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Regional Implementation Plan for Measures to Conserve Pacific Lamprey (*Entosphenus tridentatus*), California – San Joaquin Regional Management Unit

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Acronym List

BLM	Bureau of Land Management
CA	California
CalTrans	California Department of Transportation
CDFW	California Department of Fish and Wildlife
EBMUD	East Bay Municipal Utilities District
ESA	Endangered Species Act
ESRI	Environmental Systems Research Institute
HUC	Hydrologic Unit Code
Km	Kilometer
MCZ	Museum Comparative Zoology (Harvard) - Ichthyological collection
NOAA	National Oceanographic and Atmospheric Administration
PG&E	Pacific Gas and Electric Company
PLCI	Pacific Lamprey Conservation Initiative
RKM	River Kilometer
RM	River Mile
RMU	Regional Management Unit
SFPUC	San Francisco Public Utilities Commission
SU	Stanford University - Ichthyological collection
UCD	University California Davis - Ichthyological collection
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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Introduction

Pacific Lamprey, *Entosphenus tridentatus*, were historically widely distributed from Mexico north along the Pacific Rim to Japan. They are culturally important to indigenous people throughout their range, and play a vital role in the ecosystem: cycling marine nutrients, passing primary production up the food chain as filter feeding larvae, promoting bioturbation in sediments, and serving as food for many mammals, fishes and birds. Recent observations of substantial declines in the abundance and range of Pacific Lamprey have spurred conservation interest in the species, with increasing attention from tribes, agencies, and others.

In 2003 the U.S. Fish and Wildlife Service (USFWS) was petitioned by 11 conservation groups to list four species of lamprey in Oregon, Washington, Idaho, and California, including the Pacific Lamprey, under the Endangered Species Act (ESA) (Nawa et al. 2003). The USFWS review of the petition indicated a likely decline in abundance and distribution in some portions of the Pacific Lamprey's range and the existence of both long-term and proximate threats to this species, but the petition did not provide information describing how the portion of the species' petitioned range (California, Oregon, Idaho, and Washington) or any smaller portion is appropriate for listing under the ESA. The USFWS was therefore unable to define a listable entity based on the petition and determined Pacific Lamprey to be ineligible for listing (USFWS 2004).

It is the USFWS's strategy to improve the status of lampreys by proactively engaging in a concerted conservation effort. This collaborative effort, guided by the development and implementation of the Pacific Lamprey Conservation Initiative (PLCI) initiated in 2004, will facilitate opportunities to address threats, restore

habitat, increase our knowledge of Pacific Lamprey, and improve their distribution and abundance in the United States portion of their range. The approach of the PLCI is to use the best scientific and empirical information available to assess current issues affecting the viability of Pacific Lamprey throughout its range in the western United States, to resolve knowledge gaps that limit our ability to conserve the species and to identify the specific conditions that must be addressed in order to conserve both regional and local populations. This document reviews risks identified by Goodman and Reid (2012) and introduces implementation actions to aid in conservation of the species. Neither document represents analyses required by the Endangered Species Act to determine if a species is warranted for listing as threatened or endangered.

The 2012 Assessment and Template for Conservation Measures in California (Goodman and Reid 2012) includes introductory chapters describing the overall assessment and conservation strategy of the PLCI, general biology of and threats to Pacific Lamprey, and methods. Successive chapters focus on Pacific Lamprey in the California Region as a whole and in seven specific geographic subregions (Regional Management Units - RMUs) within California. Each RMU is further examined at the watershed level, using 4th field Hydrologic Unit Code watersheds (HUC). Habitat conditions, population status and threats are evaluated for each HUC. The demographic information and identified threats were then used to qualitatively assess the relative risks of extirpation for Pacific Lamprey within each HUC using a NatureServe Assessment Model.

Implementation Plans

In this stage of the PLCI, we use the combined results of viability and threats assessments in the 2012 California Assessment to develop implementation plans for each of seven RMUs (Figure 1); identifying conservation efforts, knowledge gaps, and key implementation projects that will reduce risks to Pacific Lamprey within each RMU and its HUCs, thereby promoting conservation and management of the species range-wide.

Regional Conservation Strategy

The California regional conservation strategy uses the combined results of the viability and threats assessments in the 2012 California Assessment, collaborative input from partners and stakeholders, and drainage specific needs assessments to develop implementation plans for each Regional Management Unit (RMU). These plans will identify specific conservation efforts, knowledge gaps, and key implementation projects that will reduce risks to Pacific Lamprey within each of California's seven RMUs and their component HUC watersheds, thereby promoting the conservation and management of Pacific Lamprey both locally and range-wide through collaborative solutions. They are intended to provide a tool for managers and conservation biologists to guide conservation efforts, prioritize projects, and monitor progress. Ultimately, the various RMU plans will be incorporated into a

Figure 1**.** Map of seven California Regional Management Units (RMUs).

regional plan for the whole of California and coordinated with implementation efforts in other regions.

Our current understanding of the biology and conservation needs of the Pacific Lamprey is relatively limited. Unlike western salmonids, which have long commercial management histories and have been extensively studied, little attention has been given to Pacific Lampreys in the past. Therefore, key conservation needs include the incorporation of lampreys into existing conservation and restoration projects, education of stakeholders and the general public, as well as filling major gaps in our basic understanding of their life history, distribution, behavior, habitat utilization and sensitivity to environmental factors such as temperature, flow regimes, and eutrophication. Nevertheless, it is also a primary goal of this implementation strategy to move forward with prioritized on-the-ground projects and recognized conservation needs that can be rapidly addressed over the next five years to directly benefit Pacific Lamprey.

Crucial to the success of this strategy is the collaboration of multiple and diverse stakeholders working together proactively to promote the conservation and recovery of a keystone species integral to the health and ecological function of western rivers. Both the Conservation Assessment and this Implementation Plan are intended as living documents that will be updated as we develop new information and understanding of lamprey conservation status and as implementation progresses. Already, many of the proposed implementation projects have been initiated or are well underway.

Implementation Planning – Methods

The initial phase of this implementation planning was to assess population status and identify threats within individual 4th field Hydrologic Unit Code watersheds (HUCs) through the 2012 California Assessment process (Goodman and Reid 2012). These results are incorporated into the implementation plans, where they serve to prioritize populations of particular concern and specific threats that need to be addressed by proposed implementation actions. The results of the 2012 California Assessment are summarized herein, but the Assessment itself contains additional detail and background for the reader, including introductory chapters describing the overall assessment and conservation strategy of the PLCI, general biology of and threats to Pacific Lamprey, and methods. Successive chapters focus on Pacific Lamprey in California as a whole and in specific geographic RMUs, describing conditions, population status, and threats at the watershed level. The demographic information and identified threats were then used to qualitatively assess the relative risks of extirpation for Pacific Lamprey within each watershed using a NatureServe Assessment Model. See Goodman and Reid (2012).

Collaborative stakeholder meetings and site visits were held for each HUC to seek out local experience, conservation concerns and suggestions for information needs and conservation actions (see Figure 2 and Appendix A for stakeholder meetings and

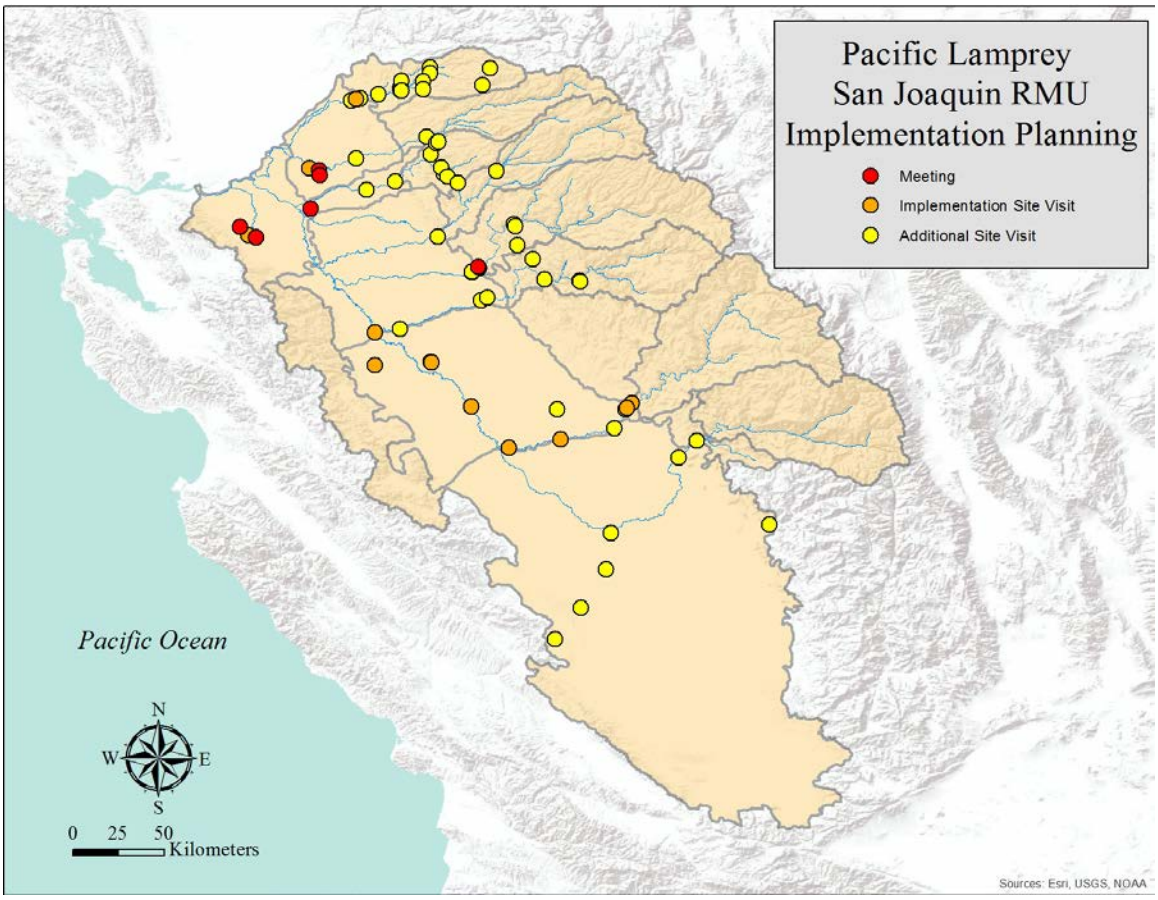

Figure 2. Map of stakeholder meetings, workshops, and site visits which informed the development of the San Joaquin implementation plan.

workshops). Outreach and information gathering included 7 stakeholder meetings or workshops and included 21 different stakeholders. Stakeholder meetings also provided an opportunity to increase collaboration, raise general awareness, and promote participation in lamprey conservation, as well as to inform the PLCI team of ongoing conservation actions in local watersheds.

The development of specific information needs and actions to be incorporated into the present implementation plan was guided by the 2012 California threat assessment and drew upon various sources of information. For each recognized threat, actions were developed to specifically address that threat, or provide information needed for further assessment and development of mitigation measures. Final development of proposed actions incorporated the results of stakeholder meetings, workshops, ongoing conversations with stakeholders and local biologists, site visits, and the experience of the PLCI team. The principal goal of the implementation plans is to identify specific conservation efforts, knowledge gaps, and key implementation projects that will reduce risks to Pacific Lamprey within each RMU and its component watersheds (HUC). However, there were also certain conservation efforts

that are universal within the RMU, and often the broader region as well. These include outreach, education, coordination and incorporation of lampreys into existing aquatic conservation efforts, as well as basic research into aspects of lamprey life-history that directly relate to their conservation needs.

All proposed actions and conservation needs were entered into an implementation database that incorporates:

1) Information on the threat addressed
2) Description of the action and its rationale
3) Scale and location of the action
4) Prioritization factors
5) Feasibility factors
6) Additional benefits of the project
7) General status and details of the project

Actions are grouped into the following categories:

1) Assessment - assessment of potential threats or project needs
2) Coordination - including, outreach, collaboration and incorporation of lampreys into existing conservation efforts
3) Research - information needs that directly relate to their conservation needs or are needed to assess general threats
4) Survey/monitor - distribution of lampreys, suitable habitat, monitor populations or mapping of point threats (e.g., diversions, barriers)
5) Instream/on the ground projects

Prioritization of conservation actions is facilitated through the implementation database by inclusion of separate factors that may guide selection of individual projects (See Appendix B for specific fields and details of the database structure). Priorities will be influenced by such factors as the specific needs of Pacific Lamprey in an area (region or HUC), the level of threat addressed (scale, scope, or severity), habitat gained, specific funds available, capabilities of participants, and stakeholder or program goals. Therefore, actions in the database were not prioritized explicitly, allowing for flexibility to accommodate a broad suite of applications. Instead, a framework is provided with a series of factors ranked independently that may contribute to a prioritization scheme. Factors evaluated for each action include the scope, scale and severity of threats addressed, effectiveness in addressing the threat, and quantity of habitat gain. These factors may be used in combination to guide strategic conservation measures in a variety of implementation scenarios. The implementation database is intended as a living document that evolves with our understanding of threats to Pacific Lamprey, their conservation needs and the status of specific conservation projects. It is intended to provide a tool to managers and recovery biologists to address the specific needs of Pacific Lamprey, guide conservation efforts, prioritize projects, and monitor progress. See Appendix C for contact information.

San Joaquin RMU - Status and Distribution of Pacific Lamprey

The San Joaquin RMU includes all drainages in the southern Central California Valley, including the San Joaquin and Tulare HUCs, downstream (north) to the delta and confluence with the Sacramento, including the San Joaquin and Tulare USGS National Hydrography Dataset subregions and accounting units (Figure 3). Due to subregional differences in hydrology and historical use, we have generally separated the San Joaquin and Tulare sub-basins within the broader San Joaquin RMU. The Tulare sub-basin was not included in the assessment as all anadromous access to the Tulare sub-basin was lost by the 1870's due to diversion of its inflows and drainage of the lakebed for agricultural purposes.. The San Joaquin sub-basin includes 14 watersheds (4th field HUCS), ranging from 629 - 6,921 km^2. It occupies the Central Californian Chaparral / Oak Woodlands, Central California Valley, and Sierra Nevada ecoregions. Population status and distribution of Pacific Lamprey in the San Joaquin RMU are reviewed below and in Table 1 (adapted from 2012 Assessment with current information).

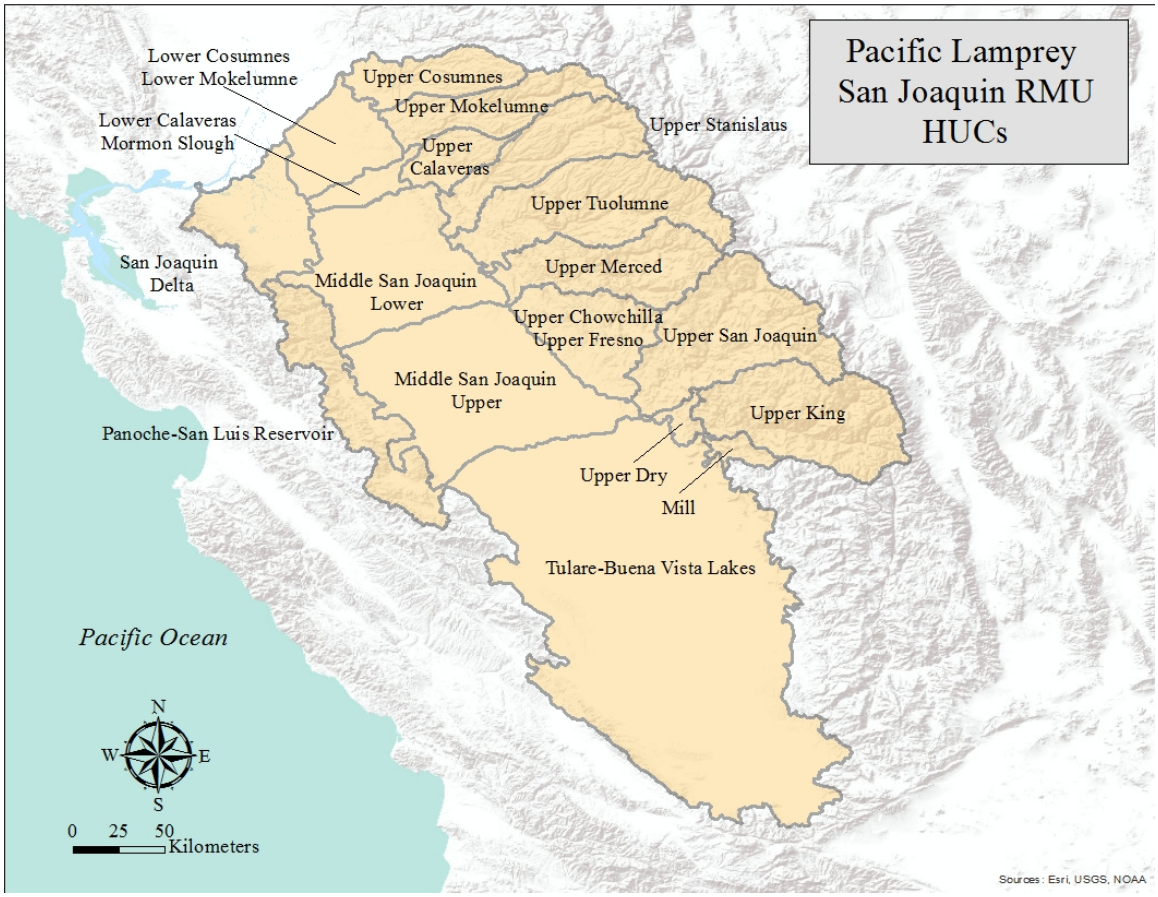

Figure 3. Map of the San Joaquin Regional Management Unit (RMU) and its watersheds (4th field HUCs). Drainages mentioned in the text and tables are labeled.

Historical Range Extent

Pacific Lamprey are assumed to have been widely distributed and abundant historically in the San Joaquin River and its larger eastern tributaries. Possible exceptions include the higher gradient reaches of small or seasonal tributaries, based on historical records, current distribution, available habitat and lack of natural barriers (Reid and Goodman 2017; in prep.). Although there was anecdotal mention of lampreys in Lake Tulare, the southernmost historical range is considered to have been the Kings River, the northernmost tributary, which connected northwards into the San Joaquin in wet years. The range limit for anadromous salmonids along the Sierran foothills is also considered to have been the Kings drainage (Yoshiyama et al. 1998). The western foothills in the San Joaquin Valley are in the rain shadow of the coast ranges and seasonal drainages are intermittent in their lower reaches, with only pockets of perennial habitat in their uppermost reaches. Many are considered fishless (Moyle 2002). Similar hydrologic conditions probably existed in the past. We have no evidence of lampreys of any species in these western valley drainages.

Current Occupancy

Pacific Lamprey currently occupy the mainstem San Joaquin and its major eastern tributaries up to the lowest major Sierran foothill dams in each drainage (Reid and Goodman 2017, in prep.).

The primary constraints on the distribution of the species in currently occupied drainages are large dams on the mainstems or major tributaries (Figure 4), instream diversion structures, seasonal reaches, sediment anoxia, and lack of suitable rearing habitat in moderate to higher gradient tributaries (Goodman and Reid 2012).

Ratio of Current Occupancy to Historical Range Extent

On the whole, the San Joaquin RMU has seen considerable loss of historical distribution by obstruction of passage by large foothill dams in most drainages (Table 1). The only major tributary with relatively natural flow and connectivity to the headwaters is the Cosumnes River, which is relatively small and limited to foothill drainage, rather than extending up into the high Sierra. The lower boundary for the upper HUCS in most drainages is delineated at the lowest dam, resulting in complete loss of occupancy from those HUC (Figure 3, Table 1). The occupied HUCs in the San Joaquin Valley are at the lower end of the eastern foothill reaches and on the valley floor.

Population Size

Population size (adults) in the RMU, similar to all other areas, is poorly understood and not formally monitored in the San Joaquin drainage. There is a video monitoring station at the Woodbridge fish ladder (Mokelumne River), but the ladder's effectiveness for providing upstream passage to adult lampreys has not been assessed. The only relative certainty is that populations have declined substantially, as they have throughout the range (Goodman and Reid 2012, Reid and Goodman 2016).

Figure 4. The primary constraints on the distribution of Pacific Lamprey in the San Joaquin RMU are large foothill dams on the mainstems. Friant Dam (shown here) blocks the upper San Joaquin River above 320 ft elevation in the Sierran foothills.

Short Term Trend

Declines within occupied HUCs in the San Joaquin RMU may be similar to those in other Californian RMU's, as well as throughout the species' range (Goodman and Reid 2012). However, the lack of monitoring of adult migrations makes any quantification of population trends impossible. We are aware of no recent changes in distribution.

NatureServe Risk Ranks

NatureServe risk ranks in occupied HUCS varied from imperiled to vulnerable (S1-S3). Populations in all HUCs are subject to metapopulation declines caused by regional threats outside the watershed. See discussion of threats below.

Table 1. Population status, maximum threat level and NatureServe ranks for Pacific Lamprey in the San Joaquin RMU. NatureServe ranks: SX, Extinct; SH, Believed extinct; and S1 to S4, critical to secure. Adapted from Goodman and Reid 2012, updated to current understanding. A revised Status and Threat Assessment is expected in 2018.

SAN JOAQUIN		**Distribution**				**Max. Threats**		
Watershed	**HUC**	**Max. Hist. (km^2)**	**Current/ Hist.**	**Population Size (#)**	**Short-term Decline (%)**	**Scope**	**Severity**	**Risk Rank**
Panoche-San Luis Reservoir	18040014	2,948	-	-	-	-	-	-
San Joaquin - Upper	18040006	4,415	0	Extinct	-	-	-	SX
Upper Chowchilla-Upper Fresno	18040007	2,482	0.001	Extinct?	-	High	High	SH
Merced - Upper	18040008	2,838	0	Extinct	-	-	-	SX
Tuolumne - Upper	18040009	4,184	0	Extinct	-	-	-	SX
Stanislaus - Upper	18040010	2,587	0	Extinct	-	-	-	SX
Kings - Upper	18030010	4,018	0	Extinct	-	-	-	SX
Calaveras - Upper	18040011	971	0.1	Unknown	Unknown	High	Mod.	S1
Calaveras / Mormon Slough	18040004	629	1	Unknown	Unknown	Mod.	Mod.	S2
Mokelumne - Upper	18040012	2,038	0	Extinct	-	-	-	SX
Cosumnes - Upper	18040013	1,654	1	Unknown	Unknown	High	Low	S3
Cosumnes / Lower Mokelumne	18040005	1,963	1	Unknown	Unknown	High	Mod.	S2
San Joaquin - Middle-Upper	18040001	6,921	0.37	Unknown	Unknown	High	High	S2
San Joaquin - Middle-Lower	18040002	4,758	1	Unknown	Unknown	High	Mod.	S3
San Joaquin Delta	18040003	2,477	1	Unknown	Unknown	High	Mod.	S2

San Joaquin RMU - Threats and Limiting Factors to Pacific Lamprey

Threats and limiting factors to Pacific Lamprey in the San Joaquin RMU are provided in Table 2 for the principal five threats, also discussed below. The remaining threat categories were either of low risk throughout the RMU or were not considered in this assessment as a whole due to lack of information (see discussion under Goodman and Reid 2012, Chap. 4 - California Regional Summary: Small Population Size, Disease, Lack of Awareness, Ocean Conditions, and Climate Change). Populations in all HUCs are subject to metapopulation declines caused by regional threats outside the watershed.

Beyond the historical elimination of much of the lamprey habitat in the San Joaquin by impassable dams, the primary threats to currently occupied HUCs are passage constraints and stream channel degradation in the Calaveras and lower Cosumnes-Mokelumne HUCs, and flow management and water quality in the San Joaquin HUCs. A major uncertainty is the effects of the large water diversions at the Tracy Pumping Facility (USBR) and Clifton Forebay Diversion Facility (CDFG) in the lower San Joaquin, which potentially impact passage for large numbers of downstream migrating juveniles from both the San Joaquin and Sacramento

Table 2. Principal threat rankings, maximum threat level, and NatureServe risk ranks for Pacific Lamprey within the San Joaquin RMU. See map, Figure 3. Individual threat rankings for Scope and Severity: 1 to 4, Insignificant to High; U = Unknown. NatureServe ranks (Natureserve 2009): SX, Extinct; SH, Believed extinct; and S1 to S4, critical to secure. Maximum threat ranks: X, Extinct due to dams (prior to 1985); and A to H, substantial and imminent threat to unthreatened. Adapted from Goodman and Reid 2012, updated to current understanding. A revised Status and Threat Assessment is expected in 2018.

Watershed	Risk Rank	Maximum Threat	Individual Threats (Scope - Severity)				
			Passage	Dewatering /Flow	Stream Degradation	Water Quality	Predation
Panoche-San Luis Reservoir	SH	A	4 - 4	-	-	-	-
San Joaquin - Upper	SX	X	X	-	-	-	-
Upper Chowchilla-Upper Fresno	SX	X	X	-	-	-	-
Merced - Upper	SX	X	X	-	-	-	-
Tuolumne - Upper	SX	X	X	-	-	-	-
Stanislaus - Upper	SX	X	X	-	-	-	-
Kings - Upper	SX	X	X	-	-	-	-
Calaveras - Upper	S1	B	4 - 4	2 - 2	3 - 3	2 - 4	1 - 2
Calaveras / Mormon Slough	S2	C	3 - 4	2 - 2	3 - 3	2 - 4	1 - 2
Mokelumne - Upper	SX	X	X	-	-	-	-
Cosumnes - Upper	S3	D	2 - 2	2 - 2	1 - 1	2 - 4	1 - 3
Cosumnes / Lower Mokelumne	S2	B	4 - 3	3 - 4	3 - 3	2 - 4	1 - 3
San Joaquin - Middle-Upper	S2	A	4 - U	4 - 4	2 - 4	2 - 4	4 - U
San Joaquin - Middle-Lower	S3	B	4 - U	3 - 4	2 - 4	2 - 4	4 - U
San Joaquin Delta	S2	B	4 - U	3 - 4	2 - 4	2 - 4	4 - U

drainages. Assessment of entrainment and passage effects at these facilities is currently underway and is dependent on screening efficiency, diversion timing, flow management in the complicated Central Valley water system, and downstream migration timing for juvenile lampreys (Goodman et al. 2015). Secondary uncertainties include the threat of predation posed by Striped Bass in the lower river reaches that serve as major migratory corridors for both adults and outmigrating juveniles and the potential for stranding and desiccation of downstream migrant lampreys when dry reaches separate upstream spawning and rearing habitats from the Pacific Ocean. Most threats were ranked at high to moderate, with no severe threats in any HUCs.

Passage (dams, culverts, water diversions, tide gates, other barriers)

The presence of large impassable dams along the Sierran foothills of the San Joaquin has severely limited the current range of anadromous lamprey, and much of the area lost is from the higher gradient foothill and mountain reaches that provide good water quality, spawning and rearing habitat (Figure 4). Under current conditions lampreys can access about 65% of the RMU area, mostly on the valley floor and lower foothills. Most mainstem rivers remain accessible up to the large foothill

dams. The Cosumnes River is the only river with access to its upper reaches and no major barriers. Although there is a weir in the lower river (elevation ca. 150 ft), it has a fish ladder and apparent natural passage around it. There is also a natural barrier falls, Latrobe Falls, that apparently blocks salmonids near the Sacramento County line (elev. ca. 200 ft; Yoshiyama et al. 1998), but lampreys pass it and are present in the upper Cosumnes. On the Calaveras River the New Hogan Dam blocks passage to all but 12.2 km of the upper river, while migration in the lower river and tributaries is hindered by numerous weirs and culverts. At this time, we do not think that passage above the larger storage dams is feasible, primarily due to challenges in providing outmigration opportunities to juvenile lampreys heading downstream.

A special case for passage issues (ranked as 4-U for the three mainstem San Joaquin HUCs) is entrainment at the Tracy Pumping Facility (USBR) and Clifton Forebay Diversion Facility (CDFG) in the lower San Joaquin, which potentially impacts passage for large numbers of downstream migrating juveniles from both the San Joaquin and Sacramento drainages (Figure 5). Assessment of entrainment and passage effects at these facilities is currently underway (Goodman et al. 2015) and is dependent on screening efficiency, diversion timing, flow management in the complicated Central Valley water system, and downstream migration timing for juvenile lampreys.

Figure 5. The Clifton Forbay Diversion Facility near Tracy, CA. This diversion facility along with the neighboring Tracy Pumping Facility potentially entrain large numbers of downstream migrating juveniles from both the San Joaquin and Sacramento drainages.

Dewatering and Stream Flow Management (reservoirs, water diversions, instream projects)

Stream flow is highly manipulated in the San Joaquin system, resulting in channel drying in the middle reaches of the San Joaquin and lower reaches of the Mokelumne rivers, extensive diversion into agricultural ditches, and loss of flow to state water projects. Dry reaches have resulted in mortality events where outmigrant macropthalmia have been observed stranded during their migration to the sea (Figure 6). Manipulation of flow in the delta by the major pumping projects may also have substantial effects on orientation of migrating lampreys (adults and juveniles). Water storage reservoirs also reduce available flow and artificially manage winter and spring flow events, reducing flow events that are crucial for outmigration of macropthalmia (Goodman et al. 2015).

Stream and Floodplain Degradation (channelization, loss of side channel habitat, scouring)

While the San Joaquin system is highly modified, the actual threat of stream and floodplain degradation to lampreys was rated as low to moderate in the lower reaches of occupied HUCs. Channelization increases the energy of higher flows and reduces both habitat diversity and development of suitable depositional habitat for rearing ammocoetes.

Figure 6. Pacific Lamprey stranded and desiccated during a punctuated downstream migration to the Pacific Ocean. This stranding event was observed downstream of the Chowchilla Bifurcation Structure on the San Joaquin River in 2016. Photo courtesy of the Donald Portz, Bureau of Reclamation.

Predation

Non-native predatory fishes are common in the San Joaquin Valley and foothill streams. Nevertheless, while there is certainly predation on larval and juvenile lampreys by introduced centrarchids (bass and sunfish) and catfishes, they have occupied the system since the late 1800's and were generally not considered to be a major threat to lamprey populations. A possible exception is the bass population in the upper Cosumnes (Moyle et al. 2003). In the lower reaches and delta of the San Joaquin River itself, Striped Bass are abundant and represent a potential threat to lampreys. Striped Bass are large predators, capable of feeding on all stages of lampreys, including adults. They occupy the primary migration routes for adults moving upstream to spawn and juveniles outmigrating to the sea, as well as at the forebays of the two Delta diversions. However, the extent of predation on lampreys by Striped Bass and the actual threat this represents to the population are unknown.. Movement patterns expressed by Striped Bass generally overlap with nocturnal activity patterns of lampreys and downstream migration during periods of high flow and turbidity.

San Joaquin RMU – Implementation Plan

This plan is intended to identify conservation efforts, knowledge gaps and implementation projects that will reduce risks to Pacific Lamprey within the San Joaquin RMU and its component HUCs, thereby promoting the conservation and management of the species range-wide. A summary of the implementation-specific segment of the plan is provided below, with details available in the Implementation Database (Appendix C).

General Conservation Needs within the San Joaquin RMU

There are some general conservation needs that pertain to all HUCs within the San Joaquin RMU. These include coordination efforts (outreach, education, and incorporation of lampreys into existing aquatic conservation efforts), as well as basic research into aspects of lamprey life-history that directly relate and are applicable to their conservation needs region-wide. There are also common needs for distribution surveys, population monitoring, habitat assessments and barrier mapping.

Coordination

As in most of the region, the lack of awareness, understanding, and consideration of lampreys by the general public, resource managers and restoration projects in the San Joaquin RMU has resulted in the conservation needs of Pacific Lamprey being ignored or actively imperiled. A major goal of the PLCI implementation is to increase awareness of Pacific Lamprey, attract more participation by stakeholders, and promote consideration of its conservation needs by providing outreach, training and local education to stakeholders, resource managers, and community members.

A specific regional focus is proposed for coordination with other passage stakeholders (e.g., EBMUD, SFPUC, SCWD, CalTrans, CDFW, USBR, local

municipalities, landowners, irrigation districts and USFWS) to ensure lamprey needs are considered in existing passage structures, as well as current and future projects. Passage obstruction has been identified as one of the primary threats to Pacific Lamprey region-wide, isolating over 40% of potential anadromous habitat and eliminating the ecological role of Pacific Lamprey in reaches above barriers. Furthermore, active passage programs/projects focusing on salmonids often ignore the needs of or actively block lampreys due to their design and/or management (Goodman and Reid 2017).

A specific regional focus is also proposed for increasing awareness of adverse impacts caused by surface diversions, groundwater pumping and seasonal desiccation. Water withdrawals reduce flows or dewater smaller tributaries and some mainstem rivers. Even a short-term loss of surface flow is lethal to over-summering adults and resident ammocoete populations and may result in the local loss of up to seven year classes. Higher temperatures caused by lower flows and increased nutrient loading promote algal blooms in mainstem rivers that further degrade habitat used by over-summering adults and ammocoetes, which cannot tolerate anoxic conditions in the sediment or water column. Much of the impacted habitat is in lower stream reaches generally not considered as summer habitat for protected salmonids and therefore not managed to higher standards.

General research needs

Passage: Although passage obstruction is identified as a primary threat to Pacific Lamprey region-wide, there is limited information on how lampreys move past barriers or how to design instream structures to facilitate lamprey passage. Therefore, basic research is needed to investigate and develop designs or management approaches for passage at culverts, low-head dams or weirs, and fish ladders. Other projects include investigation of entrainment risk from small-scale (<4") unscreened pumping stations and development of downstream passage/screening criteria for ammocoetes and emigrating juveniles.

Ammocoete habitat: Ammocoetes are highly dependent on the habitat provided by fine sediments during their 5–7 year instream development. We know little about fine-scale habitat selection by ammocoetes, nor about the effect of sediment conditions on ammocoete populations or system carrying capacity. Therefore, a basic research goals is needed to better describe investigate sediment habitat needs of ammocoetes, the role of temperature and dissolved oxygen levels in sediment habitat quality, the impact of eutrophication and associated algal development on sediment conditions, and mitigation measures for use during in-water projects to reduce mortality of ammocoetes.

Adult holding habitat: A common life history pattern is for adult lamprey to hold over in freshwater streams and rivers during the summer/winter and spawn the following spring. Observations of dead adults in summer months, outside the expected spawning period, may be indicative of pre-spawn mortality caused by high

water temperatures and low dissolved oxygen (DO) during the holding period. Research is proposed to determine thermal and DO tolerances for adult lamprey during the summer holding period.

Due to our limited understanding of the specific distribution and population dynamics of Pacific Lamprey, distributional surveys of ammocoetes, adult spawning areas, and over-wintering habitat, as well as adult population surveys, population monitoring and assessment of emigration timing for macropthalmia are recommended for each occupied HUC. Although the need for these surveys are common to all occupied HUCs, they are specified individually for each HUC in the database due to differences in threat level, stakeholders and project development, and to facilitate progress monitoring.Similarly, general survey and assessment of potential instream barriers (including low-head dams, diversions and culverts) is recommended for all HUCs to assess and prioritize conservation needs related to lamprey passage and/or entrainment.

Below are brief summaries of principal implementation needs and proposed projects in each of the San Joaquin HUCs. Details are available in the Implementation Database.

San Joaquin - Mainstem

We have separated out the mainstem San Joaquin from its tributaries (see below) although the lower reaches of some tributaries are included in "San Joaquin" HUCs (i.e. Delta, Middle-lower, Middle-Upper). See below for discussion of specific tributaries.

The primary concerns in the mainstem San Joaquin are habitat alteration and flow management as part of its use in regional water management (including channel desiccation, diversion, and water quality), as well as operations of the large water diversions in the Delta that are capable of diverting the entire flow of the mainstem and high levels of entrainment loss due to ineffective screening (Goodman et al. 2016). The channel complexity and artificial flow management in the river also creates navigational challenges for incoming and outmigrating lampreys (see discussion in Threats and Limiting Factors above). The river is currently the focus of a large restoration program, which has the potential to address some of the primary habitat, passage and flow management concerns between Friant Dam and the confluence with the Merced River (Figure 7). However, the separation of the mainstem and the "Eastside Bypass" in the middle reaches, provides a challenge to lampreys seeking access to the higher foothill reach below Friant Dam. Two additional concerns in the mainstem are predation by non-native fishes, particularly around man-made structures, and passage. Passage challenges include man-made structures and the dry gaps caused by water management.

Proposed implementation projects focus on 1) understanding and addressing issues caused by operations and design features at the Delta pumping facilities, 2) Determining routes used and constraints on Pacific Lamprey moving upstream and downstream thru the San Joaquin restoration reach upstream of the Merced confluence, 3) assessment and resolution of passage issues at instream structures in

Figure 7. Sack Dam on the San Joaquin River near Los Banos (top) and hydraulic conditions within one gate (bottom). This site is currently an obstacle to upstream migration of adult lampreys. The dam provides water through an unscreened diversion to the Arroyo Canal which may entrain downstream migrant lamprey. Constructing a fishway over Sack Dam and screening the Arroyo Canal diversion are actions that will be accomplished by the San Joaquin River Restoration Program.

the mainstem and bypass route, primarily between the Eastside Bypass control structure and its terminus in the vicinity of the Mendota Weir. About 50 miles of suitable habitat is present from the Bypass terminus to Friant Dam.

Cosumnes - lower Mokelumne

The two principal occupied drainages in these HUCs are the Cosumnes River and the Mokelumne River, of which only the lower reach (64 mi) remains accessible due to Comanche Dam, built in 1963. The Cosumnes River is the only tributary to the San Joaquin unconstrained by a large storage dam and maintaining a relatively natural flow regime. However, it does not reach as high into the Sierras and does not benefit particularly from extended snowmelt.

The primary concerns in these HUCs are desiccation and water quality (e.g. high temperatures and low dissolved oxygen) in the lower reaches of the Cosumnes, potential passage challenges at smaller diversions in both rivers, and predation by bass in the upper Cosumnes.

Proposed implementation projects focus on 1) investigating environmental constraints and tolerances of ammocoetes, 2) assessment and resolution of any passage issues at Granlee (Cosumnes) and Woodbridge (Mokelumne) diversions (Figure 8), both of which have unassessed fishways, and 3) investigation of bass - ammocoete interactions.

Calaveras - Mormon Slough

The lower Calaveras River represents about 44 mi of river habitat, including a short reach included in the Upper Calaveras below New Hogan Dam. Mormon Slough diverges at the Calaveras Diversion in Belota and rejoins it at the San Joaquin confluence in the town of Stockton. Both are used extensively for water conveyance and management.

The primary concerns in the HUC are water quality and management, as well as potential upstream passage constraints caused by the Calaveras Diversion and entrainment due to its diversion of flow.

Proposed implementation projects focus on assessment of the diversion structure and water management at the Calaveras Diversion.

Lower Stanislaus, Tuolumne and Merced rivers

The lower reaches of these three major tributaries of the San Joaquin are included in the Middle San Joaquin - Lower HUC. However, all have relatively long reaches (ca. 50 mi) of unobstructed occupied habitat up to their lowest foothill dam: Stanislaus - Goodwin Dam (rm 58 mi), Tuolumne - La Grange Dam (rm 50 mi), and Merced - Snelling Diversion Dam (rm 52 mi). No specific implementation projects are proposed for these rivers at this time, although all will benefit from projects focused on broader RMU issues, such as maintaining a suitable in- and out- migration corridor in the lower San Joaquin, entrainment, metapopulation dynamics, non-native predators, as well as continued outreach and inclusion of Pacific Lamprey in management planning.

Figure 8. Woodbridge Diversion Dam (top) and fish screen (bottom) on the Mokelumne River. Upstream of Woodbridge, lamprey have access to approximately 30 mi of the Mokelumne River before Comanche Dam (345 ft tall) and the current extent of anadromy. Constraints on upstream and downstream passage for lamprey remain unassessed at this site.

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Appendices

Appendix A. Stakeholder implementation meetings and workshops

Meeting Type	Location	Date
Threat Assessment	Sacramento	September 15, 2009
	Tracy	June 9, 2011
	Stockton	June 7, 2011
Implementation plan		May 10, 2016
	BOR, Fresno, Don Portz	8-Aug-17
	CDFW LaGrange	9-Aug-17
	EBMUD, Lodi	10-Aug-17
	USFWS	
Site Visits	CDFW Clifton Fish Screens	19-Jan-12
	BOR Tracy fish screens	20-Dec-15
	Granlee's diversion, Cosumnes	16-Dec-16
	Merced confl., Halls Ferry	8-Aug-17
	Eastside Bypass, culvert site	8-Aug-17
	Mariposa Bypass, at Eastside B	8-Aug-17
	Eastside Bypass, control structure	8-Aug-17
	Sack Dam, Henry Miller I.D.	8-Aug-17
	Mendota Weir	8-Aug-17
	San Mateo Rd. crossing culverts	8-Aug-17
	Skaggs Bridge	8-Aug-17
	Lost Lake Park	8-Aug-17
	Friant Dam	8-Aug-17
	Woodbridge	9-Aug-17
Workshop	Tracy	January 19, 2012
Lamprey summit	Portland, OR	Jun. 20-21, 2012

Appendix B. Data fields and criteria / coding used in Implementation tables.

HUC IDENTIFIER

FID - Feature ID ESRI
HUC - USGS Hydrologic Unit Code Levels 1-4
Name - HUC Name (USGS)

THREAT

Threat_Category:

- Passage
- Dewatering/Flow
- StreamDegradation
- Water Quality
- Predation
- Population
- Other

Subcategory- depends on threat category

- T_Scope- from Calif. Conservation Assessment (Goodman & Reid 2012)
- T_Severity- from Calif. Conservation Assessment (Goodman & Reid 2012)
- T_Overall- from Calif. Conservation Assessment (Goodman & Reid 2012)
- Threat- brief description of the threat addressed.

ACTION and RATIONALE

Description- short description of proposed action
Type- type of action proposed

- Assessment - assessment of potential threats or project needs.
- Coordination - including, outreach, collaboration and incorporation of lampreys into existing conservation efforts.
- Research - information needs that directly relate to their conservation needs or are needed to assess general threats.
- Survey/monitor - distribution of lampreys, suitable habitat, monitor populations or mapping of point threats (e.g., diversions, barriers).
- Instream - on the ground projects
- Rationale- rationale for action or benefit to lampreys
- Habitat gain- in linear miles of suitable habitat
- Adult- lifestage addressed (checked)
- Juv- lifestage addressed (checked)
- Larvae- lifestage addressed (checked)

SCALE and LOCATION

Scale- area impacted or addressed by action:

- Point (Lat/Long)
- Stream
- Mainstem
- Watershed
- HUC
- Basin
- Subregion
- Region - CA

Location - description, as specific as possible, depends on scale
Lat - Decimal degrees NAD83
Long - Decimal degrees NAD83

PRIORITIZATION

Scale of threats addressed

4 - Regional: Action addresses threat in >50% of region (action's impact, not overall threat)
3 - Multi-HUC: Action addresses a threat in multiple HUC's (<50% of region)
2 - HUC: Action addresses a threat in a single HUC
1 - Drainage: Action addresses threat within a drainage, reach or site, w/o broader impacts

Scope of threats addressed

4 - High: 71-100% of total population, occurrences, or area affected
3 - Medium: 31-70% of total population, occurrences, or area affected
2 - Low: 11-30% of total population, occurrences, or area affected
1 - Insignificant: <10% of total population or area affected

Severity of threats addressed

4 - High: 71-100% degradation or reduction of habitat/habitat function, and/or 71-100% reduction of population within scope
3 - Medium: 31-70% degradation or reduction of habitat/habitat function, and/or 31-70% reduction of population within scope
2 - Low: <30% degradation or reduction of habitat/habitat function, and/or <30% reduction of population within scope
1 - Unknown or n/a: Severity of threat unknown, or assessment and severity not applicable

Effectiveness of action

4 - High: Removes or causes threat to be insignificant; or provides all information needed to address threat (ie. Assessments, Coord., Research, Survey)
3 - Medium: Substantially reduces threat; or provides substantial information/collaboration
2 - Low: Has some effect on threat, but does not reduce it substantially; or provides minimal information/collaboration

1 - Insignificant: Minimally effective or not targeted at a known threat

Feasibility

Technical difficulty
4 - Simple: Utilizes simple technology or readily achievable methods
3 - Moderate: Moderately complex, but utilizes existing technology and standard methods
2 - Difficult: Requires high level of engineering, assessment, development or multiple stakeholder support development
1 - Unfeasible: Not likely to be possible at this time (5 years) due to excessive technical difficulty or complicated economic or political issues

Duration to implement
4 - Short: 0-2 years
3 - Medium: 3-5 years
2 - Long: > 5 years
1 - Extended: extended time frame or perpetual

Readiness
4 - Underway: Already underway or funded
3 - High: Can be initiated in the next two years.
2 - Medium: Could be initiated in the next 3-5 years.
1 - Low: May take five or more years for additional assessment and planning

Cost
4 - Inexpensive: $ < 10 k
3 - Moderate: $ 10-50 k
2 - Expensive: $ 50-250 k
1 - Very Expensive: $ 250 k - millions

Funding Source
4 - Funded: Funding has been obtained
3 - Identified: Appropriate funding sources identified and likely to participate
2 - Unspecified: Various appropriate funding sources exist but have not been selected
1 - Uncertain: Funding is uncertain

Partner participation
4 - High: All potential stakeholders are supportive
3 - Medium: Necessary stakeholders are supportive
2 - Low: Additional stakeholders need to be incorporated
1 - Problematic: Necessary stakeholders are not supportive

Prerequisites: Brief description of additional actions needed.

Additional Benefits

Prerequisite for other actions: Is action necessary prior to other implementation actions?
1 - Yes

2 - No

Additional benefits

4 - High:	Will have substantial benefits beyond the specific goals of the action (e.g., outreach, technology, precedent setting)
3 - Medium:	Will provide additional benefits to conservation efforts outside the drainage
2 - Low:	Localized benefits to species or stakeholders
1 - Insignificant:	Benefits restricted to action purpose only

Public awareness

4 - High:	High public awareness and positive outreach benefit
3 - Medium:	Increased stakeholder awareness and benefit outside of action area
2 - Low:	Unlikely to come to attention of public outside action area
1 - Insignificant:	Will probably not be noticed by anyone except those carrying out the action

Status

Status

- 'No status'
- Proposed
- Funded
- Underway
- Ongoing
- Completed

Work in Progress:	Brief description of current work underway or completed
Implementing Entity:	Lead entity, and partners
Contact:	Primary contact for threat or action
Cost:	Approximate (this is difficult)
Funding Source:	Current or potential
Funds available:	Percent (%) of total cost
Stakeholders:	Involved/effected parties - not necessarily implementer or funder

Notes:

Appendix C. Proposed implementation tasks and needs - San Joaquin.

The Implementation Database is intended as a living document that will be updated as we develop new information and improve our understanding of lamprey conservation status and as implementation progresses and the status of individual projects changes. A current version of the Implementation Database is maintained at the Arcata USFWS Field Office. Interested stakeholders can contact us either for electronic access to the implementation database, to provide updated information or to recommend additional projects.

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