Central Valley Landscape Conservation Project

Climate Change Vulnerability Assessment (January 2017 version)

California Tiger Salamander

Vulnerability Assessment Summary

Overall Vulnerability Score and Components:

Vulnerability Component	Score
Sensitivity	Moderate-high
Exposure	Moderate-high
Adaptive Capacity	Low
Vulnerability	**Moderate-high**

Overall vulnerability of the California tiger salamander was scored as moderate-high with high confidence. The score is the result of moderate-high sensitivity, moderate-high future exposure, and moderate-low adaptive capacity scores.

Key climate factors affecting the California tiger salamander include precipitation timing and amount, drought, air and water temperature, and storms. Precipitation timing and amount and storms influence adult migration and juvenile dispersal movements, while precipitation and drought influence aquatic habitat availability. High air temperatures likely enforce utilization of terrestrial burrow refugia and water temperatures affect development rates.

Key non-climate factors for California tiger salamanders include urban/suburban development, agricultural and rangeland practices, invasive and problematic species, land use change, and roads and highways. Urban development, agricultural conversion, and land use change have contributed to salamander habitat loss, fragmentation, and degradation. Roads and highways can fragment habitat, increase road kill, and prevent annual breeding migrations. Invasive and problematic species (e.g., bullfrogs, non-native fish) prey on salamander larvae and prohibit use of permanent ponds for breeding. The California tiger salamander is also vulnerable to hybridization with the non-native barred salamander; hybridization undermines genetic diversity, and hybrids outcompete and prey upon native individuals.

Grazing is a key disturbance regime affecting California tiger salamanders, largely helping to maintain habitat quality and facilitate salamander mobility by controlling emergent vegetation, grass height, and thatch. California tiger salamanders display a mid-range reproductive strategy; although they have long life spans (10 years), breeding is not consistent and juvenile mortality is high (>50%). California tiger salamanders are habitat specialists and prey generalists; they rely on an aquatic breeding habitat (ephemeral pools and wetlands) adjacent to upland grassland or oak woodland habitat with abundant California ground squirrel burrows.

California tiger salamander populations in the Central Valley are isolated and fragmented; this species' low dispersal ability (typically <1 mile) limits gene flow, dispersal, and annual migration, and increases population vulnerability to extirpation during extreme events or human disturbance. Multiple landscape barriers, including agricultural and rangeland practices, urban development, land use change, roads and highways, invasive species, dams and water diversions, and energy development further inhibit tiger salamander dispersal and annual migration activities.

This species exhibits moderate intraspecific species diversity; there is genetic diversity between and within distinct population segments, and adults show some diversity in breeding habitat (e.g., using artificial ponds). This species is resistant to some degree of climate variability but not very resistant to human land uses.

Management potential for California tiger salamanders was scored as moderate. Management options may include regulatory support from the U.S. Endangered Species Act and California Endangered Species Act; preventing additional rangeland loss to intensive agriculture; managing artificial ponds and managed wetlands for ephemeral characteristics to reduce non-native species and hybrid pressure; and attempting to restore and manage farrowed agricultural land for salamander habitat.

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Introduction

Description of Priority Natural Resource

The California tiger salamander (*Ambystoma californiesnse*) utilizes a combination of aquatic breeding habitat and upland burrowing habitat, spending a majority of its life cycle underground (U.S. Fish and Wildlife Service 2016). California tiger salamanders in the Central Valley are currently listed as threatened.

As part of the Central Valley Landscape Conservation Project, workshop participants identified the California tiger salamander as a Priority Natural Resource for the Central Valley Landscape Conservation Project in a process that involved two steps: 1) gathering information about the species' management importance as indicated by its appearance in existing conservation plans and lists, and 2) a workshop with stakeholders to create the final list of Priority Natural Resources, which includes habitats, species groups, and species.

The rationale for choosing the California tiger salamander as a Priority Natural Resource included the following: the species has high management importance, and the species' conservation needs are not entirely represented within a single priority habitat or species group. Please see Appendix A: "Priority Natural Resource Selection Methodology" for more information.

Vulnerability Assessment Methodology

During a two-day workshop in October of 2015, 30 experts representing 16 Central Valley resource management organizations assessed the vulnerability of priority natural resources to changes in climate and non-climate factors, and identified the likely resulting pressures, stresses, and benefits (see Appendix B: "Glossary" for terms used in this report). The expert opinions provided by these participants are referenced throughout this document with an endnote indicating its source[1]. To the extent possible, scientific literature was sought out to support expert opinion garnered at the workshop. Literature searches were conducted for factors and resulting pressures that were rated as high or moderate-high, and all pressures, stresses, and benefits identified in the workshop are included in this report. For more information about the vulnerability assessment methodology, please see Appendix C: "Vulnerability Assessment Methods and Application." Projections of climate and non-climate change for the region were researched and are summarized in Appendix D: "Overview of Projected Future Changes in the California Central Valley".

Vulnerability Assessment Details

Climate Factors

Workshop participants scored the resource's sensitivity to climate factors and this score was used to calculate overall sensitivity. Future exposure to climate factors was scored and the overall exposure score used to calculate climate change vulnerability.

Climate Factor	Sensitivity	Future Exposure
Air temperature	High	High
Altered stream flow	Moderate	Moderate
Extreme events: drought	High	High
Extreme events: storms	Moderate-high	-
Increased flooding	-	Moderate
Precipitation (amount)	High	Moderate-high
Precipitation (timing)	High	Moderate-high
Water temperature	High	High
Overall Scores	**High**	**Moderate-high**

Climate and climate factors that may benefit the species:

- Water temperature
- Storms

It is unknown how climate change will specifically affect this species, but due to a wide geographic range, California tiger salamanders are likely to experience different effect magnitudes based on location (U.S. Fish and Wildlife Service 2016). More erratic weather patterns may outpace the rate at which tiger salamanders can adapt (U.S. Fish and Wildlife Service 2016). Southern populations may be most exposed to lower precipitation and higher air temperatures, as current breeding habitat is already limited, and future drying may eliminate these pools completely, leading to local extirpations (Bolster 2010). However, vernal pool habitat in the southern (severely water-limited) and northern (water-rich) end of the study region may show less response to climate change than pools in the central part of the study region, where pools currently provide variable habitat suitability from year to year (Pyke 2005). In general, air temperature, winter precipitation, and land use change are likely to interact and affect vernal pool and seasonal wetland hydroperiods in the future (Pyke 2004; Pyke & Marty 2005; Lawler et al. 2010).

Refugia from air and water temperature increases will likely move north in the valley, unless this region also becomes too arid, in which case translocations to southern Oregon may be needed. Elevational occurrence for California tiger salamander is currently higher in San Joaquin Valley than Sacramento Valley, so this species might move up in elevation to find refugia, and there are large ranch easements that might facilitate this upward elevational movement. Non-refugia are likely to include San Benito County sites where populations currently exist or western portions of the Central Valley due to the rain shadow[1].

Drought

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (high confidence)*
> ***Potential refugia:*** *Sites where water/pond drainage can be controlled, deeper pools with broader micro-watersheds (likely within existing vernal pool complexes).*

Compared to the preceding century (1896-1994), drought years in California have occurred twice as often in the last 20 years (1995-2014; Diffenbaugh et al. 2015). Additionally, the recent drought (2012-2014) has been the most severe drought on record in the Central Valley (Williams et al. 2015), with record accumulated moisture deficits driven by high temperatures and reduced, but not unprecedented, precipitation (Griffin & Anchukaitis 2014; Williams et al. 2015). The frequency and severity of drought is expected to increase due to climate change over the next century (Hayhoe et al. 2004; Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015), as warming temperatures exacerbate dry conditions in years with low precipitation, causing more severe droughts than have previously been observed (Cook et al. 2015; Diffenbaugh et al. 2015). Regardless of changes in precipitation, warmer temperatures are expected to increase evapotranspiration and cause drier conditions (Cook et al. 2015). Recent studies have found that anthropogenic warming has substantially increased the overall likelihood of extreme California droughts, including decadal and multi-decadal events (Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015), which will likely have implications for California tiger salamander habitat availability and persistence.

Drought periods can completely prevent vernal pool ponding and/or reduce ponding duration (Bauder 2005), eliminating or minimizing salamander breeding opportunities (Barry & Shaffer 1994). This may not lead to homogenous loss of all vernal pools used by the California tiger salamander, but lower capacity pools would likely be rendered unviable for reproduction, meaning a contraction of the range and a decrease in the usability of pools within that range (Bolster 2010). Even small hydroperiod reductions are likely to affect habitat suitability due the longer aquatic life stage of this species (Marty 2005). For example, drought conditions may prevent larvae from completing metamorphosis by causing early pond drying (U.S. Fish and Wildlife Service 2016). Relatively long adult lifespans help populations weather short-term drought (Barry & Shaffer 1994), but longer drought duration would likely negatively affect this species by limiting breeding opportunities (U.S. Fish and Wildlife Service 2016). Paired with naturally low recruitment (Trenham et al. 2000), drought could threaten California tiger salamander persistence (U.S. Fish and Wildlife Service 2016).

Air temperature

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (moderate confidence)*
> ***Potential refugia:*** *Northern portions of the Central Valley, higher elevations, deeper pools with broader micro-watersheds (likely within existing vernal pool complexes).*

Warmer air temperatures may affect California tiger salamander reproduction and recruitment (Trenham et al. 2000; U.S. Fish and Wildlife Service 2016). Hot summer temperatures may contribute to high metamorph mortality (>50%; Trenham et al. 2000). Additionally, unseasonably high temperatures may also be linked with high annual variability in number of reproducing California tiger salamander adults and number of larvae, although exact mechanisms behind these relationships are unclear (U.S. Fish and Wildlife Service 2016). Warmer temperatures may also favor hybrid tiger salamanders over native salamanders because hybrids have better endurance and are able to disperse farther at higher air temperatures (Johnson et al. 2010). California tiger salamanders use burrows as refuge from hot temperatures (Trenham 2001).

Water temperature

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (moderate confidence)*

Water temperature influences California tiger salamander development rates, including time for eggs to hatch (Anderson 1968) and time to larval metamorphosis (Ford et al. 2013). Extreme temperatures during the breeding season can also undermine egg and larval survival (U.S. Fish and Wildlife Service 2016).

Precipitation (amount)

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *Moderate-high (moderate confidence)*

Precipitation (timing)

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *Moderate-high (moderate confidence)*

Precipitation volume and timing influence adult salamander movement and overall aquatic habitat availability and quality. Adult migration to and from aquatic breeding habitat occurs following rainy periods from November-April (Loredo & van Vuren 1996; Trenham et al. 2000). Along with temperature, precipitation timing and volume also likely play a role in the highly fluctuating annual number of reproducing adults and number of larvae, although mechanisms for this relationship are unclear (U.S. Fish and Wildlife Service 2016).

Additionally, precipitation timing and amount influence wetland hydroperiod (Pyke & Marty 2005; Bauder 2005), which affects breeding habitat suitability. Pools must stay inundated long enough to permit breeding and larval metamorphosis, which cumulatively take around 3-4 months (Ford et al. 2013; U.S. Fish and Wildlife Service 2016). Pools that are inundated longer typically produce more and larger larvae than pools that dry earlier in the season (Ford et al. 2013), and ponding duration time is correlated with time of salamander metamorphosis (Loredo & van Vuren 1996). However, ephemeral ponds that completely dry out by late summer and early fall are ideal habitat for this species because the dry period prohibits bullfrog and non-native fish residency (U.S. Fish and Wildlife Service 2005). Similarly, short ponding duration (3 months) provides a competitive advantage to native salamanders over hybrid salamanders (Riley et al. 2003; Fitzpatrick & Shaffer 2004; Johnson et al. 2013). Shifting hydroperiods may also change dynamics of insect emergence. The California tiger salamander is vulnerable to predatory insect larvae, which may experience earlier emergence; if these larvae emerge first, they may outpace and consume salamander larvae[1].

Storms

> ***Sensitivity:*** *Moderate-high (moderate confidence)*
> ***Future exposure:*** *Moderate-high (moderate confidence)*
> ***Potential refugia:*** *Riparian buffers are considered refugia because of stream (dependent on flow).*

Rain storms may trigger adult breeding migration to aquatic habitat and/or juvenile emigration from ponds (if metamorphosis is complete at the time of the storm; Loredo & van Vuren 1996). Storms and associated runoff can cause rapid pond inundation (Bobzien & DiDonato 2007), and shifts in water level during the breeding season can affect egg and larval survival (U.S. Fish and Wildlife Service 2016).

Streamflow

> ***Sensitivity:*** *Moderate (moderate confidence)*
> ***Future exposure:*** *Moderate (moderate confidence)*
>> ***Low flows:*** *Moderate (moderate confidence)*
>> ***Increased flooding:*** *Moderate (moderate confidence)*

Flooded areas are avoided by native California tiger salamanders because they are dependent on ground squirrels, which get flooded out (U.S. Fish and Wildlife Service 2016). Flooding is a small issue for both native and hybrid species, and may only be an issue on farmland with dams that flood too high and in the San Luis National Wildlife Refuge complex on the Valley floor[1].

Non-Climate Factors

Workshop participants scored the resource's sensitivity and current exposure to non-climate factors, and these scores were then used to assess their impact on climate change sensitivity.

Non-Climate Factor	Sensitivity	Current Exposure
Agriculture & rangeland practices	High	Low-moderate
Dams, levees, & water diversions	Moderate	Moderate
Invasive & other problematic species	High	High
Land use change	High	High
Roads, highways, & trails	Moderate-high	Moderate-high
Urban/suburban development	High	High
Overall Scores	**High**	**Moderate-high**

Urban/suburban development

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape.*

Urban/suburban development has destroyed, fragmented, and degraded California tiger salamander habitat (U.S. Fish and Wildlife Service 2004), and continued development pressure hinders population recovery efforts (U.S. Fish and Wildlife Service 2016). Aside from directly destroying and fragmenting habitat, urban/suburban development can decrease habitat quality by altering hydroperiods, increasing aquatic contaminant exposure via urban runoff, and increasing predation risk from domestic pets and urban-adapted wildlife (e.g., raccoons; U.S. Fish and Wildlife Service 2004, 2016).

Land use change

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape (same locations as urban development and agriculture).*

Land use changes, including urbanization and agricultural development, have destroyed, fragmented, and altered critical upland and aquatic habitat used by California tiger salamanders (U.S. Fish and Wildlife Service 2004). For example, ground disturbance activities can expose salamanders to adverse conditions (e.g., extreme heat, low humidity; U.S. Fish and Wildlife Service 2004). Further land use change will continue to fragment remnant populations, increasing their spatial and genetic isolation and vulnerability to extirpation (U.S. Fish and Wildlife Service 2016).

Invasive & other problematic species

> ***Sensitivity:*** *High (high confidence)*
> ***Current exposure:*** *High (high confidence)*
> ***Pattern of exposure:*** *Localized.*

Salamanders (both hybrids and non-hybrids) are sensitive to several invasive species, including bullfrogs and non-native fish such as largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and non-native crayfish (*Pacifastacus*, *Orconectes*, *Procambarus* spp.) (U.S. Fish and Wildlife Service 2004, 2016). These species prey directly on salamander larvae, and can cause complete loss of salamander populations (Jennings & Hayes 1994). Mosquitofish (*Gambusia affinis*) also prey on larvae, as well compete with salamanders for aquatic invertebrate prey, leading to reduced salamander size and fitness (Leyse and Lawler 2000). In general, these non-native species prevent salamander utilization of permanent pond habitat (Fisher & Shaffer 1996). Neither bullfrogs or non-native fish can permanently utilize vernal pools or seasonal wetlands, although bullfrogs can migrate during winter and spring and temporarily colonize these ephemeral water sources, threatening both larvae and migrating adults (U.S. Fish and Wildlife Service 2016).

Agricultural & rangeland practices

> ***Sensitivity:*** *High (high confidence)*
> ***Current exposure:*** *Low-moderate (moderate confidence)*
> ***Pattern of exposure:*** *Consistent across the landscape, particularly in areas with flood irrigation.*

Alongside development, intensive agricultural conversion has destroyed, degraded, and fragmented California tiger salamander habitat (U.S. Fish and Wildlife Service 2004). Albeit at slower rates than historically, continued conversion pressure, including conversion to orchards[1], hinders population recovery efforts (U.S. Fish and Wildlife Service 2016). Areas most at risk for agricultural conversion include those areas adjacent to current agricultural parcels, such as the fringes of remnant habitat on the San Joaquin Valley floor (U.S. Fish and Wildlife Service 2004).

Agricultural practices including grading, leveling, and deep-ripping destroy habitat and can cause direct injury of burrowing salamander adults and juveniles (U.S. Fish and Wildlife Service 2016). Similar to urban development, intensive and irrigated agriculture can have secondary effects on salamander populations by degrading habitat quality. For example, pond modifications, particularly those that shift pools from ephemeral to permanent water availability, may favor invasive predators and/or hybrid and non-native salamanders (Riley et al. 2003; Fitzpatrick & Shaffer 2004; Johnson et al. 2013; U.S. Fish and Wildlife Service 2016). Any agricultural activities that decrease rodent populations – including ground squirrel eradication and flood irrigation – likely have negative impacts on the California tiger salamander by reducing habitat availability and quality (U.S. Fish and Wildlife Service 2016). Additionally, pesticides can lead to direct salamander mortality, retarded larval growth (Larson et al. 1998), increased susceptibility to viral infection (Forson & Storfer 2006; Kerby & Storfer 2009) and predation (Verrell 2000), altered sex ratios, and reduced larval prey (Ryan et al. 2013). Native salamanders appear more sensitive than hybrid salamanders to pesticides and cumulative impacts from multiple stressess (Ryan et al. 2013).

Comparatively, rangeland may provide and sustain habitat for this species, as this land practice typically results in minimal landscape modifications (U.S. Fish and Wildlife Service 2004), helps control grasses, and promotes stock ponds, which can be utilized by salamanders (U.S. Fish and Wildlife Service 2004, 2016).

Roads & highways

> ***Sensitivity:*** *Moderate-high (moderate confidence)*
> ***Current exposure:*** *Moderate-high (high confidence)*
> ***Pattern of exposure:*** *Consistent across the landscape.*

California tiger salamanders are vulnerable to road crossing mortality, particularly during mass breeding migrations affiliated with rain events and in areas where roads fragment aquatic and upland habitat (U.S. Fish and Wildlife Service 2004). Runoff from roads can also introduce contaminants to aquatic salamander habitat (U.S. Fish and Wildlife Service 2004).

Dams, levees, & water diversions

> ***Sensitivity:*** *Moderate (high confidence)*
> ***Current exposure:*** *Moderate (high confidence)*
> ***Pattern of exposure:*** *Localized; Los Vaqueros reservoir, any seasonal pond diversions, most common on Valley floor.*

Dam expansion is flooding out California tiger salamander habitat[1]. Diversions away from seasonal ponds can affect breeding by preventing ponding or reducing ponding length (U.S. Fish and Wildlife Service 2004); this issue is particularly problematic on the Valley floor. Diversions are not as much of a problem on ranches because water is needed for stock ponds[1].

Disturbance Regimes

Workshop participants scored the resource's sensitivity to disturbance regimes, and these scores were used to calculate climate change sensitivity.

> ***Overall sensitivity to disturbance regimes:*** *Moderate-high (moderate confidence)*

Grazing

Low to moderate intensity grazing likely helps maintain habitat quality and availability for California tiger salamanders (Pyke & Marty 2005; Fehmi et al. 2005). For example, Pyke & Marty (2005) found that grazing helped maintain vernal pool hydrological conditions ideal for salamander breeding by increasing the duration of pool inundation. Removal of grazing, particularly in areas near Merced or Sacramento, could reduce habitat availability for this species, particularly in a drier climate (Pyke & Marty 2005). Grazing can also be used to reduce emergent pond vegetation, which if present in moderate or high levels, is linked with reduced breeding activity (Ford et al. 2013). In addition, livestock grazing may help control tall grass and dense thatch in upland habitats, which can inhibit salamander mobility, migration, and dispersal (U.S. Fish and Wildlife Service 2016) and cause declines in ground squirrel populations (Ford et al. 2013), reducing salamander burrowing habitat. Grazing may also support creation of artificial salamander breeding habitat via stock pond installation and maintenance (U.S. Fish and Wildlife Service 2004, 2016).

Life history and reproductive strategy

Workshop participants scored the resource's life history and reproductive strategy, and these scores were used calculate climate change sensitivity.

> ***Species reproductive strategy, representing generation length and number of offspring****: Mid-range reproductive strategy (moderate confidence)*
> ***Average length of time to reproductive maturity:*** *4-5 years*

Although California tiger salamanders are somewhat long lived (10 years), they have low reproductive success; they breed infrequently, and juvenile and young adult mortality is high (Trenham et al. 2000).

Dependency on habitat and/or other species

Workshop participants scored the resource's dependency on habitat and/or other species, and these scores were used calculate climate change sensitivity.

Overall degree of specialization: *Moderate-high (high confidence)*

> ***Dependency on one or more sensitive habitat types:*** *High (high confidence)*
> > ***Description of habitat:*** *Vernal pools and grasslands.*
>
> ***Dependency on specific prey or forage species:*** *Low-moderate (high confidence)*
> ***Dependency on other critical factors that influence sensitivity:*** *High (high confidence)*
> > ***Description of other dependencies:*** *Ground squirrel burrows.*

California tiger salamanders are prey generalists at all life stages, feeding on a variety of invertebrate species (reviewed in U.S. Fish and Wildlife Service 2016). California tiger salamanders utilize aquatic habitat for breeding, including vernal pools and ponds, stock ponds, and artificial ephemeral ponds (U.S. Fish and Wildlife Service 2016). They lay eggs attached to leaves, stems, or other debris in the water (U.S. Fish and Wildlife Service 2016), and eggs and larvae remain in this aquatic habitat for up to six months (Petranka 1998). After metamorphosis in late spring or summer, juveniles make nocturnal migrations to adjacent upland grassland or oak woodland habitat searching for burrows (Petranka 1998) created by the California ground squirrel (*Otospermophilus beecheyi*) or Botta's pocket gopher (*Thommomys bottae*) (Loredo et al. 1996). Adults, sub-adults, and juveniles utilize these burrows year-round and remain largely underground before emerging for breeding migrations (Trenham 2001; van Hattem 2004). Large parcels of upland habitat with multiple breeding pools help maintain viable salamander populations (U.S. Fish and Wildlife Service 2016).

Adaptive Capacity

Workshop participants scored the resource's adaptive capacity and the overall score was used to calculate climate change vulnerability.

Adaptive Capacity Component	Score
Extent, Status, and Dispersal Ability	Low-moderate
Landscape Permeability	Low
Intraspecific Species Diversity	Moderate
Resistance	Low
Overall Scores	**Low**

Extent, status, and dispersal ability

Overall degree of extent, integrity, connectivity, and dispersal ability: *Low-moderate (high confidence)*
Geographic extent: *Transboundary (high confidence)*
Health and functional integrity: *Endangered (high confidence)*
Population connectivity: *Isolated and/or quite fragmented (high confidence)*
Dispersal ability: *Low (high confidence)*
Maximum annual dispersal distance of species: *<1 km (high confidence)*

In 2004, the Central California distinct population segment of California tiger salamander was listed as a federally threatened species under the Endangered Species Act (U.S. Fish and Wildlife Service 2004), and the State of California listed this species as threatened throughout its range in 2010 (California Fish and Game Commission 2010). Additional distinct population segments can be found in Santa Barbara and Sonoma Counties; these populations are federally classified as endangered (U.S. Fish and Wildlife Service 2004).

In the study area, tiger salamander populations occur in the foothills ringing the Central Valley from Kern and Tulare Counties north to Sacramento and Yolo Counties (U.S. Fish and Wildlife Service 2016). Current Central Valley populations are increasingly isolated and fragmented, which limits inter-pond dispersal and genetic exchange, and increases individual population vulnerability to extirpation from extreme events (U.S. Fish and Wildlife Service 2016). Maximum annual migration for breeding adults is around 1.5 miles, with average annual movements closer to 562 meters (Searcy & Shaffer 2011); pond complexes may feature higher dispersal rates than isolated pools (U.S. Fish and Wildlife Service 2016).

Landscape permeability

Overall landscape permeability: *Low (high confidence)*
Impact of various factors on landscape permeability:
Urban/suburban development: *High (high confidence)*
Roads, highways, & trails: *High (high confidence)*
Agricultural & rangeland practices: *High (high confidence)*
Dams, levees, & water diversions: *High (high confidence)*
Land use change (urban development, roads, and orchards): *High (high confidence)*
Invasive & other problematic species (hybrid salamanders): *High (low confidence)*
Energy production & mining: *Moderate-high (high confidence)*

Barrier-free landscapes are essential for California tiger salamander dispersal and annual migration (Loredo et al. 1996). Urbanization and intensive agriculture are common landscape barriers, completely preventing dispersal to new areas and blocking migration pathways between aquatic and upland habitat (U.S. Fish and Wildlife Service 2016). Roads and highways can similarly create permanent barriers, isolating metapopulations (U.S. Fish and Wildlife Service 2016).

Species diversity

Overall species diversity: *Moderate (moderate confidence)*
Diversity of life history strategies: *Low-moderate (moderate confidence)*
Genetic diversity: *Moderate-high (moderate confidence)*
Behavioral plasticity: *Moderate (moderate confidence)*
Phenotypic plasticity: *Moderate (moderate confidence)*

There is some genetic diversity within the Central California distinct population segment, mirroring geographic separations. For example, the southern San Joaquin Valley population shows genetic differentiation from the Central Valley, Bay Area, and Central Coast Range populations (Shaffer et al. 2004). There is little to no gene flow between the Central California, Santa Barbara, and Sonoma distinct population segments (Shaffer et al. 2004).

This species also exhibits some behavioral and life history diversity. For example, adults have been documented to use non-traditional aquatic habitat to breed (e.g., sewage treatment plants, seasonal wetlands formed in ditches; Cook et al. 2005; U.S. Fish and Wildlife Service 2016). Although not common, larvae have also been observed to overwinter (Alvarez 2004).

Resistance

Resistance to stresses/maladaptive human responses: *Low (high confidence)*

California tiger salamanders are somewhat tolerant of the highly variable precipitation regimes characteristic of California's Mediterranean climate (U.S. Fish and Wildlife Service 2016). For example, they have evolved to use a variety of water sources for breeding (e.g., vernal pools, seasonal wetlands, stock ponds), which buffers potential water-related climate impacts (Cook et al. 2005). However, it is not clear whether this species will be able to adapt at the same rate as climate change progresses (U.S. Fish and Wildlife Service 2016). Genes from southern populations – which currently experience shorter pond duration – may be important for the persistence of this species if drier conditions prevail (Bolster 2010). This endemic species requires specialized habitat (vernal pools/burrows), and does not appear very resistant to human land use changes, including urbanization and agriculture (U.S. Fish and Wildlife Service 2004, 2016).

Other Factors

Overall degree to which other factors affect adaptive capacity: *High (high confidence)*

Hybrids

Hybrids

California tiger salamanders are able to hybridize with the non-native barred tiger salamander (*Ambystoma tigrinum mavortium*) (U.S. Fish and Wildlife Service 2004). Hybridization threatens the genetic integrity of the native population, as several genes become "fixed" or "frozen" (i.e., native genes are lost; Fitzpatrick et al. 2009, 2010). Preliminary evidence indicates that these frozen genes affect larval growth and body size at metamorphosis (Johnson et al. 2010b cited in U.S. Fish and Wildlife Service 2016).

Hybrids typically become dominant in perennial ponds (e.g., livestock ponds, managed seasonal and permanent wetlands, breeding ponds) due to more consistent breeding and recruitment across years, higher reproductive rates (Fitzpatrick & Shaffer 2004), and the ability to forego metamorphosis and reproduce as paedomorphs (adult salamanders with gills; Collins et al. 1988). Paedomorphs enhance the competitive advantage of hybrids because they produce more offspring, are larger, breed earlier, and cannibalize native salamanders (Collins et al. 1988; Pfennig et al. 1999; Fitzpatrick & Shaffer 2004; Ryan et al. 2009). Hybrids may also fare better under certain climate changes, including warmer temperatures (Johnson et al. 2010), altered inundation regimes, and increased habitat connectivity during potentially wetter winters[1]. Comparatively, native salamanders compete better under conditions that promote emphemeral wetlands (e.g., drought; Fitzpatrick & Shaffer 2004; U.S. Fish and Wildlife Service 2016).

Current known hybrid distribution in the Central Valley includes populations in Merced County and ponds in the Altamont Pass region (U.S. Fish and Wildlife Service 2015). Hybrids have also been present at the San Joaquin National Wildlife Refuge for at least 20 years[1]. Although their use is prohibited, non-native salamanders are often introduced as fishing bait (Fitzpatrick & Shaffer 2004; U.S. Fish and Wildlife Service 2016).

Management potential

Workshop participants scored the resource's management potential.

Management Potential Component	Score
Species value	Moderate
Societal support	Moderate-high
Agriculture & rangeland practices	High
Extreme events	Low-moderate
Converting retired land	Low-moderate
Managing climate change impacts	Low
Overall Score	**Moderate**

Value to people

Value to people: *Moderate (moderate confidence)*
Description of value: *Charismatic; uses wetlands.*

Support for conservation

Degree of societal support for management and conservation: *Moderate-high (high confidence)*
Description of support: *Regulatory and recovery plan.*

Degree to which agriculture and/or rangelands can benefit/support/increase resilience: *High (high confidence)*
Description of support: *Stockponds on actively grazed rangelands.*

Degree to which extreme events (e.g., flooding, drought) influence societal support for taking action: *Low-moderate (high confidence)*
Description of events: *Unlikely to find support.*

Likelihood of converting land to support species

Likelihood of (or support for) converting retired agriculture land to maintain or enhance species: *Low-moderate (high confidence)*
Description of events: *Unlikely to convert back to vernal pools and California tiger salamander habitat.*

Likelihood of managing or alleviating climate change impacts: *Low (high confidence)*

There is regulatory support for the California tiger salamander through listing as a threatened species under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service 2004) and as a threatened species under the California Endangered Species Act (California Fish and Game Commission 2010). For example, the recently released federal Draft Recovery Plan focuses on using aquatic and upland habitat conservation to promote connectivity and reduce habitat loss and fragmentation in order to increase population resilience, redundancy, and representation (U.S. Fish and Wildlife Service 2016). By ensuring that individual populations are large, that there are many populations, and that genetic diversity is maintained between these populations, this species may be more resilient to climate impacts and other extreme events (U.S. Fish and Wildlife Service 2016). Listing as a federally threatened species has also stimulated several land banking efforts (used to offset potential habitat losses) and voluntary conservation agreements with private landowners (U.S. Fish and Wildlife Service 2016).

Conserving rangeland is a high priority for this species in the Central Valley and San Joaquin Valley federal management units because it maintains habitat relative to other land uses (e.g., agriculture; U.S. Fish and Wildlife Service 2016). Other management options include managing pond and wetland hydroperiods in controlled systems to create the rapid-drying conditions that favor native salamanders over hybrids (Johnson et al. 2013) and attempting to manage fallow agriculture fields for habitat (U.S. Fish and Wildlife Service 2004). Although fallowed agricultural land is unlikely to provide aquatic breeding habitat for California tiger salamanders, it may provide aestivation, upland, or migration habitat for this species depending on management and proximity to breeding habitat (U.S. Fish and Wildlife Service 2004).

Literature Cited

Anderson JD. 1968. A comparison of the food habits of Ambystoma macrodactylum sigillatum, Ambystoma macrodactylum croceum, and Ambystoma tigrinum californiense. Herpetologica **24**:273–284.

Barry SJ, Shaffer HB. 1994. The status of the California tiger salamander (Ambystoma californiense) at Lagunita: a 50-year update. Journal of Herpetology **28**:159–164.

Bauder ET. 2005. The effects of an unpredictable precipitation regime on vernal pool hydrology. Freshwater Biology **50**:2129–2135.

Bobzien S, DiDonato JE. 2007. The status of the California tiger salamander (Ambystoma californiense), California red-legged frog (Rana draytonii), foothill yellow-legged frog (Rana boylii), and other aquatic herpetofauna in the East Bay Regional Park Distrist, California. East Bay Regional Park District, Oakland, CA. Available from http://www.ebparks.org/Assets/files/stew_Amphibian_Final_Report_2007.pdf.

Bolster BC. 2010. A status review of the California tiger salamander (Ambystoma californiense). Report to the Fish and Game Commission. California Department of Fish and Wildlife. Available from https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=21754.

California Fish and Game Commission. 2010. Section 670.5, Title 14, CCR, list California tiger salamander as a threatened species. Approved regulatory language. August 19, 2010. Available from http://www.fgc.ca.gov/regulations/2010/670_5ctsfsor.pdf.

Collins JP, Jones TR, Berna HJ. 1988. Conserving genetically distinctive populations: the case of the Huachuca tiger salamander (Ambystoma tigrinum stebbinsi Lowe). Gen. Tech. Rep. Rocky

Mountain Forest and Range Experiment Station, USDA Forest Service. Available from http://agris.fao.org/agris-search/search.do?recordID=US9008525 (accessed April 25, 2016).

Cook BI, Ault TR, Smerdon JE. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances **1**:e1400082.

Cook DG, Trenham PC, Stokes D. 2005. Sonoma County California tiger salamander metapopulation, preserve requirements, and exotic predator study. Report prepared for the U.S. Fish and Wildlife Service. Available from http://www.lagunadesantarosa.org/pdfs/Cook%20CTS%20Metapop%2022Dec05Final%20%282%29.pdf.

Diffenbaugh NS, Swain DL, Touma D. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences **112**:3931–3936.

Fehmi JS, Russo SE, Bartolome JW. 2005. The effects of livestock on California ground squirrels (Spermophilus beecheyii). Rangeland Ecology & Management **58**:352–359.

Fisher RN, Shaffer HB. 1996. The decline of amphibians in California's Great Central Valley. Conservation Biology **10**:1387–1397.

Fitzpatrick BM, Johnson JR, Kump DK, Shaffer HB, Smith JJ, Voss SR. 2009. Rapid fixation of non-native alleles revealed by genome-wide SNP analysis of hybrid tiger salamanders. BMC Evolutionary Biology **9**:176.

Fitzpatrick BM, Johnson JR, Kump DK, Smith JJ, Voss SR, Shaffer HB. 2010. Rapid spread of invasive genes into a threatened native species. Proceedings of the National Academy of Sciences **107**:3606–3610.

Fitzpatrick BM, Shaffer HB. 2004. Environment-dependent admixture dynamics in a tiger salamander hybrid zone. Evolution **58**:1282–1293.

Ford LD, Van Hoorn PA, Rao DR, Scott NJ, Trenham PC, Bartolome JW. 2013. Managing rangelands to benefit California red-legged frogs and California tiger salamanders. Alameda County Resource Conservation District, Livermore, California. Available from http://www.ebparks.org/Assets/_Nav_Categories/Stewardship_Resources/Grazing/ManagingRangelandsCRLF-CTS.pdf.

Forson DD, Storfer A. 2006. Atrazine increases ranavirus susceptibility in the tiger salamander, Ambystoma tigrinum. Ecological Applications **16**:2325–2332.

Griffin D, Anchukaitis KJ. 2014. How unusual is the 2012–2014 California drought? Geophysical Research Letters **41**:9017–9023.

Hayhoe K et al. 2004. Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of Sciences **101**:12422–12427.

Jennings MR, Hayes MP. 1994. Amphibian and reptile species of special concern in California. Final Report submitted to California Department of Fish and Game, Inland Fisheries Division. Rancho Cordova, California. Available from http://www.elkhornsloughctp.org/uploads/files/1401225720%2382%20%3D%20Jennings%20and%20Hayes.pdf.

Johnson JR, Johnson BB, Bradley Shaffer H. 2010. Genotype and temperature affect locomotor performance in a tiger salamander hybrid swarm. Functional Ecology **24**:1073–1080.

Johnson JR, Ryan ME, Micheletti SJ, Shaffer HB. 2013. Short pond hydroperiod decreases fitness of nonnative hybrid salamanders in California. Animal Conservation **16**:556–565.

Kerby JL, Storfer A. 2009. Combined effects of atrazine and chlorpyrifos on susceptibility of the tiger salamander to Ambystoma tigrinum virus. EcoHealth **6**:91–98.

Lawler JJ et al. 2010. Resource management in a changing and uncertain climate. Frontiers in Ecology and the Environment **8**:35–43.

Loredo I, van Vuren D. 1996. Reproductive ecology of a population of the California tiger salamander. Copeia **1996**:895–901.

Loredo I, Van Vuren D, Morrison ML. 1996. Habitat use and migration behavior of the California tiger salamander. Journal of Herpetology **30**:282–285.

Pfennig DW, Collins JP, Ziemba RE. 1999. A test of alternative hypotheses for kin recognition in cannibalistic tiger salamanders. Behavioral Ecology **10**:436–443.

Pyke CR. 2004. Habitat loss confounds climate change impacts. Frontiers in Ecology and the Environment **2**:178–182.

Pyke CR. 2005. Assessing climate change impacts on vernal pool ecosystems and endemic branchiopods. Ecosystems **8**:95–105.

Pyke CR, Marty J. 2005. Cattle grazing mediates climate change impacts on ephemeral wetlands. Conservation Biology **19**:1619–1625.

Riley SPD, Bradley Shaffer H, Randal Voss S, Fitzpatrick BM. 2003. Hybridization between a rare, native tiger salamander (Ambystoma californiense) and its introduced congener. Ecological Applications **13**:1263–1275.

Ryan ME, Johnson JR, Fitzpatrick BM. 2009. Invasive hybrid tiger salamander genotypes impact native amphibians. Proceedings of the National Academy of Sciences **106**:11166–11171.

Ryan ME, Johnson JR, Fitzpatrick BM, Lowenstine LJ, Picco AM, Shaffer HB. 2013. Lethal effects of water quality on threatened California salamanders but not on co-occurring hybrid salamanders. Conservation Biology **27**:95–102.

Searcy CA, Shaffer HB. 2011. Determining the migration distance of a vagile vernal pool specialist: How much land is required for conservation of California tiger salamanders? Pages 73–87 in D. G. Alexander and R. A. Sclising, editors. Research and recovery in vernal pool landscape. California State University, Chico, CA.

Shaffer HB, Pauly GB, Oliver JC, Trenham PC. 2004. The molecular phylogenetics of endangerment: cryptic variation and historical phylogeography of the California tiger salamander, Ambystoma californiense. Molecular Ecology **13**:3033–3049.

Trenham PC. 2001. Terrestrial habitat use by adult California tiger salamanders. Journal of Herpetology **35**:343–346.

Trenham PC, Bradley Shaffer H, Koenig WD, Stromberg MR. 2000. Life history and demographic variation in the California tiger salamander (Ambystoma californiense). Copeia **2000**:365–377.

U.S. Fish and Wildlife Service. 2004. Endangered and threatened wildlife and plants; determination of threatened status for the California tiger salamander; and special rule exemption for existing routine ranching activities; final rule. Federal Register **69**:47212–27248.

U.S. Fish and Wildlife Service. 2005. Endangered and threatened wildlife and plants; designation of critical habitat for the California tiger salamander, central population; final rule. Federal Register **70**:49380–49548.

U.S. Fish and Wildlife Service. 2015. California tiger salamander, central California distinct population segment, (Ambystoma californiense): 5-year review: summary and evaluation. U.S. Fish and Wildlife Service, Sacramento, CA.

U.S. Fish and Wildlife Service. 2016. Draft recovery plan for the central California distinct population segment of the California tiger salamander (Ambystoma californiense). U.S. Fish and Wildlife Service, Sacramento, CA. Available from http://ecos.fws.gov/docs/recovery_plan/20160113_DRAFT_RP_CTSCentral_surnamed.pdf.

Verrell P. 2000. Methoxychlor increases susceptibility to predation in the salamander Ambystoma macrodactylum. Bulletin of Environmental Contamination and Toxicology **64**:85–92.

Williams AP, Seager R, Abatzoglou JT, Cook BI, Smerdon JE, Cook ER. 2015. Contribution of anthropogenic warming to California drought during 2012-2014. Geophysical Research Letters **in press**:1–10.

[1] Expert opinion, Central Valley Landscape Conservation Project Vulnerability Assessment Workshop, Oct. 8-9, 2015.