Southern California Riparian Habitats

Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for riparian habitats based on expert input and existing information. Specifically, the information presented below comprises habitat expert vulnerability assessment survey results and comments, peer-review comments and revisions, and relevant references from the literature. The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

Executive Summary

Southern California riparian habitats vary widely with regard to species composition, geomorphology, and hydrologic regimes. For the purposes of this assessment, discussion will be limited to three focal types of low-gradient riparian habitats: vernal pools, springs, and wet meadows. These categories include both precipitation- and groundwater-dominated systems, and they are frequently characterized by a high water table, periodic flooding, hydric and/or mesic vegetation, and the presence of rare, endemic, and threatened or endangered species adapted to these habitat types (Bauder and McMillan 1998, Zedler 2003, Weixelman et al. 2011). Southern California vernal pools are ephemeral wetlands that occur in soils with low permeability in bedrock depressions, inland valleys, and coastal or inland mesas (Bauder and McMillan 1998). Vernal pool hydrology is entirely dependent on precipitation, and pools cycle between annual periods of flooding and drying (Zedler 2003). Springs are created by the upwelling of groundwater to the surface, and outflows typically form isolated pools or feed into streams (Comer et al. 2012). Discharge volume, temperature, and water chemistry create unique systems around springs that often support very high levels of biodiversity (Comer et al. 2012). Wet meadows typically occur at high elevations where the water table is near the surface and are dominated by herbaceous species that tap into the groundwater; they can be further classified based on factors such as substrate, water source, topography, and vegetation (Weixelman et al. 2011).

The relative vulnerability of riparian habitats in southern California was evaluated to be moderate[1] by habitat experts due to moderate-high sensitivity to climate and non-climate stressors, high exposure to future climate changes, and moderate adaptive capacity.

Sensitivity and Exposure	<u>Climate sensitivities</u>: Precipitation, drought, low stream flows, soil moisture, snowpack depth, timing of snowmelt/runoff <u>Disturbance regimes</u>: Wildfire, flooding <u>Non-climate sensitivities</u>: Dams and water diversions, land-use conversion,

[1] Confidence: Moderate

invasive and other problematic species

Within arid and semi-arid regions such as southern California, riparian habitats are critically sensitive to changes in the amount, source, and duration of water within a system, which can alter hydrologic and flooding regimes. Habitats that rely solely on precipitation are most sensitive to changes in the amount or timing of rain and snow, while groundwater-dependent systems such as springs may be less immediately responsive to changes. Drought conditions have widespread effects on all system types, and may shift species composition towards vegetation that can tolerate drier conditions. Severe flooding can cause erosion and channel entrenchment that may alter habitat structure and function, and wildfire greatly increases the risk of flash flooding and debris flows. Climate vulnerabilities in riparian habitats are further exacerbated by habitat degradation or loss due to anthropogenic stressors.

Adaptive Capacity	Habitat extent, integrity, and continuity: Low-moderate geographic extent, low integrity (i.e., degraded), low continuity Resistance and recovery: Low-moderate resistance potential, moderate-high recovery potential Habitat diversity: Moderate overall diversity Management potential: Moderate societal value and management potential

Many riparian habitats have already been lost or heavily degraded by factors that alter their hydrological regime, including development, invasive species, and grazing. Although riparian habitats are adapted to variable conditions as a whole, degraded systems may be unable to recover from disturbance such as these, and management intervention may be needed to restore normal system processes (e.g., flooding regimes and sediment transport). Riparian habitats support very high numbers of endemic and threatened/endangered species due to their unique conditions and isolated nature. They provide valuable ecosystem services including the provision of clean water, flood control, and sediment transport.

Sensitivity

The overall sensitivity of riparian habitats to climate and non-climate stressors was evaluated to be moderate-high by habitat experts.[2]

Sensitivity to climate and climate-driven changes

Habitat experts evaluated riparian habitats to have moderate sensitivity to climate and climate-driven changes,[3] including: precipitation, drought, low stream flows, soil moisture, snowpack depth, and timing of snowmelt/runoff.[4]

Precipitation and soil moisture

All riparian habitats are sensitive to reduced precipitation, which leads to extended dry periods and impacts vernal pool flooding, streamflow, groundwater recharge, the level of the water

[2] Confidence: Moderate

[3] Confidence: High

[4] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

table, and spring discharge rate (Comer et al. 2012; Viers et al. 2013). Precipitation-dominated riparian systems are the most sensitive to changes in the amount and timing of rain and snow since they rely on it for inundation and water storage (Poff et al. 2002; Winter 2000; Zedler 2003). Groundwater-dependent systems (e.g., springs) still need precipitation for groundwater recharge, but they are less vulnerable than precipitation-dependent habitats, and impacts of reduced precipitation in groundwater-dependent systems are typically delayed (Winter 2000). For example, changes in the discharge rate of springs occur more gradually and lag behind decreases in precipitation, especially in high-volume springs or those connected to large regional aquifers (Rice 2007).

Increased precipitation would likely benefit some species that require vernal pool flooding for an extended period in order to successfully reproduce. For instance, the California tiger salamander (*Ambystoma californiense*) requires an inundation period of at least 90 days in order to successfully reproduce and survive to adulthood (Pyke and Marty 2005). More intense rainfall would increase flooding, sediment movement, and erosion, especially in meadows connected to streams (Hunsaker et al. 2014). Increased runoff from the surrounding catchment area could also affect turbidity and water chemistry, impacting species that may be adapted to specific conditions within a relatively closed system (e.g., acidity or calcium levels within a spring; Comer et al. 2012).

Changes in the timing of precipitation could affect the timing and duration of wet and dry periods in vernal pools, which play a key role in the composition of biological communities (Keeley and Zedler 1998; Zedler 2003). Many species are adapted to predictable cycles of flooding and desiccation or to the timing of spring peak flows, and changes in these patterns could impact the reproduction and larval development of amphibians and invertebrates (Comer et al. 2012; Pyke and Marty 2005; Zedler 2003). Species composition in riparian vegetation could also be affected by changes in the timing of precipitation, which could alter germination, flowering, and seed set (Bartolome et al. 2014; Comer et al. 2012; Perry et al. 2012; Poff et al. 2002).

<u>Drought</u>

Although riparian systems are adapted to periods of summer drought, increasingly severe and/or longer-duration droughts can have impacts on both biotic and abiotic processes. Warm air temperature and increased evapotranspiration accelerate drying, especially in habitats surrounded by upland communities where evapotranspiration rates are high (Marty 2005; Viers et al. 2013). Evaporation may cause dissolved minerals and salts to become concentrated, altering water chemistry and decreasing habitat suitability for specialized species (Comer et al. 2012). Additionally, as small pools and standing water dry up, amphibian eggs and larvae become desiccated (Viers et al. 2013). Large decreases in groundwater, streamflow and/or spring discharge may eliminate aquatic species in some systems (Comer et al. 2012; Viers et al. 2013).

Decreases in groundwater supply and a drop in the water table can also prompt shifts towards xeric vegetation in all riparian systems (Patten et al. 2008; Stromberg et al. 2010; Viers et al.

2013). In wet meadows, these shifts can trigger a feedback loop: as the fibrous root systems associated with hydric plants are lost, banks begin to erode, causing stream channel to widen. Wider channels reduce the likelihood of bank overflow (which normally decreases water velocity), and the energy of moving water remains with the channel where it cuts deeper still and ultimately causes additional drops in the water table (Viers et al. 2013). Declines in the groundwater level allow drought-tolerant species to become more dominant, and, eventually, type conversion to upland habitat can occur (Perry et al. 2012; Millar et al. 2004; Stromberg et al. 2010).

Snowpack depth and timing of snowmelt/runoff

Although snow is not a primary driver of hydrology for most riparian habitats in southern California, decreased snowfall, reduced snowpack, and earlier snowmelt are likely to have an impact on high-elevation montane habitats. Sites within the San Bernardino, San Gabriel, and San Jacinto Mountains (typically above 2,000 m) receive over 200 mm of snowfall per month; at the highest elevations, sites can receive over 300 mm of snowfall per month, which stays on the ground until the beginning of June (Sun et al. 2015). Montane meadows and springs within these watersheds are most likely to be affected by changes in snowpack. For instance, snowmelt and spring runoff infiltrate the soil surface to provide moisture, groundwater recharge, and increased base flows (Perry et al. 2012; Sheffield et al. 2004).

An increase in the percentage of annual precipitation received as rain would reduce snowpack and accelerate snowmelt, shifting the timing of spring high flows earlier in the year and diminishing summer flows (Hunsaker et al. 2014; Knowles et al. 2006). Spring peak flows contribute to groundwater recharge, which is important for systems like meadows and springs that depend on a high water table (Perry et al. 2012). However, springs that are fed by very deep sources of groundwater may not be affected by surface flows (Vulnerability Assessment Reviewers, pers. comm., 2015). Changes in the timing of snowmelt and spring high flows could impact species that depend on predictable periods of flooding (e.g., amphibians), or on cold-water habitat created by snowmelt-fed streams (e.g., salmonids; Viers et al. 2013).

Low stream flows

Riparian communities that are connected to streams are impacted by changes in the timing and magnitude of streamflow (Perry et al. 2012). Warming temperatures and associated changes in evapotranspiration, snowpack, and the timing of snowmelt contribute to longer and more severe summer low-flow conditions (Franco-Vizcaino et al. 2002; Hamlet et al. 2007; Hayhoe et al. 2004; Perry et al. 2012; Stewart et al. 2005). These conditions may cause some stream reaches to transition from perennial to intermittent, heavily impacting riparian plants (Perry et al. 2012; Stromberg et al. 2010). Vegetation loss and/or shifts toward xeric species would likely occur under these conditions, and in meadows a loss of the fibrous root systems typical of riparian species can cause bank erosion and channel incision (Viers et al. 2013).

Species that are sensitive to the availability and quality of aquatic habitat are significantly affected by low stream flows (Viers et al. 2013). Lower flows and longer duration of low/no-flow conditions decreases the availability of connected stream and floodplain segments, and increased temperatures in shallow water can lead to the loss of salmonids and other cold-water fish (Viers et al. 2013). A decrease in the area and/or duration of standing water may also impact amphibian reproduction (Viers et al. 2013).

Sensitivity to disturbance regimes

Habitat experts evaluated low-gradient riparian habitats to have moderate sensitivity to disturbance regimes,[5] including: flooding and wildfire.[6] Habitat experts also suggested that insects may have an impact on riparian habitats.

Flooding

Flood events are the dominant geomorphological drivers in meadows, causing both river channel entrenchment and floodplain expansion depending on the physical landscape and vegetation present at a particular location (Ward 1998). These mechanisms are critical in maintaining riparian habitat connectivity and a heterogeneous mosaic of disturbed patches (Ward 1998). Flooding in riparian ecosystems also deposits alluvial material from floodwaters (e.g., nutrients and sediment), and drives the lateral gradient of riparian habitat types across a floodplain (Ward 1998). River entrenchment or the creation of meander segments during flood events provides structural diversity to support a wide array of plant communities (Ward 1998).

However, riparian communities are often negatively impacted by severe and/or frequent flood events associated with intense storms or rain-on-snow events (Perry et al. 2012). Flooding can deposit thick layers of coarse sediment that increase the distance from the soil surface to the water table; this may contribute to the establishment of xeric plant species (Stromberg et al. 2010). Flooding also increases suspended silt and sediment and can wash pollutants into the water, affecting water quality and biological communities (Poff et al. 2002). Systems that are connected to large drainage areas or are currently degraded are more likely to experience severe flooding and/or negative impacts from flooding (Viers et al. 2013), as are riparian habitats that are within recently burned areas (Cooper et al. 2014; Long 2008). Meadows are particularly vulnerable to flash floods and high runoff events, which can cause severe bank erosion, channel incision and, eventually, a drop in the water table (Weixelman et al. 2011; Viers et al. 2013).

Flooding may affect the reproductive success of cold-water fish and amphibians, as eggs could be washed away or buried in sediment and debris (Viers et al. 2013). Populations can also be extirpated following severe floods and associated debris flows (Long 2008). However, flooding can remove local populations of invasive species such as bullfrogs (*Rana catesbeiana*) and mosquitofish (*Gambusia affinis*), allowing native species that are more adapted to flooding to recolonize the area (Doubledee et al. 2003; Gamradt and Kats 1996; Meffe 1984).

[5] Confidence: Moderate

[6] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

Wildfire
Loss of riparian vegetation and changes in soil structure following a wildfire create a high risk for flash flooding and debris flows in recently burned areas (Cannon and DeGraff 2009; Cannon et al. 2008), especially when coupled with early spring storms or extreme precipitation events (Hunsaker et al. 2014; Morrison and Kolden 2015). These can negatively affect habitat structure, water quality and the community structure of vertebrates, invertebrates, and algae (Cooper et al. 2014; Morrison and Kolden 2015; Klose et al. 2015). Wildfires also release nutrient pulses from ash and increase the risk of fire retardants entering aquatic systems, where the ammonia content may lead to fish and invertebrate mortality (Cooper et al. 2014; Morrison and Kolden 2015).

The impact of wildfire on riparian habitats is strongly associated with fire severity as well as the occurrence of post-fire rainstorms (Long 2008, Long et al. 2005). In Arizona, Long (2008) found that Apache trout (*Oncorhynchus gilae apache*) had been extirpated in watersheds where over half of the watershed was burned at a moderate or severe level. However, landscape heterogeneity is also an important factor, and habitat response may vary depending on topography, slope, and upland cover type (Long et al. 2005).

Insects
Insect outbreaks primarily impact riparian habitats by altering the surrounding upland communities; for instance, dead and dying trees provide additional fuel for wildfires (McKenzie et al. 2009). Conifer and mixed conifer forests are vulnerable to bark beetles, and additional stressors such as drought or pollution may increase the likelihood of insect attack and tree mortality (Bentz et al. 2010; McKenzie et al. 2009). Temperature is associated with insect population success, and warmer temperatures can affect the timing of insect reproduction, developmental stages, and mortality (Bentz et al. 2010).

Sensitivity and current exposure to non-climate stressors
Habitat experts evaluated riparian habitats to have high sensitivity to non-climate stressors[7] and to have an overall moderate-high exposure to these stressors within the study region.[8] Key non-climate stressors identified by habitat experts for riparian habitats include: dams and water diversions, land-use conversion, and invasive and other problematic species.[9] The literature also suggests that grazing impacts riparian habitats (Long and Pope 2014; Marty 2005). Because riparian habitats typically have rich, productive soils and sustained water availability, they have been heavily impacted by human activity over the past century (Griggs 2009).

Dams and water diversions
One of the greatest threats to riparian habitats is anthropogenic water use and associated infrastructure (e.g., dams and water diversions). In southern California, most streams have

[7] Confidence: High
[8] Confidence: High
[9] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

dams or diversions at some point along their reaches (Stephenson and Calcarone 1999). Dams and water diversions reduce flow volume and variability in order to maintain reservoir storage and water delivery, and the loss of fluctuating stream flows and natural flooding regimes alters the dynamic processes that contribute to the biodiversity of riparian ecosystems (Ward 1998; Perry et al. 2012). Altered streamflow patterns and dam placement also reduce longitudinal connectivity (e.g., between stream reaches) and lateral connectivity (e.g., isolating river channels from floodplain systems; Ward 1998).

Groundwater withdrawals impact meadows and springs heavily by reducing stream flows and spring discharge rates (Patten et al. 2007). The effect of groundwater withdrawals can be magnified if the level of the water table falls below the depth of riparian plant roots, which reduces bank stability and promotes channel incision (Loheide and Booth 2011; Micheli and Kirchner 2002; Patten et al. 2007; Viers et al. 2013). Desert springs are particularly susceptible to decreasing groundwater levels, as they are typically reliant on a limited water source (Patten et al. 2007). Together, the impacts caused by regulated streamflows and groundwater withdrawal may exacerbate the effects of warming temperatures and increasing water stress.

Invasive species

Shifts in climate conditions may allow invasive species to establish or expand into riparian habitats. For instance, warming temperatures and extended dry conditions may reduce the length of time that vernal pools are filled with water, allowing invasive species to encroach into the basin in dry periods (Bartolome et al. 2014). Invasive species compete with native plants and wildflowers and also increase evapotranspiration, which speeds drying and creates conditions even more susceptible to invasion (Marty 2005).

Overall, lower-elevation and/or drier sites may be more vulnerable to invasive species; in southern California, two species that are particularly aggressive at lower elevations are saltcedar (*Tamarix* spp.) and giant reed (*Arundo donax*; Stephenson and Calcarone 1999). Both grow well in areas of high disturbance and form dense stands that may outcompete native vegetation (Stephenson and Calcarone 1999). Saltcedar is more tolerant of drought and can use water very efficiently (Vandersande et al. 2001). However, it also takes up large quantities of water, resulting in reduced groundwater levels, and exudes salts that accumulate in the soil; both of these factors make surrounding areas less suitable for native groundwater-dependent riparian plants (Stephenson and Calcarone 1999; Vandersande et al. 2001). Regular flooding flushes salts out of the soil and inundates vegetation, creating conditions allow the reestablishment of native species better suited to flooding (Vandersande et al. 2001).

Invasive fish and wildlife species can also alter competition and/or predation dynamics. For example, reduced flooding is associated with increases of invasive predatory bullfrogs and reduced abundance of the threatened California red-legged frog (*Rana draytonii*; Doubledee et al. 2003). However, within stream reaches that flood at least every five years, bullfrog populations may be impaired, allowing red-legged frog populations to be maintained (Doubledee et al. 2003).

Land-use change

Development pressure in southern California is very high, and riparian habitats are in demand for conversion to agriculture, urban development, and water supply/energy infrastructure (Stephenson and Calcarone 1999; Vulnerability Assessment Reviewers, pers. comm., 2015). Most historical vernal pools have already been lost to development, including extensive complexes that comprised hundreds of pools (Bauder and McMillan 1998). Many high-discharge springs have also been developed for off-site use, especially in low-elevation areas (Comer et al. 2012; Vulnerability Assessment Reviewers, pers. comm., 2015). High-elevation sites, including montane meadows and springs, are more likely to remain undisturbed due to their remote location and lack of accessibility (Comer et al. 2012).

In addition to the direct loss of habitat, development can also have indirect impacts to hydrology. Development is associated with increased water use, which can cause large drops in groundwater levels (Comer et al. 2012), and proximity to human populations is typically associated with heavier recreational use (Vulnerability Assessment Reviewers, pers. comm., 2015). Grading for transportation infrastructure, as well as the runoff from the roads themselves, alters sedimentation, erosion, and flow regimes when they are in or near riparian habitats (Hunsaker et al. 2014; Long et al. 2005).

Finally, increases in the amount of impervious surface affect the amount and speed of stormwater runoff by preventing precipitation from percolating directly into the soil or being filtered through vegetation before entering aquatic habitats. Impervious surfaces also absorb heat, which increases the temperature of runoff, and heated runoff may include contaminants such as sediments, oil, salts, heavy metals, pesticides, fertilizers, and viruses/bacteria (Nelson et al. 2009; Poff et al. 2002; Walsh et al. 2005). Climate change is likely to interact strongly with urbanization and development; for instance, increased storms and heavy precipitation amounts could create larger amounts of runoff, which would carry pollutants into streams and wetlands at a high velocity, affecting water quality, channel morphology, and species assemblages (Hawley et al. 2012; Nelson et al. 2009).

Grazing

Domestic grazing practices are often viewed as negative drivers of disturbance (Marty 2005) and poorly managed grazing has, in many cases, degraded riparian habitats through channel incision, bank instability, and riparian vegetation loss (Medina and Long 2004). In meadows, grazing has been associated with changes in litter cover and depth, percentage of bare ground, soil strength, erosion, channel structure, vegetation cover, and sometimes lower faunal abundance and diversity (Holmquist et al. 2013; Long and Pope 2014; Ramstead et al. 2012). However, the impacts of grazing are dependent on the specific management practices used, and grazing can have complex interactions with other factors (e.g., non-native plants), which may mediate or exacerbate the impact of grazing (George et al. 2011). Although a review of wet meadow restoration efforts found that the majority of studies recommended removing or reducing grazing to promote soil and vegetation recovery (Ramstead et al. 2012), good livestock management practices may be equally effective at accomplishing this goal (Freitas et al. 2014).

Grazing can be beneficial to vernal pools, potentially ameliorating the impact of changes in temperature and precipitation that contribute to drier conditions (Pyke and Marty 2005). Various studies have shown that grazing can increase native plant and wildlife diversity, decrease invasive species (e.g., exotic grasses), and extend the length of pool hydroperiod (Bartolome et al. 2014; Marty 2005; Pyke and Marty 2005). A comparison of grazed and non-grazed pools in central California found that year-round grazing was tied to higher native plant cover, decreased exotic grass cover, and increased cover of forbs relative to grasses (Marty 2005). Water remained in pools 49-50 days longer when they were grazed year-round (compared to ungrazed pools), and 24 days longer in pools that were grazed only during the wet period (Marty 2005). Finally, Marty (2005) found that invertebrate diversity was higher in grazed pools, probably because of the longer period of inundation that allows successful reproduction for a greater number of species.

Around springs, livestock and other large ungulates can compact soils, reduce vegetation, and alter species composition (Comer et al. 2012; Long et al. 2005). Moderate grazing in spring-fed wetlands resulted in decreased cover but higher species richness, evenness, and diversity within pastures; it had no effect on the percentage of native species vs. invasive species (Jackson and Allen-Diaz 2006). Grazing did not decrease cover at spring-fed creeks, and moderate grazing seems to have an overall positive effect on their stability and productivity (Jackson and Allen-Diaz 2006).

Future Climate Exposure

Habitat experts evaluated riparian habitats to have high exposure to future climate and climate-driven changes,[10] and key climate variables to consider include: changes in precipitation, extreme high flows/runoff, and decreased snowpack (Table 1).[11] For a detailed overview of how these factors are projected to change in the future, please see the Southern California Climate Overview (http://ecoadapt.org/programs/adaptation-consultations/socal).

Riparian habitats with a long-term stable groundwater source are more likely to serve as refugia than systems with shorter recharge cycles (J. Long, pers. comm., 2015). For instance, springs with a deep groundwater source and/or springs that are connected to large regional aquifers maintain stable water temperature and chemistry (Rice 2007). Due to their stable conditions and heterogeneous nature, springs and spring-fed creeks often serve as thermal refugia for aquatic species, including salmonids and invertebrates (Erman 2002; Ebersole et al. 2003).

[10] Confidence: Moderate

[11] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

Table 1. Anticipated response of low-gradient riparian ecosystems to climate and climate-driven changes.

Climate and climate-driven changes	Anticipated riparian habitat response
Precipitation and soil moisture *Variable annual precipitation amount and timing; decreased soil moisture, especially in the summer*	• Changes in water quality and/or chemistry associated with increased runoff • Shifts in vegetation community composition • Altered timing and duration of inundation for vernal pools, affecting invertebrate and amphibian survival/reproduction • Change in spring discharge rates
Drought *Longer, more severe droughts with drought years twice as likely to occur*	• Altered water chemistry due to concentration of dissolved minerals and salts • Extirpation of aquatic species where pools and standing water dry up • Compositional shift towards xeric vegetation • Change in spring discharge rates
Snowpack depth and timing of snowmelt/runoff *Up to 50% reduction in snowfall and 70% reduction in snowpack by 2100 (greatest loss in low elevations); snowmelt and peak runoff occurring 1-3 weeks earlier*	• Reduced soil moisture and lower summer stream flows • Delayed or reduced groundwater recharge • Compositional shift towards xeric vegetation • Losses or compositional shifts in species that depend on spring flooding and/or cold-water habitat created by snowmelt
Low stream flows *More extreme low flows and increased duration of low- or no-flow conditions*	• Compositional shift towards xeric vegetation and associated bank erosion in meadows • Decreased stream connectivity, impacting aquatic species • Loss of salmonids due to increased water temperature and reduced dissolved oxygen concentrations • Declines in amphibian reproduction associated with decreased area of available habitat
Flooding *30-40% increase in flash floods in small river/stream basins, altered storm frequency*	• Potential loss of groundwater-dependent vegetation in areas of heavy sediment deposition • Increased bank erosion, channel incision and/or sedimentation, although sediment can also rebuild downstream riparian habitats • Decreased water quality associated with suspended sediment and/or contaminants • Decreased reproductive success of fish and amphibians due to loss of eggs • Extirpation of aquatic species after flood events • Possible mortality and/or selective pressure

	against invasive species, such as bullfrogs
Wildfire *Increased fire size, frequency, and severity*	• Loss of organic and inorganic ground cover • Changes in soil structure • Flash flooding and debris flows in recently burned areas, leading to severe erosion and sediment scouring/deposition • Shifts in species composition and/or extirpation of local populations due to changes in habitat structure and water quality

Changes in evapotranspiration, precipitation, drought, snowpack, and other hydrological factors may increase the climatic water deficit over the next 100 years (Christensen and Lettenmaier 2007; Ficklin et al. 2010). While the greatest deficit is associated with climate scenarios that predict decreased precipitation, increased evapotranspiration caused by warmer temperatures may lead to overall drying even if precipitation increases modestly (Ficklin et al. 2010).

The loss of additional riparian habitat area is likely in the future; for instance, reductions in grazed area would likely result in conversion of some montane meadow and vernal pool habitats to urban/suburban development (Sulak and Huntsinger 2007). Encroachment of upland forests into meadows may also increase, although the exact mechanism for this is unclear (Millar et al. 2004). Lodgepole pine encroachment into meadows has been associated with complex interactions among minimum temperature, precipitation amount, and the Pacific Decadal Oscillation (Millar et al. 2004).

Adaptive Capacity

The overall adaptive capacity of low-gradient riparian habitats was evaluated to be moderate by habitat experts.[12]

Habitat extent, integrity, continuity, and landscape permeability
Habitat experts evaluated riparian habitats to have a low-moderate geographic extent (i.e., habitat is quite limited in the study area),[13] low integrity (i.e., habitat is degraded),[14] and feature low continuity (i.e., habitat is isolated and/or quite fragmented).[15] Habitat experts identified geologic features as the primary barrier to habitat continuity and dispersal for this ecosystem type.[16]

[12] Confidence: High
[13] Confidence: High
[14] Confidence: High
[15] Confidence: High
[16] Barriers presented are those ranked most critical by habitat experts (not all habitat experts agreed on these landscape barriers). A full list of evaluated barriers can be found at the end of this document.

Riparian systems are naturally patchy and/or isolated (Zedler 2003; Vulnerability Assessment Reviewers, pers. comm., 2015); however, habitat loss due to anthropogenic factors (e.g., development, dams, groundwater pumping) has further decreased connectivity and destroyed historical wetland complexes (Bauder and McMillan 1998). Low-elevation sites are usually impacted more heavily, while high-elevation sites are somewhat protected due to their lack of accessibility (Stephenson and Calcarone 1999). Heavily altered habitats have a reduced capacity to support native fauna and flora and are more susceptible to invasive species (Stephenson and Calcarone 1999).

Vernal pools in southern California are likely the most threatened type of riparian habitat (Vulnerability Assessment Reviewers, pers. comm., 2015). It is estimated that vernal pool soils once covered 5-6% of San Diego County, or an area of about 200 square miles (Bauder and McMillan 1998). However, more than 90% of California's vernal pools have been lost, and the remaining pools are degraded (Bauder and McMillan 1998). Montane meadows are less degraded than vernal pools as a whole, but anthropogenic or climatic stressors have impacted many sites (Vulnerability Assessment Reviewers, pers. comm., 2015). Springs have also been degraded, particularly those with a high discharge rate, and/or those that occur along streams that have been dammed or diverted (Comer et al. 2012).

Resistance and recovery
Habitat experts evaluated low-gradient riparian habitats to have low-moderate resistance to climate stressors and maladaptive human responses,[17] and moderate-high recovery potential.[18]

While riparian habitats are well adapted to variable hydrological regimes, systems that have already been impacted can be very slow to recover (Viers et al. 2013). Degraded meadows often cannot recover without active management interventions to restore ecological processes such as bank overflow, sediment transport, and establishment of riparian vegetation to maintain bank stability (Long and Pope 2014). However, the variable conditions and isolated nature of habitats such as vernal pools and springs has given rise to very high levels of endemic and specially adapted species (Keeley and Zedler 1998; Zedler 2003), which may be well-suited to fill the niche left vacant by large disturbance events such as flooding (Gamradt and Kats 1996).

Springs are fairly resistant to stressors such as increased temperature and decreased precipitation, especially when they are connected with deep groundwater sources or large regional aquifers (Rice 2007). After disturbance events like severe wildfire, management actions could focus on increasing the ability of the habitat to return to a natural balance of dynamic conditions (Long et al. 2005).

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[17] Confidence: High
[18] Confidence: Moderate

Habitat diversity
Habitat experts evaluated low-gradient riparian habitats to have low-moderate physical and topographical diversity,[19] high component species diversity,[20] and moderate functional group diversity.[21]

Riparian habitats harbor tremendous amounts of biodiversity, supporting the existence of many endemic and rare species (Comer et al. 2012). Springs support particularly high levels of diversity, and can include fish and invertebrate species that may only be found within a single system (Comer et al. 2012). A study of mountain cold springs and outflows in the Sierra Nevada found that invertebrate assemblages, abundance, and timing of emergence were different from spring to spring, even within the same watershed, and that species richness was greater in deeper, more permanent springs (Erman 2002). Despite the high level of species diversity found in spring ecosystems, the small size and isolated nature of this habitat type typically does not include many different species within a given functional group. Additionally, species are often highly specific to the characteristics of the habitat, increasing their vulnerability to changes in hydrology and/or water chemistry (Comer et al. 2012).

Montane meadows are typically interspersed within a mix of hardwood and conifer forests at lower elevations and mixed conifer forests at higher elevations (Stephenson and Calcarone 1999). The high water table limits woody vegetation within meadows, which are dominated by mesic or hydric herbaceous plants (Viers et al. 2013). Wet meadows support sedges, rushes, grasses, and perennial herbs, and some also support riparian shrubs such as willow (*Salix* spp.) and alder (*Alnus* spp.; Stephenson and Calcarone 1999; Viers et al. 2013). Meadows with pools and standing water are typically found in depressions and lacustrine fringes, and these commonly support amphibians (especially where fish are absent) and invertebrates that can tolerate warmer, less oxygenated water (Viers et al. 2015). Wet meadows associated with lotic systems support more aquatic life, including fish and benthic macroinvertebrates (Viers et al. 2013), while vertical structure and habitat complexity associated with riparian shrubs and trees support greater bird diversity (Merritt and Bateman 2012).

Vernal pool vegetation is adapted to harsh conditions characterized by cycles of inundation and desiccation (Bartolome et al. 2014; Zedler 2003). These habitats support a range of specialized, endemic, and threatened/endangered species, including some species that are limited to a single pool sub-type (Bauder and McMillan 1998; Zedler 2003). Typically, plants germinate underwater and live their adult lives in dry conditions (Bartolome et al. 2014). Orcutt's quillwort (*Isoetaceae orcuttii*), California Orcutt grass (*Orcuttia californica*), and goldfields (*Lasthenia* spp.) commonly occur on the edge of vernal pools. Slightly higher in elevation and farther away from the basin, vegetation begins to blend with the upland community and *Bromus* spp. and *Erodium* spp. become more common (Keeley and Zedler 1998).

[19] Confidence: High
[20] Confidence: High
[21] Confidence: Moderate

Because fish cannot survive in vernal pools, species such as amphibians and fairy shrimp are able to reproduce in a predator-free environment; however, reproduction is limited by the timing and length of the hydroperiod (Zedler 2003). Species that thrive in vernal pools typically are able to respond quickly to pool formation and have a short reproductive cycle, surviving in upland habitats while the pool is dry (Bartolome et al. 2014; Zedler 2003). Vernal pools are heavily used by breeding amphibians, including the California tiger salamander and the California red-legged frog (Bartolome et al. 2014).

Herbaceous species found in or near many riparian habitats include grass (e.g., *Bromus* spp.), sedge (*Carex* spp.), bulrush (*Schoenoplectus* spp.), spikerush (*Eleocharis* spp.), miner's lettuce (*Claytonia perfoliata*), Douglas sagewort (*Artemisia douglasiana*), poison-hemlock (*Conium maculatum*), hoary nettle (*Urtica holosericea*), columbine (*Aquilegia* spp.), monkey flower (*Mimulus* spp.), horsetail (*Equisetum* spp.), and orchids (e.g. *Spiranthes* spp., *Habenaria* spp.; Comer et al. 2012; Grenfell Jr. 1988). Woody species may include cottonwood (*Populus* spp.), willow (*Salix* spp.), mesquite (*Prosopis* spp.), California sycamore (*Platanus racemosa*), valley oak (*Quercus lobata*), velvet ash (*Fraxinus velutina*), Oregon ash (*Fraxinus latifolia*), white alder (*Alnus rhombifolia*), boxelder (*Acer negundo*), wild grape (*Vitis californica*), wild rose (*Rosa californica*), California blackberry (*Rubus ursinus*), blue elderberry (*Sambucus cerulea*), poison oak (*Toxicodendron diversilobum*), and buttonbush (*Cephalanthus occidentalis*; Comer et al. 2012; Grenfell Jr. 1988).

Management potential

Habitat experts evaluated riparian habitats to be of moderate societal value.[22] Riparian habitats are valued for their biodiversity and endemism, wildlife support, recreation, open space, and scenery (e.g., wildflowers; Vulnerability Assessment Reviewers, pers. comm., 2015). However, their perceived value varies somewhat by habitat type, and vernal pools, in particular, may be undervalued outside of the conservation community (L. Criley, pers. comm., 2015). Low-gradient riparian habitats provide a variety of ecosystem services, including: biodiversity, water supply/quality/sediment transport, recreation, grazing, carbon sequestration, nitrogen retention, and flood and erosion protection (Vulnerability Assessment Reviewers, pers. comm., 2015).

Habitat experts identified moderate potential for managing or alleviating climate impacts for riparian habitats.[23] Based on the literature, the following management activities may help to ameliorate the impacts of climate change:

- Managed grazing may benefit vernal pools by extending the length of the hydroperiod and increasing habitat suitability for invertebrates (including fairy shrimp) and amphibians (Marty 2005; Pyke and Marty 2005).
- Structural treatments within wet meadows may raise the water level of channels, dissipating stream energy and allowing the deposition of fine sediments; this could

[22] Confidence: Moderate

[23] Confidence: Moderate

result in the restoration of degraded stream banks and improved habitat value for fish, benthic invertebrates, and other species (Long and Pope 2014; Medina and Long 2004).

- Following a severe wildfire, recovery efforts for springs may include livestock exclusion to facilitate recovery of riparian vegetation, road rehabilitation to minimize erosion and concentrated runoff, and structural treatments to stabilize incising channels (Long et al. 2005).

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