Central Valley Landscape Conservation Project

Climate Change Vulnerability Assessment (January 2017 version)

Pacific Lamprey

Vulnerability Assessment Summary

Overall Vulnerability Score and Components:

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

Overall vulnerability of the Pacific Lamprey was scored as moderate-high. The score is the result of moderate-high sensitivity, high future exposure, and moderate adaptive capacity scores.

Key climate factors that affect Pacific lamprey include the timing of snowmelt and runoff, water temperature, snowpack amount, altered streamflow regimes, drought, storms, and changes in stream sediments. These factors impact Pacific lamprey distribution, abundance, and survival, primarily by affecting their larval and juvenile life stages.

Key non-climate factors include dams, levees, and water diversions, roads/highways, and agricultural and rangeland practices; these primarily impact stream connectivity and water quality.

The key disturbance regime is flooding, which impacts newly emerge larvae (ammoceotes). Pacific lamprey eggs are hatched in graveled upstream areas and the newly emerged larvae drift downstream to slow moving silt areas; however, sediment and streamflow can be severely limited by dams. This species is dependent on sediment and host availability, as well as the availability of both upstream and ocean habitats.

Pacific lamprey are distributed widely from Mexico to Alaska; within the Central Valley, they appear to occupy suitable habitat below impassable man-made structures, with the exception of the southern San Joaquin/Tulare drainages and tributaries of the Sacramento that lack perennial flow. Dams and water diversions are major barriers to lamprey, impeding upstream migrations by adult lamprey and downstream movement of larval and juveniles. This species has moderate-high intraspecific species diversity, but gaps in our knowledge of the life history for this species remain.

Management potential for Pacific lamprey was scored as low. The species can tolerate a wide range of environmental conditions, making them relatively resistant to changes, and there are a number of management strategies that could be implemented to improve the survival of Pacific lamprey. These include modifying dams and fish ladders to allow for pacific lamprey passage and synchronizing the release of water from dams to mimic the natural hydrograph. However, the lack of awareness of Pacific lamprey and their ecological and cultural importance may prove challenging to their conservation.

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Introduction

Description of Priority Natural Resource

The Pacific lamprey (*Entosphenus tridentatus*) is an anadromous parasitic species that was historically distributed from Mexico north along the Pacific Rim to Japan (Goodman & Reid 2012). They are culturally important to indigenous people throughout their range, and play a vital role in the ecosystem as a food source for mammals, fish, and birds, nutrient cycling and storage, and a prey buffer for other species, such as salmonids (*Oncorhynchus* spp.; Close et al. 2002). Recent observations in the reduction of abundance and range of Pacific lamprey have spurred conservation interest in the species with increasing attention from tribes, agencies, and others (Goodman et al. 2015).

As part of the Central Valley Landscape Conservation Project, workshop participants identified the Pacific Lamprey 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 Pacific Lamprey as a Priority Natural Resource included the following: the species has high management importance, the species' conservation needs are not entirely represented within a single priority habitat or species group, and because the species is a keystone species and an umbrella species for many other fishes, and the ammocete life-stage is an important filter feeder[1]. 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
Altered stream flow	High	High
Extreme events: drought	High	Moderate
Extreme events: more heat waves	-	Moderate
Extreme events: storms	High	-
Precipitation (amount)	-	High
Snowpack amount	High	High
Timing of snowmelt/runoff	High	High
Water temperature	High	High
Other factors: Sedimentation	High	-
Overall Scores	**High**	**High**

Snowpack amount

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

Snowpack from mountainous areas surrounding the Central Valley plays a large part in water storage and supply for the Central Valley, releasing meltwater gradually to recharge aquifers and flow downstream (Knowles & Cayan 2002; Scanlon et al. 2012; California Rice Commission 2013). Reduced snowpack, which is tied to increased air temperatures and shifts in snow-to-rain ratios, could contribute to summer water shortages, altered streamflow patterns, and changes in natural flooding regimes (Miller et al. 2001; Knowles & Cayan 2002; Kiparsky & Gleick 2003; Vicuna et al. 2007). Because deep snowpack in mountainous areas maintains higher streamflows that last later into the season (Goodman & Reid 2012), reduced snowpack is likely to impact lamprey spawning survival (Brumo 2006) and seasonal migrations (Goodman et al. 2015), both of which are dependent upon adequate flows.

Timing of snowmelt & runoff

Sensitivity: *High (high confidence)*

Future exposure: *High (high confidence)*

Pacific lamprey are extremely sensitive to changes in the timing of snowmelt and runoff due to their dependence on high spring peak flows for movement and spawning (Moursund et al. 2002; Brumo 2006; Goodman et al. 2015). Adult Pacific lamprey generally migrate upstream to spawn from late fall to spring (Luzier et al. 2006), and Pacific lamprey emigration is associated with high spring flows (Goodman et al. 2015). Spawning generally occurs from April to July (Wydoski & Whitney 2003), and spawning survival has also been linked with water flows (Brumo 2006), suggesting that a change in the timing of snowmelt and peak runoff could impact successful lamprey migration and reproductive success.

Water temperature

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

Pacific lampreys are sensitive to water temperature, which impacts multiple reproductive factors including incubation, egg predation, and spawning and larvae survival (Bayer & Seelye 1999; Meeuwig et al. 2005; Brumo 2006). For instance, (Brumo 2006) observed that length of the incubation period was dependent on water temperature, ranging from 18−49 days. Larvae survival is highest in water temperatures between 10−18°C, and there is a sharp decline in survival at 22°C that coincides with an increase in morphological abnormalities (Meeuwig et al. 2005). Consequently, water temperature may be important in determining ammocoete abundance (Bayer & Seelye 1999). Additionally, egg predation by speckled dace (*Rhinichthys osculus*) has been observed at temperatures over 14°C, and appears to increase in intensity with increasing water temperatures (Brumo 2006).

Streamflow

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

Spring river runoff (April-July) has declined by 9% for the Sacramento River system and by 7% for the San Joaquin River system in the 20th century (Hunsaker et al. 2014). Combined with higher demands for water for agriculture and urban sources, lower spring and summer flow volume during the summer and spring will likely impact Pacific lamprey negatively, especially in the southern part of their range (Goodman and Reid 2012).

Pacific lamprey depend on adequate streamflow for migration and reproduction, and utilize areas of low, moderate and high flows at varying points throughout their lifecycle (Moursund et al. 2002; Torgersen & Close 2004; Brumo 2006; Goodman et al. 2015). For instance, Pacific lamprey emigration is associated with high spring flows (Goodman et al. 2015), and spawning and larval survival have been linked with water flows as well (Brumo 2006). During metamorphosis, Pacific lamprey move from fine substrates in low velocity areas to silt-covered gravel in moderate currents (Beamish 1980). When fully transformed, they are found in gravel or boulder substrate where overlying currents are moderate to strong (Beamish 1980; Potter 1980; Richards & Beamish 1981).

Larval occurrence is linked with low water velocity, pool habitats, and the availability of suitable burrowing habitat (Roni 2002; Pirtle et al. 2003; Torgersen & Close 2004; Graham & Brun 2005). However, newly emerged ammocoetes are poor swimmers and their movement is likely driven by flow conditions and velocities (Moursund et al. 2002), and has been linked with stream discharge (Hammond 1979; Potter 1980; Beamish & Levings 1991; Close et al. 1995).

Drought

Sensitivity: *High (high confidence)*

Droughts and resulting low-flow conditions have multiple effects that may impact Pacific lamprey, including poor water quality, streambed alterations, and dewatering (Goodman & Reid 2012). Drought may impact stream temperature, sediments, and nutrient runoff by altering riparian vegetation (Perry et al. 2012; Allen et al. 2015; Millar & Stephenson 2015; Dilts et al. 2015) and/or by contributing to more frequent and disturbances (Millar & Stephenson 2015), including wildfire (Vose et al. 2016). Low- or no-flow conditions occurring during drought periods, which may be accelerated by dewatering in response to increased water demands, may strand multi-year ammocoete populations in the substrate, leading to large mortality events (U.S. Fish and Wildlife Service 2010; Goodman & Reid 2012). For example, in 2016, both lamprey ammocoetes and listed steelhead (*O. mykiss*) were lost due to dewatering and over allocation of water in the Eel River[1].

Storms

Sensitivity: *High (high confidence)*

Changes in the frequency and magnitude of winter storms (Kim 2005; Cannon & DeGraff 2009) could increase severe flooding events (Vivoni et al. 2009). Major floods can result in streambed scouring and the removal of some or much of the riparian vegetation, thereby affecting stream temperature and sediment loads (Stromberg et al. 1993).

Precipitation (amount)

Future exposure: *Moderate (low confidence)*

Larger rain events associated with flooding could increase floodplain/fine sediment availability[1]. High flows associated with large amounts of rain may also facilitate faster downstream migration of ammocoetes, with a potential reduction in predation[1].

Heat waves

Workshop participants did not further discuss this factor beyond assigning a score.

Future exposure: *Moderate (low confidence)*

Other Factors: Sedimentation

Sensitivity: *High (high confidence)*

Pacific lamprey use specific stream substrates at different stages of their life cycle, and patterns of erosion and sediment deposition can impact habitat availability and ammocoete survival

(Close et al. 2002; Goodman & Reid 2012; Goodman et al. 2015). Adult Pacific lamprey spawn in gravel in low gradient stream reaches, often at the tailouts of pools and riffles (Mattson 1949; Pletcher 1963; Kan 1975). Ammocoetes of all sizes are known to use slow depositional areas along streambanks to filter feed and burrow into fine sediments mixed with organic matter and detritus during rearing periods (Pletcher 1963; Lee et al. 1980; Richards 1980; Potter 1980; Torgersen & Close 2004; Graham & Brun 2005; Cochnauer et al. 2006; Goodman & Reid 2012). Spawning habitat may be lost when upstream sediment is blocked by dams, leading to rock embedment in spawning areas and restricted movement for nest creation, an important component of lamprey reproduction (Goodman et al. 2015). Reduced sediment deposition below large dams, combined with channelization, may also reduce suitable habitats available for ammocoetes (Close et al. 2002).

Climatic changes that may benefit the species:

- Larger flows as a result of rain events and snowmelt

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	Moderate-high	High
Dams, levees, & water diversions	High	High
Roads, highways, & trails	High	High
Overall Scores	**High**	**High**

Agricultural & rangeland practices

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

Agricultural and rangeland practices can increase inputs of nutrients, pesticides, herbicides and sediment into streams, decreasing the amount of suitable habitat for Pacific lamprey (U.S. Fish and Wildlife Service 2010). Lampreys are typically rare or absent from river reaches heavily influenced by agriculture, and Pacific lampreys, in particular, are usually eliminated from streams that are heavily polluted (Gunckel et al. 2009). However, the specific effects of pesticides, organic compounds, and heavy metals in urban and agricultural areas on Pacific lamprey populations are largely unknown (Goodman & Reid 2012). Rapid fluctuations in reservoir and stream water levels from irrigation diversions can strand ammocoetes in the substrate and isolate them from flowing water (Goodman & Reid 2012), and reductions in riparian vegetation associated with agricultural activity or grazing reduce the input of coarse woody debris into streams (U.S. Fish and Wildlife Service 2010).

Dams, levees, & water diversions

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

Dams, levees, and water diversions act as barriers, limiting the availability of spawning and rearing habitat by impeding upstream migrations of adults and downstream movement of ammocoetes and juveniles (Close et al. 1995; Vella et al. 1999; Ocker et al. 2001; Lucas et al. 2009). Dams with suitable passage alternatives, such as fish ladders with rough and rounded surfaces, may allow passage of adults moving upstream (Moser et al. 2002), but many fish ladders designed for salmonids can still block lamprey passage (Moser et al. 2002; Mesa et al. 2003). In addition, downstream migrating juveniles and drifting ammocoetes often become entrained in water diversions or turbine intakes (Moursund et al. 2002; Dauble et al. 2006). Juvenile lampreys are particularly vulnerable to entrainment because of their poor swimming performance (Dauble et al. 2006) and have been found impinged on juvenile salmonid screening facilities (Moursund et al. 2003). Finally, predation is a major threat to juvenile Pacific lamprey when they leave rearing refuges to migrate downstream (Mather 1998), and dam-induced reductions in high streamflows may reduce turbidity, increasing predation during emigration (Gregory & Levings 1998; Utne-Palm 2002).

Roads, highways, & trails

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

Roads and highways fragment stream habitat, and many culverts are impassable for Pacific lamprey (Columbia River Basin Lamprey Technical Workgroup 2004). If these culverts have a drop at the outlet, they can be impassable for a variety of reasons, including high streamflow velocities, insufficient resting areas, and lack of suitable attachment substrate (Columbia River Basin Lamprey Technical Workgroup 2004). Many of these culverts are located at smaller road crossings in tributaries (Goodman & Reid 2012).

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 (moderate confidence)*

Flooding

Floods are an important disturbance factor for Pacific lamprey, primarily due to their impact on sedimentation processes and stream channel structure (Gasith & Resh 1999; Stromberg et al. 2007). Flooding could scour streambeds and the slow depositional areas along streambanks that ammocoetes use for burrowing into fine sediments (Pletcher 1963; Lee et al. 1980; Richards 1980; Potter 1980; Stromberg et al. 1993; Torgersen & Close 2004; Graham & Brun 2005; Cochnauer et al. 2006). Increased sediment delivery following a flood can affect concentrations of contaminants and potentially the abundance of disease-causing organisms in streams (Grimm et al. 2013).

Newly emerged ammocoetes are poor swimmers and their survival may be affected by floods, as they are typically found in fine sediments within areas of low water velocity (Roni 2002; Pirtle et al. 2003; Torgersen & Close 2004; Graham & Brun 2005). Adult Pacific lamprey migrating upriver to spawning grounds appear to be less affected by flooding than other species, such as green sturgeon (*Acipenser medirostris*) (Moursund et al. 2002).

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 (high confidence)*
> ***Average length of time to reproductive maturity:*** *6-10 years*

Female Pacific lamprey have high fecundity, and reproduce in a single spawning event that produces 30,000–238,400 eggs each year (Kan 1975; Close et al. 2002; Wydoski & Whitney 2003), but regional differences in fecundity exist and some population sizes appear to be related to the distance of upstream migration (Beamish 1980). Adults typically die between 3 and 36 days after spawning (Pletcher 1963; Kan 1975; Beamish 1980). Eggs hatch into larvae (ammocoetes) and drift downstream to slow velocity areas where they live in silt and sand substrates as filter feeders for 3-7 years (Goodman et al. 2015). Juveniles migrate to the ocean where they develop into adults and spend 1-3 years, mostly feeding on host fish (Goodman & Reid 2012). After this period of time, the newly developed adults migrate back to freshwater (Kan 1975; Beamish 1980), where they can live for up to a year before spawning and dying[1]. Thus, the average age at spawning is between 6-10 years[1].

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: *High, upstream refugia for adults to overwinter and spawn (+1 year). Larvae use sediment throughout entire system as they grow and move downstream.*
Dependency on specific prey or forage species:
Freshwater habitat: *Low (high confidence)*
Ocean habitat: *High (high confidence)*
Dependency on other critical factors that influence sensitivity: *Moderate-high (moderate confidence)*
Description of other dependencies: *Sediment contaminants*

Pacific lamprey are dependent on multiple habitats and associated prey throughout their lifespan (Goodman & Reid 2012). Specific habitat requirements include graveled upstream areas for egg hatching and slow moving silt areas to support the downstream drifting of newly emerged larvae (Stone & Barndt 2005; Goodman & Reid 2012). These larvae remain in streams as filter feeders consuming detritus, diatoms, and algae (Hammond 1979; Potter 1980); during this stage they are sensitive to the availability of sediment and may also be sensitive to contaminants, although the effects of contaminants are largely unknown (Goodman & Reid 2012).

Pacific lamprey spend up to several years in the ocean before returning to freshwater to reproduce, but the estuarine and nearshore habitat requirements for juveniles (or macropthalmia) are also largely unknown (Goodman & Reid 2012). Food resources for Pacific lamprey include a variety of ocean fish species, including Pacific salmon (*Oncorhynchus spp*.), flatfish (*Pleuronectes* spp., *Platichthys* spp.), rockfish (*Sebastes* spp.), Pacific hake (*Merluccius productus*), and walleye pollock (*Theragra chalcogramma*; U.S. Fish and Wildlife Service 2004). Ocean currents and food resources may significantly influence Pacific lamprey populations within this habitat (Orlov et al. 2008). However, how changes in ocean temperature, chemistry, and currents (El Niño) due to climate change may affect oceanic lamprey dispersal is unknown[1]. Lamprey depend on hosts for transport back to streams for spawning[1].

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	High
Landscape Permeability	Low
Intraspecific Species Diversity	Moderate-high
Resistance	Moderate-high
Overall Scores	**Moderate**

Extent, status, and dispersal ability

Overall degree of extent, integrity, connectivity, and dispersal ability: *High (high confidence)*
Geographic extent: *Transcontinental (high confidence)*
Health and functional integrity: *Robust (high confidence)*
Population connectivity: *Continuous (high confidence)*
Dispersal ability: *High (high confidence)*
Maximum annual dispersal distance of species: *>100 km (high confidence)*

The historical range of Pacific lamprey in California likely extended upstream into most stream habitat accessible to migrating organisms, including high-elevation headwaters (Goodman & Reid 2012). Although current records of their distribution are incomplete, it is generally assumed that Pacific lamprey now occupy most of their historically habitat below impassable man-made structures, most of which were installed after 1900 on the valley floor and foothills of the Sacramento and San Joaquin Rivers (Goodman & Reid 2012). Pacific lamprey remain with the Sacramento River system as a whole, but only below large rim dams[1]. They have been extirpated within the southern San Joaquin/Tulare drainages and within tributaries of the Sacramento that no longer have perennial flows (Goodman & Reid 2012).

Although little data is available on population size in most watersheds, Pacific lamprey have, overall, declined significantly in abundance compared to their historical numbers (Goodman & Reid 2012). They remain relatively common, however, and are not listed under the Endangered Species Act or California Endangered Species Act (Goodman & Reid 2012).

Landscape permeability

Overall landscape permeability: *Low (moderate confidence)*
Impact of various factors on landscape permeability:

Dams, levees, & water diversions: *High (high confidence)*
Abundance of ocean host fish: *High (low confidence)*

Dams, levees, and water diversions are the primary barriers for Pacific lamprey, limiting the availability of coldwater spawning and rearing habitat by impeding upstream migrations of adults and downstream movement of ammocoetes and juveniles (Close et al. 1995; Vella et al. 1999; Ocker et al. 2001; Lucas et al. 2009). Dams with suitable passage alternatives, such as fish ladders with rough and rounded surfaces, may allow passage of adults moving upstream (Moser et al. 2002). However, many fish ladders designed for salmonids can still block lamprey passage, particularly if they have sharp angles to which lamprey cannot attach (Keefer et al. 2010) and high water velocities (Moser et al. 2002; Mesa et al. 2003). Beamish and Northcote (1989) found that Pacific lamprey populations can only persist for a few years above impassable barriers before local extirpation.

Water quality and quantity also affect lamprey dispersal, limiting movement into habitat that would otherwise be available[1].

Species diversity

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

Pacific lamprey life cycles have a relatively long duration (about 10 years), and this species has varied morphological characteristics. Pacific lamprey survives in a diversity of habitats, including freshwater streams and rivers and salt water. However, compared to other species, such as Pacific salmon, there are large gaps in knowledge about the biology and life history of Pacific lamprey (Goodman & Reid 2012). For instance, little is known about the behavioral or phenotypic plasticity of the species. In fact, much of what is assumed about Pacific lamprey stems from knowledge about the landlocked sea lamprey (*Petromyzon marinus*) in the Great Lakes (Clemens et al. 2010). Nonetheless, there have been a few studies that have examined the genetic diversity of Pacific lamprey that indicate there has been a high level of historical gene flow between populations (Goodman et al. 2008; Lin et al. 2008).

Resistance

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

Although Pacific lamprey are genetically diverse and can tolerate a range of environmental conditions (Goodman et al. 2015), the degree of modification in Central Valley rivers and streams prevent them from accessing coldwater refugia, precluding species adaptation to warmer ambient air and water temperature[1].

Management potential

Workshop participants scored the resource's management potential.

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

Value to people

Value to people: *Moderate (high confidence)*
Description of value: *Tribes place high value on this species. Recreational fishing is limited (mostly juveniles for bait purposes).*

Support for conservation

Degree of societal support for management and conservation: *Low-moderate (high confidence)*
Description of support: *Lamprey is a trust species used for tribal purposes, which requires some degree of management by the Department of the Interior and the State. Additionally, the range-wide Pacific Lamprey Conservation Initiative (led by the U.S. Fish and Wildlife Service Region 1) includes a Conservation Agreement signed by federal and state agencies.*

Degree to which agriculture and/or rangelands can benefit/support/increase resilience: *Low-moderate (moderate assessed)*
Description of support: *Water diversions pose a risk to juveniles. Passage inhibits access to spawning habitat for adults. The impacts of agricultural contaminants are unknown.*

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

Likelihood of converting land to support species

Likelihood of (or support for) converting retired agriculture land to maintain or enhance species: *Low (high confidence)*

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

Description of likelihood: *No emphasis on Pacific lamprey, system is managed for winter-run salmonids.*

The range-wide Conservation Agreement identifies many threats for this species, and several implementation and best management plans are being developed to address some of these threats (U.S. Fish and Wildlife Service 2010; Goodman & Reid 2012; Poytress et al. 2014). Lamprey is also a species that Native Americans utilize for food, ceremonies, and other traditions, which requires special state and federal management (Goodman et al. 2015).

Strategies that could be implemented to improve the survivability of Pacific lamprey include modifying dams and fish ladders to allow for passage (U.S. Fish and Wildlife Service 2010); for example, the Coleman fish ladder in Battle Creek allows lamprey passage[1]. Lamprey have different passage requirements than many other types of fish; they cannot jump, so they need smooth, non-vertical surfaces with rounded corners of less than 90 degrees (Moser et al. 2002; Keefer et al. 2010). In addition, synchronizing the release of water from dams to match the natural hydrograph, which could improve the survival of juveniles (Goodman et al. 2015).

However, the lack of awareness of Pacific lamprey and their ecological and cultural importance may prove challenging to their conservation (Goodman & Reid 2012). For example, dewatering a stream to replace a culvert may strand ammocoetes and use of heavy equipment to dig out channels can remove ammocoetes from the channel (King et al. 2008; U.S. Fish and Wildlife Service 2010). To date, Pacific lamprey have rarely been included in the analysis of impacts of land management activities, such as stream alteration or channel dredging, likely because their presence and distribution is not well known (Goodman & Reid 2012).

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