.1.7.6 Mammals

Covered mammal species include the riparian brush rabbit, riparian woodrat (San Joaquin Valley), salt marsh harvest mouse, San Joaquin kit fox, and Suisun shrew.

Although there is evidence that mammals respond to effects of climate warming on body temperature, mammal species also interact with climate change through indirect effects on food resources, habitat, and predators (Janetos 2008). There is also evidence that climate change has affected key life history characteristics among many mammal species, including body size, geographic range, and reproductive traits (Isaac 2009).

The valley/foothill riparian natural community provides habitat for riparian brush rabbit and riparian woodrat. Implementation of the BDCP will enhance the resilience of populations of these species in the Plan Area through protection and restoration of riparian habitat that meets the species' ecological requirements (e.g., dense willow understory and oak overstory) and is adjacent to or facilitates connectivity with occupied or potentially occupied habitat. The most serious ongoing problem has been the lack of suitable habitat above the level of regular floods where these animals could find food and cover for protection from weather and predators. Increases in flood levels with climate change will exacerbate this problem. By increasing the area and connectivity of suitable riparian habitat, implementation of the BDCP will help reduce the species' vulnerability to habitat reduction during flooding.

The salt marsh harvest mouse is endemic to saline and brackish tidal wetlands of San Francisco, San Pablo, and Suisun Bays. Restoring tidal wetland communities and the historical ecological functions of Suisun Marsh as part of the conservation strategy will provide a more sustainable environment for salt marsh harvest mouse populations than the managed wetland habitats on which they primarily depend currently. By enhancing and restoring tidal brackish wetland habitat in Suisun Marsh, the implementation of the BDCP will help enhance the resilience of the salt marsh harvest mouse to climate change.

The San Joaquin kit fox has shown population declines in the Central Valley as a result of the loss of grassland habitat, which has led to displacement, isolation of populations, creation of barriers to movement, direct and indirect mortality, and reduction of prey populations (U.S. Fish and Wildlife Service 1998). All of these factors make the species vulnerable to continued loss of grasslands with climate change. Implementation of the BDCP conservation strategy will enhance the resilience of kit fox and other grassland wildlife species to climate change by protecting the highest functioning grassland supporting kit fox breeding habitat and reestablishing habitat corridors to link isolated populations into a viable metapopulation.

5.A.1.8 Vulnerability of Covered Species

Vulnerability to climate change refers to the extent to which a system is susceptible to harm from climate change (Schneider et al. 2007). To address the potential effects of climate change on terrestrial covered species, a vulnerability screening was conducted. A vulnerability assessment considers the susceptibility of a species (or natural community or ecological system) to harm from climate change as a function of the exposure of that species to climate changes, the sensitivity of the species to those changes, and the species' adaptive capacity to adjust to those changes.

California's plant and animal species show a variety of responses to changes in temperature, precipitation, sea level rise, hydrology, extreme events (droughts, floods), and water availability. Observed changes include altered phenology, disruption of biotic interactions, changes in physiological performance, species range shifts, changes in relative abundances, increases in invasive species, altered migration patterns, changes in forage base, and local extinctions (California Department of Fish and Game 2010).

Life history, behavioral characteristics, and habitat requirements predispose certain species and functional types to have greater sensitivity to climate change than others. In general, the most sensitive species are those with the following traits.

- Specialized habitat requirements.
- Narrow physiological tolerances.
- Limited dispersal ability.
- Dependence on environmental cues for initiation of critical life history events.
- Dependence on interactions with other species.
- Limited adaptive potential because of limited phenotypic plasticity and genetic variability.

In general, a species with high vulnerability will experience greater impacts from climate change, while a less vulnerable species will be less affected and may even benefit from the changes (Glick et al. 2011).

A vulnerability screening provides the following advantages.

- Uses readily available information to identify a subset of species that may require more in-depth analysis.
- Determines which species are likely to be the most strongly affected by climate change using a simple methodology that helps prioritize management actions (Glick et al. 2011).
- Identifies the reasons that a particular species may be vulnerable, helping to guide conservation planning and adaptive management (Glick et al. 2011).

- Identifies critical life-history information needed to better understand a species' vulnerability and adaptation needs.

The results of this vulnerability assessment should be updated periodically during Plan implementation and used to guide adaptive management and monitoring of the covered species.

5.A.1.8.1.1 Methods

A vulnerability screening combines indicators of **sensitivity** and **exposure**. For the analysis reported here, indicators of sensitivity included key life-history traits related to species-specific responses to climatic variables. Exposure is based on the relative degree to which climate change is expected to affect the community formation composing the dominant habitat of each species.

5.A.1.8.1.2 Data Sources

The species accounts (and references cited therein) were the primary sources of information on the life-history traits of the covered species that were evaluated (Appendix 2.A, *Covered Species Accounts*).

5.A.1.8.1.3 Scoring System

The indicators for each dimension of vulnerability (sensitivity, exposure) were given ranks of *high, moderate,* or *low* depending on the relative susceptibility of the indicator to the effects of climate change. For example, a species that is a habitat specialist was given a rank of *high* on that trait, indicating high sensitivity to climate change because of its specialized habitat requirements, while a species that is found in many types of habitat (a habitat generalist) received a *low* for that trait, indicating low sensitivity to climate change in terms of habitat needs.

This qualitative ranking system was used because of the limited information available on covered species' sensitivity to climate variables and potential exposure to climate change. When sufficient information is available, a numeric scoring system may be used. In a typical numeric system (e.g., Gardali et al. 2012) the numbers 1, 2, and 3 are used in place of *low, moderate,* and *high*, respectively. A species' scores on each dimension of vulnerability (sensitivity, exposure) are summed, and these sums are combined to develop the overall ranking. This type of system is possible, however, only when information is available for each of the sensitivity and exposure indicators. If information is not available in the scientific literature, a group of experts may be consulted to provide a consensus ranking.

5.A.1.8.1.4 Sensitivity

Sensitivity traits were selected on the basis of key characteristics that will help determine a species' response to climate change. These included traits used in other vulnerability assessments, such as Foden and coauthors (2008), Williams and coauthors (2008), Young and coauthors (2010), Dawson and coauthors (2011), Glick and coauthors (2011), Point Reyes Bird Observatory (PRBO) (2011), Rowland and coauthors (2011), and Gardali and coauthors (2012).

The traits used as sensitivity indicators and their definitions and rationale are discussed below and summarized in Table 5.A.1.8-1.

Table 5.A.1.8-1. Sensitivity Indicators and Their Definitions and Rationale

Indicator	Definitions and Rationale
Degree of habitat specialization	Species with generalized and unspecialized habitat requirements are more likely to tolerate a greater degree of climatic change than habitat specialists.
Physiological sensitivity	Species with high sensitivity to temperature, precipitation, moisture or other climatic variables are more likely to be affected by climate change.
Limits to dispersal ability	Species with slow or short dispersals are less likely to migrate fast enough to keep up with shifting bioclimatic envelopes.
Dependence on environmental triggers	Species that rely on environmental conditions to signal the time to initiate migration or other key life cycle activities may be unable to successfully complete these activities if climate change alters the cues.
Dependence on ecological interactions	Interactions among species, such as predator-prey or pollinator-plant relationships, will be disrupted by climate change when conditions reverse or decouple the interaction. This could lead to the decline or loss of a resource, or alter synchronization in phenology.
Limits to adaptive potential	Adaptive potential depends on a species' ability to adapt in place through phenotypic plasticity and/or adaptive evolution or by shifting geographic range.

Sources: Foden et al. 2008; Williams et al. 2008; Young et al. 2010; Bagne et al. 2011; Beardmore and Winder 2011; Dawson et al. 2011; Gardali et al. 2012; Glick et al. 2011; Point Reyes Bird Observatory 2011; Council on Environmental Quality and U.S. Department of the Interior (2012)

Habitat Specialist

Species with generalized and unspecialized habitat requirements are likely to tolerate a greater degree of climatic change than habitat specialists. For example, a species found in many of natural communities would be interpreted as having low habitat specialization.

- High = found in only one natural community.
- Moderate = found in two or three natural communities
- Low = found in four or more natural communities.

Physiological Sensitivities

Sensitivity to Temperature, Precipitation, Moisture, or Weather Extremes

Species with narrow physiological tolerances or living close to ecological or physiological thresholds are more likely to exceed their tolerance limits as climate changes. For example, amphibians and reptiles are known to be strongly affected by seasonal temperatures and humidity.

- High = high physiological sensitivity to one or more climate variables (e.g., low tolerance of high temperatures).
- Moderate = some degree of physiological sensitivity to one or more climate variables.
- Low = minimal or no physiological sensitivity to climate variables.

Limits to Dispersal

Species with slow or short dispersal abilities are less likely to migrate fast enough to keep up with shifting bioclimatic envelopes. Examples of dispersal-limited species are amphibians and reptiles, or plants that are dispersed by animals that themselves have small ranges or short dispersal distances. Species with large home ranges generally include large mammals and large raptors. Successful dispersal also depends on a species' ability to withstand rapid fluctuations in climate that may occur during dispersal (Early and Sax 2011).

- High = low dispersal ability.
- Moderate = moderate dispersal ability.
- Low = high dispersal ability.

Dependence on Environmental Triggers

Species that rely on environmental cues for activities such as migration or egg-laying are more likely to experience difficulty completing these activities because environmental cues may change as a result of climate change.

- High = highly dependent on environmental triggers to initiate or complete key life cycle events; lack of trigger may lead to poor success or even failure in completion of activity.
- Moderate = some dependence on one or a few environmental triggers.
- Low = minimal or no dependence on environmental triggers.

Dependence on Ecological Interactions

Interactions among species, such as predator-prey or pollinator-plant relationships, may be disrupted by climate change if conditions reverse or the interaction is decoupled (Walther 2010). This could lead to the decline or loss of a resource or alter synchronization in phenology, such as when migration occurs after the time when food resources are available.

- High = strongly dependent on interactions with other species for reproduction, growth, or survival (e.g., requires a particular pollinator for pollination).
- Moderate = moderate dependence on interactions with other species for reproduction, growth, or survival.
- Low = no dependence on interactions with other species for reproduction, growth, or survival.

Limits to Adaptive Potential

Adaptation involves adapting in place through phenotypic plasticity and/or adaptive evolution or by shifting geographic range. Phenotypic plasticity involves modifying behavior, morphology, or physiology to adjust to climate changes. Thus, species that are highly specialized in their feeding habits (e.g., sandhill crane that feed primarily on harvested corn) may have less adaptive potential than species that are able to diversify their diet. Adaptive evolution involves changes in gene frequencies as a result of natural selection. Low adaptive potential and failure to adapt result in reduced fitness and, ultimately, a decline toward extinction (Running and Mills 2009).

Most evidence to date indicates that adaptation to climate change can occur at specific locations and can be modified by evolutionary processes (Parmesan 2006). The best examples of adaptation in place through phenotypic plasticity involve changes in phenology (Parmesan and Yohe 2003). Although there is less evidence of adaptive evolution in response to climate change, Hairston and coauthors (2005) showed in studies of lizards that adaptive evolution can occur on ecological time scales. Running and Mills (2009) suggested that traits that favor adaptive evolution include large body size, short generation times, rapid population growth, high connectivity, and generalist phenotypes.

- High = limited adaptive potential.
- Moderate = moderate adaptive potential.
- Low = high adaptive potential.

5.A.1.8.1.5 Exposure

A species' vulnerability also depends on the type and rate of environmental changes to which it is exposed, including not only climate change but also related factors such as the location of the species within the landscape (Glick et al. 2011). An exposure variable based on the natural community types included in the BDCP was used to account for both climate change and landscape position. Each natural community type was ranked as *high*, *moderate*, or *low* based on the relative exposure of that community to the effects of projected climate changes in California as summarized in recent reports (e.g., California Natural Resources Agency 2009; Moser et al. 2009). In general, California is expected to experience hotter and drier conditions, a reduction in winter snows along with an increase in winter rains, and accelerating sea level rise. As indicated in Table 5.A.1.8-2, intertidal communities (tidal mudflat, tidal brackish emergent wetland, tidal freshwater emergent wetland) are considered among the most vulnerable natural communities because of their vulnerability to sea level rise, and they therefore were ranked *high* (i.e., greatest vulnerability). The managed wetland natural community is included in this category because it is highly susceptible to sea level rise and levee failure.

Cultivated lands are ranked *moderate*, based on a California Agriculture Vulnerability Index developed by Haden et al. (2012). The alkali seasonal wetland complex, vernal pool complex, grassland, and inland dune scrub communities were ranked *moderate* because they are vulnerable to expected increases in precipitation variability, even though they are not vulnerable to sea level rise. The valley/foothill riparian, nontidal perennial aquatic, nontidal freshwater perennial emergent wetland, and other natural season wetland communities were ranked *low* because they are habitats with a perennial water supply. The tidal perennial aquatic community is deepwater habitat, and therefore this community also falls in the *low* category. Most grasslands are annual grasslands and therefore are not susceptible to climate change.

Table 5.A.1.8-2. Exposure Ranks of Natural Community Types Used in the Vulnerability Screening

	Relative Exposure		
Natural Community	**High**	**Moderate**	**Low**
Tidal perennial aquatic			√
Tidal mudflat	√		
Tidal brackish emergent wetland	√		
Tidal freshwater emergent wetland	√		
Valley/foothill riparian			√
Nontidal perennial aquatic			√
Nontidal freshwater perennial emergent wetland			√
Alkali seasonal wetland complex		√	
Vernal pool complex		√	
Managed wetland	√		
Cultivated lands		√	
Other natural seasonal wetland			√
Grassland			√
Inland dune scrub		√	

5.A.1.8.1.6 Results

The results of the preliminary vulnerability assessment are provided in Table 5.A.1.8-3. Figure 5.A.1.8-1 presents a matrix showing the relative vulnerability of the species evaluated based on the information in the screening table. The matrix indicates the qualitative ranking (*low, moderate, high*) of a species on the basis of its sensitivity to climate change (on the x-axis) and its exposure to climate change (on the y-axis). The total rank for each species on each dimension of vulnerability (sensitivity, exposure) was based on the rank indicated by the most of the individual ranks for that dimension, accounting for missing information. The overall vulnerability of a species to climate change (*low, moderate, high)* is determined by the combination of its exposure and sensitivity rankings, as shown in the matrix in Figure 5.A.1.8-1. Rankings would change as additional information on a species' sensitivity or exposure becomes available.

5.A.1.8.1.7 Limitations and Uncertainties

This vulnerability screening provides a starting point for the Implementation Office and reserve system planners and managers charged with restoration and protection site selection and design, and maintaining and, when feasible, expanding populations of covered species in the face of climate change. Managers should design and implement species-specific conservation actions and monitoring programs that will pay particular attention to the covered species most vulnerable to the effects of climate change (i.e., those in the *highly vulnerable* category), as well as habitats that include a high number of vulnerable species. However, the limitations and uncertainties in this analysis should be taken into account. In particular, it is difficult to predict how a given species will respond to climate changes because of uncertainty in the climate projections as well as uncertainty about the future environmental conditions and the underlying mechanisms that will govern species responses. These uncertainties will be addressed through ongoing monitoring, adaptive management, and directed research, as discussed in detail in Chapter 3, *Conservation Strategy*.

1 **Table 5.A.1.8-3. Vulnerability Screening Table Giving Species' Rankings on Sensitivity Indicators**

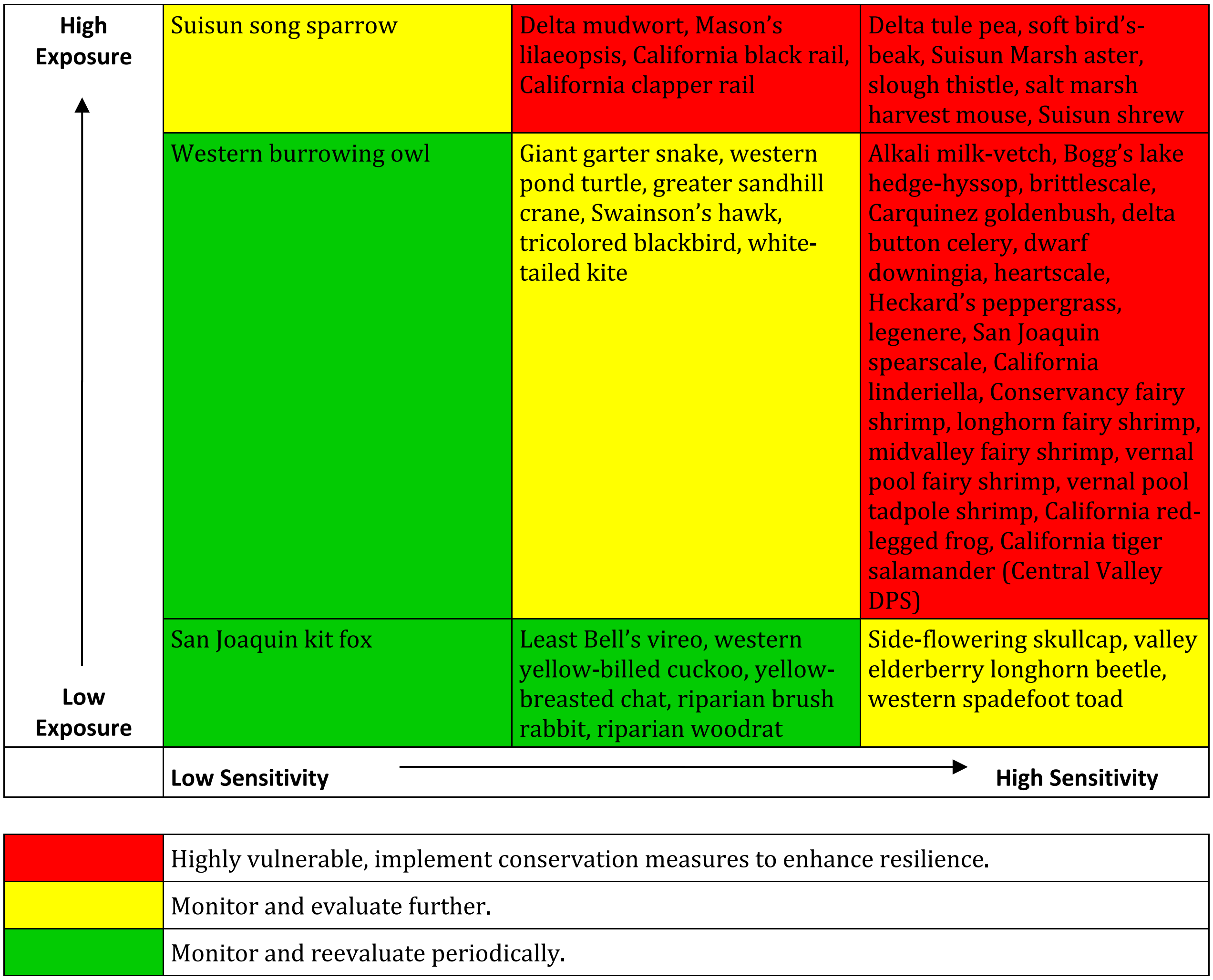
2 H = high sensitivity, M = moderate sensitivity, L = low sensitivity. See text for explanation.

Taxon/Species	Habitat Specialization	Physiological Sensitivity	Limits to Dispersal	Dependence on Environmental Triggers	Dependence on Ecological Interactions	Limits to Adaptive Potential	Natural Community[a]
Plants							
Alkali milk-vetch	High	High	High	High	High	High	VPC
Boggs Lake hedge-hyssop	High	High	High	High	High	High	VPC
Brittlescale	Moderate	High	High	High	Moderate	High	ASWC, VPC, G
Carquinez goldenbush	Moderate	High	High	High	High	High	ASWC, G
Delta button celery	Low	High	High	High	High	High	V/FR, ASWC, VPC, G
Delta mudwort	Low	High	Moderate	High	Moderate	High	TM, TBEW, TFEW, V/FR
Delta tule pea	Moderate	High	Moderate	High	High	High	TBEW, TFEW, V/FR
Dwarf downingia	High	High	High	High	Moderate	High	VPC
Heartscale	Moderate	High	High	High	Moderate	High	ASWC, VPC, G
Heckard's peppergrass	High	High	High	High	Moderate	High	VPC
Legenere	High	High	High	High	Moderate	High	VPC
Mason's lilaeopsis	Low	High	Moderate	High	Moderate	Moderate	TM, TBEW, TFEW, V/FR
San Joaquin spearscale	Moderate	High	High	High	Moderate	High	ASWC, VPC, G
Side-flowering skullcap	High	High	Moderate	High	High	High	V/FR
Slough thistle	High	High	High	High	High	High	V/FR
Soft bird's-beak	High	High	High	High	High	High	TBE
Suisun Marsh aster	Moderate	High	Moderate	High	High	High	TBEW, TFEW, V/FR
Slough thistle	High	High	High	High	High	High	TBEW
Invertebrates							
California linderiella	High	High	High	High	Low	High	VPC
Conservancy fairy shrimp	High	High	High	High	Low	High	VPC
Longhorn fairy shrimp	High	High	High	High	Low	High	VPC
Midvalley fairy shrimp	High	High	High	High	Low	High	VPC
Valley elderberry longhorn beetle	Moderate	Moderate	High	High	High	High	V/FR, G

Taxon/Species	Habitat Specialization	Physiological Sensitivity	Limits to Dispersal	Dependence on Environmental Triggers	Dependence on Ecological Interactions	Limits to Adaptive Potential	Natural Community[a]
Vernal pool fairy shrimp	High	High	High	High	Low	High	VPC
Vernal pool tadpole shrimp	High	High	High	High	Low	High	VPC
Amphibians							
California red-legged frog	Low	High	High	High	Moderate	High	TFEW, V/FR, NPA, NFPE, ASWC, VPC, MW, ONS, G
California tiger salamander (Central Valley DPS)	Low	High	High	High	High	High	ASWC, VPC, ONS, G
Reptiles							
Giant garter snake	Low	Low	High	Moderate	Low	Moderate	TPA, TFEW, NPA, NFPE, ASWC, VPC, MW, CL, ONS, G
Western pond turtle	Low	High	Low	Moderate	Low	Low	TBEW, TFEW, V/FR, NPA, NFPE, ASWC, VPC, MW, CL, ONS, G
Birds							
California black rail	Low	Moderate	Moderate	Low	Low	High	TBEW, TFEW, NFPE, MW
California clapper rail	Moderate	Moderate	Moderate	Low	Low	Low	TM, TBEW
Greater sandhill crane	Low	Low	Low	Low	Low	High	ASWC, VPC, MW, CL, ONS, G
Least Bell’s vireo	High	Moderate	Low	Low	Low	Moderate	V/FR
Suisun song sparrow	Moderate	Low	Low	Low	Low	Low	TBEW, TFEW, MW
Swainson’s hawk	Low	Low	Low	Low	Moderate	High	V/FR, ASWC, VPC, MW, CL, ONS, G
Tricolored blackbird	Low	Moderate	Low	Low	Low	High	TBEW, TFEW, V/FR, NFPE, ASWC, VPC, MW, CL, ONS, G
Western burrowing owl	Low	Low	Low	Low	High	Low	ASW, VPC, MW, ONS, G
Western yellow-billed cuckoo	High	Moderate	Low	Low	Low	Moderate	V/FR
White-tailed kite	Low	Low	Low	Low	Moderate	High	V/FR, ASWC, VPC, MW, CL, ONS, G
Yellow-breasted chat	High	Moderate	Low	Low	Low	Moderate	V/FR

Taxon/Species	Habitat Specialization	Physiological Sensitivity	Limits to Dispersal	Dependence on Environmental Triggers	Dependence on Ecological Interactions	Limits to Adaptive Potential	Natural Community[a]
Mammals							
Riparian brush rabbit	High	Moderate	High	Low	High	High	V/FR
Riparian woodrat (San Joaquin Valley)	High	Moderate	High	Low	High	High	V/FR
Salt marsh harvest mouse	Moderate	High	High	Moderate	High	Moderate	TBEW, MW
San Joaquin kit fox	High	Low	Low	Low	Moderate	Low	G
Suisun shrew	Moderate	High	High	Moderate	High	Moderate	TBEW, MW

[a] **High Exposure:** TM = tidal mudflat, TBEW = tidal brackish emergent wetland, TFEW = tidal freshwater emergent wetland, MW = managed wetlands; **Moderate Exposure:** ASWC=alkali seasonal wetland complex, VPC = vernal pool complex, CL=cultivated lands, IDS = inland dune scrub; **Low Exposure:** TPA = tidal perennial aquatic, VFR = valley foothill/riparian, NPA = nontidal perennial aquatic, NFPEW = nontidal freshwater perennial emergent wetland, ONSW = other natural seasonal wetland, G = grasslands.



High Exposure ↑	🟨 Suisun song sparrow	🟥 Delta mudwort, Mason's lilaeopsis, California black rail, California clapper rail	🟥 Delta tule pea, soft bird's-beak, Suisun Marsh aster, slough thistle, salt marsh harvest mouse, Suisun shrew
	🟩 Western burrowing owl	🟨 Giant garter snake, western pond turtle, greater sandhill crane, Swainson's hawk, tricolored blackbird, white-tailed kite	🟥 Alkali milk-vetch, Bogg's lake hedge-hyssop, brittlescale, Carquinez goldenbush, delta button celery, dwarf downingia, heartscale, Heckard's peppergrass, legenere, San Joaquin spearscale, California linderiella, Conservancy fairy shrimp, longhorn fairy shrimp, midvalley fairy shrimp, vernal pool fairy shrimp, vernal pool tadpole shrimp, California red-legged frog, California tiger salamander (Central Valley DPS)
Low Exposure	🟩 San Joaquin kit fox	🟩 Least Bell's vireo, western yellow-billed cuckoo, yellow-breasted chat, riparian brush rabbit, riparian woodrat	🟨 Side-flowering skullcap, valley elderberry longhorn beetle, western spadefoot toad
	Low Sensitivity →		**High Sensitivity**

🟥	Highly vulnerable, implement conservation measures to enhance resilience.
🟨	Monitor and evaluate further.
🟩	Monitor and reevaluate periodically.

Figure 5.A.1.8-1. Vulnerability Matrix

5.A.1.9 References Cited

5.A.1.9.1 Literature Cited

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5.A.1.9.2 Personal Communications

Tansey, M. Bureau of Reclamation. March 25, 2013—Comments on the Bay Delta Conservation Plan. Revised Administrative Draft. Appendix 5.A.1.