PACIFIC LAMPREY
Entosphenus tridentatus

Status: Moderate Concern. Pacific lampreys are in decline throughout their range in California. However, they are still widespread so the species does not appear in immediate danger of extinction in the state. Some local or regional (e.g., southern California) populations may face considerably higher threat of extirpation in the near future.

Description: Pacific lampreys are the largest (> 40 cm TL) lampreys in California. However, landlocked Pacific lamprey populations may have dwarf (15-30 cm TL) morphs. The sucking disc is characterized by having sharp, horny plates (teeth) in all areas (Vladykov and Kott 1979). The crescent-shaped supraoral lamina is the most distinctive plate, with three sharp cusps, of which the middle cusp is smaller than the two lateral ones. There are four large lateral plates on both sides of the supraoral lamina. The outer two lateral plates are bicuspid, while the middle two are tricuspid (formula 2-3-3-2). The tip of the tongue has 14-21 small points (transverse lingual lamina), of which the middle one is slightly larger than the rest. The two dorsal fins are discontinuous but the second dorsal is continuous with the caudal fin. Adults generally have 62-71 body segments (myomeres), while juveniles have 68-70 body segments between the anus and last gill opening (Wang 1986). The diameter of the eye and oral disc, respectively, are 2-4 percent and 6-8 percent of the total length. Males tend to have higher dorsal fins than females, lack a conspicuous anal fin and possess genital papillae. Body color varies by developmental stage. For juveniles (ammocoetes), the body and lower half of the oral hood is dark or medium brown, with a pale area near the ridge of the caudal region. Newly metamorphosed juveniles (macropthalmia) are silvery with a slightly bronze cast. Spawning adults are usually dark greenish-black or dark brown in color.

Taxonomic Relationships: The use of the genus name *Entosphenus* reflects the phylogenetic study of Gill et al. (2003) that places this genus as a separate lineage from *Lampetra,* into which all western North American lampreys had been lumped. Genetic analysis of populations of from British Columbia to southern California have found little variation among populations, suggesting that gene flow occurs readily throughout their range (Goodman et al. 2008, Docker 2010). However, populations in the northern part of the range exhibit reduced genetic richness (Goodman et al. 2008), perhaps reflecting locally adapted population segments.

Pacific lampreys have given rise to landlocked populations throughout their range, including predatory species (e.g., *E. similis;* refer to separate species accounts). Populations have also become isolated upstream of reservoirs resulting from dam construction, including populations in Clair Engle Reservoir (Trinity River) and Clear Creek, upstream of Whiskeytown Reservoir (Brown and May 2007). Considerable overlap of morphometric characters exists between Pacific lamprey and its derivatives, as well as between predatory and nonpredatory forms, especially in the Klamath River basin (Bond and Kan 1973, Bailey 1980, Lorion et al. 2000), so careful examination is required for identification. Studies of mitochondrial DNA (Docker et al. 1999) and statistical analysis of morphometric characteristics (Meeuwig et al. 2006) show promise in resolving interrelationships among species.

Life History: Pacific lampreys have more diverse life histories than generally recognized. Within the same river system they may have more than one run (Anglin 1994) or individuals that do not migrate to sea. For example, two forms of Pacific lamprey exist in the Trinity River, one smaller and paler than the other, representing either separate runs or resident and anadromous individuals (T. Healey, CDFW, pers. comm. 1995). It is possible that lamprey in the Klamath and Eel rivers, as well as other large river systems, have a number of distinct runs, similar to salmon. One indication is that many adults migrate upstream and hide under logs and boulders for months until they mature, with a life history akin to that of summer steelhead or spring-run Chinook salmon (Beamish 1980, ENTRIX 1996). Two distinct runs may exist in the Klamath River: a spring-run of adults that spawn immediately after upstream migration and a fall-run of individuals that wait to spawn until the following spring (Anglin 1994). A large spring-run and smaller fall-run have been observed in the Russian River (Brown et al. 2010); the two runs were observed from 2000 to 2007 (S. Chase, Sonoma County Water Agency, unpubl. data) with the use of underwater video (at Mirabel, 37 rkm), primarily from the beginning of August to the onset of heavy rains (November to December), as well as in the spring months. The general run trend is low numbers of migrants in October and November and higher numbers in the spring.

Adult Pacific lampreys are micropredators (i.e., they feed on prey larger than themselves) during their oceanic existence, consuming the body fluids of a variety of fishes, including salmon and flatfishes (Beamish 1980) and marine mammals (Close et al. 2002). Beamish (1980) found that 14-45 percent of the salmon returning to British Columbia had scars from lamprey predation. Similar data are not available for salmon in California. Adult lampreys themselves are prey for other fishes, including sharks, and are often found with parts of their tails missing. Sea lions, near the mouth of the Rogue River, Oregon, have been observed eating large numbers of migrating lampreys (Jameson and Kenyon 1977). Lamprey predation is largely confined to fishes that occupy estuaries and nearshore coastal areas. However, some individual lampreys have been caught in waters up to 70 m deep (Beamish 1980) and as far as 100 km from shore (Close et al. 2002). The oceanic phase lasts approximately 3-4 years in British Columbia, but is likely of shorter duration in southern waters. Pacific lamprey predation appears to have little effect on fish populations (Moyle 2002, Orr et al. 2004).

Adult (30-76 cm TL) spawning migrations usually take place between early March and late June, but migration has also been documented in January and February (ENTRIX 1996, Trihey and Associates 1996b), as well as in July in northern streams. Spawning migrations have been documented in August and September in the Trinity River (Moffett and Smith 1950). Most upstream movements occur in surges at night, with some individuals migrating fairly continuously over the course of two to four months. In the Santa Clara River (Ventura County), migration was initiated after the sand bar blocking the lagoon at the mouth was breached by winter rains in January, February, or March; adults reached a fish ladder 16.8 km upstream within 6-14 days of the breach (ENTRIX 1996). In the Santa Clara River, lampreys migrated mostly during high flows, but also moved in flows ranging from 25 to 1700 m^3/min (ENTRIX 1996).

Lampreys will migrate considerable distances and are stopped only by major barriers, such as dams. Lampreys were observed spawning in Deer Creek (Tehama County), about 440 km from the ocean (P. Moyle, unpublished observation). Presumably, migrations of more than 500 km were once common. In the Klamath River, Humboldt County, radio tagged lampreys migrated an average of 34 km over the course of 25 days at a travel rate of 2 km/day (McCovey et al. 2007). Adults do not feed during spawning migrations (Beamish 1980) but can survive extended periods (months to two years) without food, allowing them to migrate long distances (Whyte et al. 1993). Pacific lampreys seem to have poorly developed homing abilities (Hatch and Whiteaker 2009). If this is true, then lamprey populations are likely regulated by source-sink dynamics, where large river populations (such as those historically present in the Eel River) sustain populations in smaller adjacent rivers or tributaries, where localized extinctions can occur periodically due to stochastic events such as floods and droughts (e.g. a drying event, even short-term, could eliminate multiple age classes of ammocoetes). The source-sink model would also explain persistence of lampreys in habitats that are often unsuitable (e.g. in southern California rivers). The sink populations may disappear as source populations shrink and the number of potential recruits to the sink population becomes reduced or non-existent. This model is speculative but seems to fit with recent findings of lamprey behavior and population dynamics and is consistent with ecological theory (metapopulation dynamics).

Once at a spawning site, typically in a low-gradient riffle, both sexes build a nest depression 21-270 cm in diameter (Gunckel et al. 2009), with depths of 30-150 cm, at temperatures of 12-18 °C (Moyle 2002). Depths of nests range from 30-82 cm (mean of 59 cm) in the American River, while ranging from 36 to 73 cm (mean of 50 cm) in Putah Creek. Nest construction has been observed in water as deep as 1.5 m in Deer Creek, Tehama County (Moyle, unpublished observations). Water velocity at nests in the American River ranged from 24-84 cm/sec, in comparison to 17-45 cm/sec in Putah Creek. Although Pacific lampreys most commonly spawn in flowing water, spawning has also been observed in lentic systems (Russell et al. 1987). Lampreys attach themselves to the downstream end of rocks and swing vigorously in reverse to remove substrates during nest construction. More than one individual may pull at the same rock until the combination of pulling and pushing dislodges the rock (Stone 2006). Adults may test several nest sites (‘false digs’) before fully digging a nest (Stone 2006). Nests are shallow depressions, with piles of stones at either the downstream (Moyle 2002) or upstream (Susac and Jacobs 1999) end of the nest. In order to mate, the female attaches to a rock on the upstream end of the nest, while the male attaches himself to the head of the female and wraps his body around hers. Occasionally, both will attach to rocks while staying side by side (Wang 1986). Eggs and milt are released when both vibrate rapidly. Fertilized eggs float downstream, where most adhere to rocks at the downstream end of the nest.

After spawning, lampreys loosen sediment upstream of the nest to cover the embryos. Spawning is repeated in the same nest until the adults are spent. Males may mate with more than one female (Wang 1986). About 48 individuals were observed using the same nest in the Smith River, Oregon (Gunckel et al. 2006). The average time spent in spawning areas is less than seven days for both sexes (Brumo 2006). Adults may defend their nests; Stone (2006) observed a male using his oral disc to remove a sculpin

(*Cottus* spp.) from its nest in Cedar Creek, Washington. Both sexes usually die after spawning. However, some adults may live to spawn for one more year in Washington streams (Michael 1984). Repeat spawning may also occur in the Santa Clara River, as indicated by the fact that live adults have been caught in downstream migrant traps (ENTRIX 1996). The fecundity of females ranges from 20,000 to 238,000 eggs (Kan 1975).

At 15 °C, embryos hatch in 19 days. Upon hatching, ammocoetes stay in the nest for a short period of time and then swim into the water column where they are washed downstream to areas of sand or mud. Ammocoetes burrow into soft stream sediments tail first, at which point they begin filter feeding by sucking organic matter and algae from stream substrates. Survival to this stage may be related to stream discharge at time of spawning and density dependent effects (e.g., amount of rearing habitat and prey items) associated with ammocoete abundance (Brumo 2006). Ammocoetes leave their burrows and drift to other areas at night throughout their freshwater residency (White and Harvey 2003). Larger ammocoetes commonly drift in spring high flows, while smaller ammocoetes drift during the summer. Consequently, they can be trapped during much of the year (Moffett and Smith 1950, Long 1968). In the Trinity River, ammocoetes as small as 16 mm recolonized areas from which they had been removed by winter floods (Moffett and Smith 1950)

The ammocoete stage probably lasts 5-7 years, at the end of which ammocoetes measure 12-14 cm TL and metamorphosis to macropthalmia begins. Lampreys develop large eyes, a sucking disc, silver sides and dark blue backs during metamorphosis. Their physiology and internal anatomy (McPhail and Lindsey 1970) also change dramatically. Physiological changes allow adult lampreys to tolerate salt water, which is lethal to ammocoetes (Richards and Beamish 1981). Saltwater tolerance coincides with the opening of the foregut lumen (Richards and Beamish 1981). Downstream migration begins when metamorphosis is completed and is often associated with high flow events in the winter and spring, perhaps coincident with adult upstream migration. Most volitional movement of macropthalmia occurs at night (Dauble et al. 2006).

It is likely that Pacific lamprey life history has played a key role in their persistence. The extended freshwater residency of ammocoetes allows populations to withstand low flows or other conditions that might block adult spawning runs over the course of several years. This may explain, for example, why a small population of Pacific lamprey persists in the San Joaquin River near Fresno (D. Mitchell, CDFW, pers. comm. 2007).

An underappreciated aspect of Pacific lampreys is their importance in the food webs of stream ecosystems. Ammocoetes break down detritus and are sources of prey for other fishes (Cochran 2009). Adult carcasses may be an important source of marine derived nutrients (e.g. nitrogen) to oligotrophic streams (Wipfli et al. 1998, Close et al. 2002, Lewis 2009).

Habitat Requirements: Pacific lampreys share many habitat requirements with Pacific salmonids (*Oncorhynchus* spp; Close et al. 2002, Stone 2006), particularly cold, clear water (Moyle 2002) for spawning and incubation. They also require a wide range of habitats across life stages. In general, peak spawning appears to be closely tied to water temperatures that are suitable for early development (Close et al. 2003, Meeuwig et al.

2005) but can occur at temperatures above 22 °C (Luzier et al. 2006). Consequently, temperature may be important in determining ammocoete abundance (Young et al. 1990, Youson et al. 1993, Bayer et al. 2000). Juveniles can persist in flows of up to 40 cm/s but are generally most common at velocities of 20-30 cm/s (Close 2001).

Adults use gravel areas to build nests, while ammocoetes need soft sediments in which to burrow during rearing (Kostow 2002). Nests are generally associated with cover, including gravel and cobble substrates, vegetation and woody debris. Likewise, most nests observed in Cedar Creek, Washington, were observed in pool-tail outs, low gradient riffles and runs (Stone 2006). Pacific lamprey embryos hatch at a wide range of temperatures (10-22 °C). However, in the laboratory, time from fertilization to hatching was around 26 days at 10 °C and around 8 days at 22 °C (Meeuwig et al. 2005). Survival of embryos was highest at temperatures ranging from 10 to 18 °C. Survival declined sharply, with a significant increase in abnormalities, at 22 °C.

Ammocoetes burrow into larger substrates as they grow (Stone and Barndt 2005). Ammocoetes also need detritus that produces algae for food (Kostow 2002) and habitats with slow or moderately slow water velocities (0-10 cm/s; Stone and Barndt 2005), such as low gradient riffles, pool tailouts and lateral scour pools (Gunckel et al. 2009).

Adults can climb over waterfalls and other barriers, using their sucking disc, as long as there is a rough surface and some amount of flow. These features are rarely present on dams, so even small dams or fish ladders can be barriers if not designed with surfaces and features that allow climbing (as in CRBLTW 2004).

Distribution: Pacific lampreys occur along the Pacific coast from Hokkaido Island, Japan (Morrow 1980), through Alaska and south to Rio Santo Domingo in Baja California (Ruiz-Campos and Gonzalez-Guzman 1996). Anadromous forms of Pacific lamprey occur below impassible barriers throughout their range. In California, Pacific lampreys occur from Los Angeles to Del Norte counties and the rivers in the Central Valley. Although a few individuals have been recorded in the Santa Ana, Los Angeles, San Gabriel and Santa Margarita rivers, the occurrence of all forms is infrequent south of Malibu Creek, Los Angeles County. The southernmost record in California is a single ammocoete collected from the San Luis Rey River, San Diego County, in 1997 (Swift and Howard 2009). A sizable run was recorded in the 1990s in the Santa Clara River (Chase 2001). However, their numbers appear to have significantly declined in the last few years (Swift and Howard 2009). There are also records from the Rio Santo Domingo, Baja California (Ruiz-Campos and Gonzalez-Guzman 1996). In general, lamprey distribution in California becomes irregular and erratic south of San Luis Obispo County (Swift et al. 1993, Swift and Howard 2009). An unusual landlocked population has persisted in Clair Engle Reservoir (Trinity River, Trinity County) since 1963, when the dam was constructed.

In the Central Valley, their upstream range appears to be limited by impassable dams that exist on all large rivers. Ammocoetes and spawning individuals have been observed in the San Joaquin River below Friant Dam and in most major tributaries from the Merced River north to the Feather River, as well as in some smaller tributaries, such as Putah Creek, Yolo-Solano counties. Ammocoetes have been observed along the edges of channels in the Sacramento-San Joaquin Delta, primarily in the north Delta (e.g. around McCormick-Williamson Tract; P. Moyle unpublished data). Both downstream migrating juvenile lampreys and returning adults must pass through the entire San Francisco Estuary, but their requirements for passage are not known.

Trends in Abundance: Anadromous Pacific lamprey abundance has declined so that large runs have disappeared from rivers such as the Eel River (Moyle 2002, Yoshiyama and Moyle 2010), although small runs persist in some portions of their range. Runs have also largely disappeared from southern California streams (Swift and Howard 2009). Abundance estimates for Pacific lamprey populations in California are scarce, but rotary screw trap data from 1997 to 2004 in the Klamath River basin suggested a declining trend for all life stages (USFWS 2004). Native American fishermen in the Klamath basin have also observed that runs are much smaller than they once were in this system (Larson and Belchik 1998). Traps for salmonid smolts in Redwood Creek, Humboldt County, capture 5-91 lampreys per year, all post-spawners (M. Sparkman, CDFW, pers. comm. 2011). Lampreys in Oregon and Washington have also shown significant declines, similar to those in California. For example, counts at Winchester Dam on the lower Umpqua River, Oregon, have declined from a maximum of 46,785 in 1966 to 34 in 2001 (ODFW in Close et al. 2002). In the Columbia River basin, the number of Pacific lamprey passing Bonneville Dam has declined from an estimated 50,000 adults prior to 1970 to less than 25,000 with a progressively sharper decline in Pacific lamprey abundance further upstream (Kostow 2002). Despite obvious declines wherever lampreys are actually counted, declines in Pacific lamprey are largely unrecognized, in part because they still occupy much of their historic range and most streams appear to retain at least small runs. The latter may be due to a low degree of fidelity to spawning areas (Goodman et al. 2006, Docker 2010), so recolonization of altered streams may occur fairly quickly when conditions improve, provided there is a source population nearby. However, this pattern of rapid dispersal may actually mask an overall decline in numbers.

Thus, a population in Putah Creek (Yolo and Solano counties) reestablished itself following completion of the Solano Project, which dewatered lower portions of the stream, and, again, following an extended drought during which much of the stream was dry. The apparent lack of strong homing tendencies in Pacific lampreys suggests that they have the ability to temporarily colonize impaired habitats, even if they cannot sustain populations in these areas. However, the apparent loss of the largest known southern California population in the Santa Clara River (Swift and Howard 2009) indicates that their distribution and abundance is shrinking and certain portions of their range may no longer provide suitable habitats.

Nature and Degree of Threats: Threats to Pacific lampreys are diverse and usually multiple for any given population (Table 1). The nature and degree of these threats are poorly understood, given the general lack of information on factors affecting lamprey populations. The Pacific lamprey has such a wide geographic range that different factors likely influence its abundance in different areas. Hence, there are no ‘high’ or ‘critical’ scores for threats to all California populations, combined, but a remarkable nine ‘medium’ scores, which could actually be ‘critical’ or ‘high’ in different rivers (Table 1). It is likely that factors that have led to population declines of anadromous salmonids across California may also be the main causes for decline of Pacific lamprey, especially given these fishes share so many ecological and habitat requirements.

One universal factor, related to all others but not rated here, is reduction in prey abundance, especially salmonids, due to stressors such as dams, diversions, habitat degradation and over-exploitation. Adult Pacific lampreys depend on having large populations of large prey species, such as salmon, to maintain their own numbers. In British Columbia, salmon are among the most important prey of lampreys (Beamish 1980), as they may be elsewhere in their range. While the importance of different prey species is unknown for populations of lampreys in California, the fact that Chinook and coho salmon populations have severely declined in most California rivers suggests that lamprey declines may be closely tied to salmonid declines.

Dams and diversions. Large dams have reduced the range of Pacific lampreys in many streams, as they have for salmon and steelhead, by preventing upstream passage to spawning and rearing areas and reducing suitability of downstream habitats. Lampreys are capable of passing over some small dams and diversion structures, either by using fish ladders or by using their suction cup-like mouths to work their way over barriers, provided the surfaces are wet and rough. Large dams without passage structures, however, occur throughout their range and prohibit upstream migration to large portions of their former range.

Where documentation exists for regulated streams, lamprey populations have declined from historic numbers. Unsuitable flow regimes for migration, along with loss of spawning and backwater rearing habitats combine to make regulated streams unfavorable for lampreys. Flow regimes that limit emigration or immigration may have delayed effects and declines may be difficult to detect; the long lifespan of ammocoetes and the apparent lack of homing behavior in adults can give the impression of persisting populations in streams with only intermittent access. During unseasonably high-flow events, ammocoetes may be flushed to unsuitable habitats because they are poor swimmers (Dauble et al. 2006). Spawning habitat is lost when recruitment of sediments from upstream areas is blocked by dams; lack of sediment imbeds rocks in spawning areas, making them more difficult to move for nest creation. Reduction in sand and silt recruitment, combined with channelization, may also reduce suitable habitats available for ammocoetes below large dams (Close et al. 2002).

Agriculture. Lampreys are typically rare or absent from river reaches heavily influenced by agriculture. In particular, Pacific lampreys are usually eliminated from streams that are heavily polluted (Gunckel et al. 2006), such as the lower San Joaquin River.

Urbanization. The broad range of Pacific lampreys includes many areas that are now heavily urbanized. Typically, they are rare or absent in these areas, such as most of southern California, although the exact causes are poorly documented. Presumably, the disappearance of lampreys from urban areas has multiple causes related to habitat alteration (water diversion, channelization, concrete channels, etc.) and to pollution such as stormwater runoff and pesticides, although most urban streams are also dammed and diverted.

Instream mining. Gravel mining has been common in the lower reaches of streams favored by lampreys. While impacts have not been documented, gravel mining may disrupt spawning and displace ammocoetes, particularly through mobilization of fine sediment deposits, which are key rearing habitats, as well as removal of preferred substrates for spawning.

Mining. Hardrock mines are present in many lamprey watersheds but their effects (e.g., acid mine drainage) are largely unknown.

Logging. Coastal rivers, such as the Eel River (named for its lampreys), that have been heavily altered by logging and road building are generally less suitable for lampreys than they were historically because of excessive deposition of gravels in backwater areas needed for rearing, alteration of the annual hydrograph, increased sediment loads, increased solar input and corresponding higher water temperatures, or similar changes in habitats.

Estuary alteration. Estuaries have been significantly altered throughout the range of Pacific lamprey. Estuaries may be as important to lamprey as they are to anadromous salmonids, which rely on them for foraging, rearing and holding habitat, as well as transitional habitats that enable osmoregulation and migration orientation. Lamprey ammocoetes were commonly observed in the soft sediments of the Smith River estuary from 1997 to 2001 (R. Quiñones, pers. observations), an estuary that retains many of its natural characteristics because stream flows have not been altered significantly.

Harvest. Lampreys have long supported subsistence fisheries by coastal tribes, especially in the Klamath River, because their early arrival and high fat content made them highly desirable as food. This fishery continues today, although only small numbers are likely taken (Lewis 2009). Of greater concern is the fishery for spawning lampreys that has developed because of their value as bait for sturgeon. Adult lampreys are extremely vulnerable to capture when on their nests and the fishery is largely unregulated and unmonitored. Ammocoetes are also collected for bait on occasion and are called “worms” by striped bass fishermen.

Alien species. Alien species increasingly co-occur with Pacific lampreys but their impacts on lamprey populations are not well understood; however, localized impact may be considerable. Ammocoetes are documented prey of many predatory fishes. In the Eel River, for example, introduced Sacramento pikeminnows were observed feeding heavily on ammocoetes (P. Moyle, personal observations; Brown and Moyle 1997).

	Rating	Explanation
Major dams	Medium	Major dams present on many Pacific lamprey rivers; dams prevent access to spawning habitats and reduce habitat suitability downstream
Agriculture	Medium	Minor influence on lower Klamath and Eel rivers, major impact in Central Valley
Grazing	Low	Pervasive across Pacific lamprey range but probably minor impacts on large river habitats
Rural residential	Low	Can cause localized habitat loss or degradation
Urbanization	Medium	Large urban areas in southern part of range and Central Valley contribute to habitat degradation, stream channelization, input of pollutants and flashy flows associated with hardscapes
Instream mining	Medium	Gravel mining and gold dredging alter rearing habitats and increases mortality of ammocoetes; effects are highly localized
Mining	Low	Mines common in lamprey watersheds; direct effects unknown
Transportation	Medium	Roads line many rivers and streams, simplifying habitats (channelization, bank stabilization, etc.); sources of sediments and pollutants that may affect spawning and survivorship; culverts and other structures create barriers to migration
Logging	Medium	Major source of sediments via roads; greater historic impacts in most Pacific lamprey habitats than today
Fire	Low	Fire severity is increasing due to landscape changes, along with climate change, potentially increasing siltation and changing water quality
Estuary alteration	Medium	Most estuaries in California are highly altered through diking, draining, channelization and dredging
Recreation	Low	Possible disturbance to spawning and rearing
Harvest	Medium	Potential reduction of adult abundance in some streams, rivers and Delta; impacts not well understood
Hatcheries	n/a	
Alien species	Medium	Predation on ammocoetes may limit abundance in some areas

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of Pacific lamprey in California. Factors were rated on a five-level ordinal scale where a factor rated "critical" could push a species to extinction in 3 generations or 10 years, whichever is less; a factor rated "high" could push the species to extinction in 10 generations or 50 years whichever is less; a factor rated "intermediate" is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated "low" may reduce populations but extinction is unlikely as a result. A factor rated "n/a" has no known negative impact to the taxon

under consideration. Certainty of these judgments is low. See methods section for descriptions of the factors and explanation of the rating protocol.

Effects of Climate Change: Predicted increases in river temperatures (to > 22 °C) brought about by climate change may increase incidence of deformities and mortalities of incubating eggs and of ammocoetes (Meeuwig et al. 2005). Summer water temperatures already frequently exceed 20°C in many California streams and temperatures are expected to increase under all climate change scenarios (Hayhoe et al. 2004, Cayan et al. 2008). Increases in summer temperatures may affect growth and metabolic costs of juveniles and stress adult Pacific lamprey holding in rivers throughout the summer (Clemens et al. 2009).

Climate change is also predicted to change the flow regime in rivers. For instance, flows in the Klamath River may peak earlier in the spring and continue tapering through the summer before pulsing again later in the fall (Quiñones 2011). Resulting changes in river flows and temperatures may alter the timing of adults and juveniles entering and exiting California rivers. Large flow events can disrupt incubation and rearing habitat due to increased bed mobility (Fahey 2006). However, flow-related impacts may be attenuated by dam operations in some systems or exacerbated by competing demands for water (e.g., agricultural irrigation) during low flow periods in others. The Pacific lamprey's migratory plasticity may facilitate movement into watersheds with more favorable habitat conditions (provided passage exists) so their populations may not be as threatened by climate change as are species with high migratory fidelity (e.g., salmon and steelhead). Nonetheless, the geographic range of Pacific lamprey may shift northward as temperatures and flows because unsuitable in more southern streams. Populations south of Monterey Bay may disappear, following those in southern California. Shifts upward in elevation toward remaining cold water refuges may be impeded by barriers or difficulties associated with passage through dams, as well as increased distance of migration and lack of suitable habitats in high-gradient reaches. Because of these concerns, Moyle et al. (2013) rated Pacific lamprey as "highly vulnerable" to extinction in California due to climate change impacts in the next 100 years.

Status Determination Score = 3.3 - Moderate Concern (See Methods section, Table 2). Pacific lampreys apparently still occupy much of their native range in California, but evidence suggests that large declines may have occurred in the past 50 years. Pacific lampreys no longer have access to numerous upstream habitats blocked by large dams or other impassable structures and they are no longer present in streams at the southern end of their range. The large runs that once occurred in coastal streams such as the Eel and Klamath have dwindled to a fraction of their former size.

Metric	Score	Justification
Area occupied	4	Present throughout much of their historic range; blocked from large portions of watersheds by dams
Estimated adult abundance	2	Population estimates lacking; large river populations presumably are >500 in most years
Intervention dependence	4	Improved flow management and habitat restoration efforts needed to prevent further declines, especially for more southern populations
Tolerance	3	Local populations are vulnerable to stochastic events and degraded habitats
Genetic risk	5	Gene flow apparently largely unimpaired between populations throughout range
Climate change	2	Limited spawning and rearing habitats suggests vulnerability to increased temperatures and altered flow regimes, especially in southern end of range
Anthropogenic threats	3	Nine factors rated as 'medium' (Table 1)
Average	3.3	23/7
Certainty (1-4)	2	Population size and environmental tolerances poorly understood

Table 2. Metrics for determining the status of Pacific lamprey, where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. See methods section for further explanation.

Management Recommendations: Pacific lamprey conservation and management is currently hindered by lack of information on their distribution, abundance, and life history. However, given their apparent decline throughout much of the historical range in California, additional conservation measures can and should be pursued in order to afford greater protection (Streif 2009). Management recommendations include the following:

1. Establish a Pacific lamprey research and monitoring program, with three primary goals: 1) determine the status of lampreys statewide and identify key conservation opportunities; 2) improve understanding of life history attributes and habitat requirements in California streams in order to enable a limiting factors analysis; and 3) determine if different genetic stocks of lampreys exist in California. Ideally, such a program would provide critical information about status, population dynamics and life history variability of the species throughout its range in order to inform management and conservation measures. Beneficial research should include studies to: (1) identify the presence or absence of multiple runs in large rivers; (2) document landlocked populations in large river systems; and (3) evaluate metapopulation dynamics to determine if a few large main-river populations sustain smaller tributary populations (source-sink dynamics).
2. Establish a lamprey data center, as part of the proposed research and monitoring program, which would standardize, collect and integrate *all* lamprey information collected in California. The many rotary screw traps used to monitor outmigration of juvenile salmonids, in particular, are a largely untapped source of

data. Many trap operators record captures of lamprey ‘smolts’ and ammocoetes. The lampreys are rarely identified to species, but most are likely Pacific lampreys.

3. Determine if conservation efforts for salmonids also benefit Pacific lampreys, especially in regulated streams. The following questions remain largely unanswered and should be the focus of additional research:
    a. Do passage structures constructed for salmonids also allow passage for lampreys?
    b. Do habitat restoration programs focused on salmonids also create backwater habitat for lampreys?
    c. Are populations of Pacific lamprey tied to those of salmon and steelhead (e.g., predator-prey interactions, migratory timing)?
4. Require that all instream alteration or diversion projects address lamprey habitat and life history requirements and provide appropriate mitigation measures. Strief (2009) documented that a single stream dewatering event, even of short duration, can inhibit up to seven years of lamprey production by eliminating all age classes of ammocoetes.
5. Address potential threats in order to reduce or reverse population declines. In many respects, addressing threats to lamprey requires restoring flows and habitats in most of California’s rivers. Possible actions include:
    a. Subsistence and bait fisheries for lamprey should be monitored to determine their effects on population structure and abundance.
    b. Where feasible, large dams should be retrofitted with fishways that are passable to all migratory stages of lamprey.
    c. Estuary and river restoration projects should consider establishing natural flow regimes, minimum base flows, and sediment budgets (to reestablish deposits of soft sediment in low velocity habitats and improve spawning gravel quality).

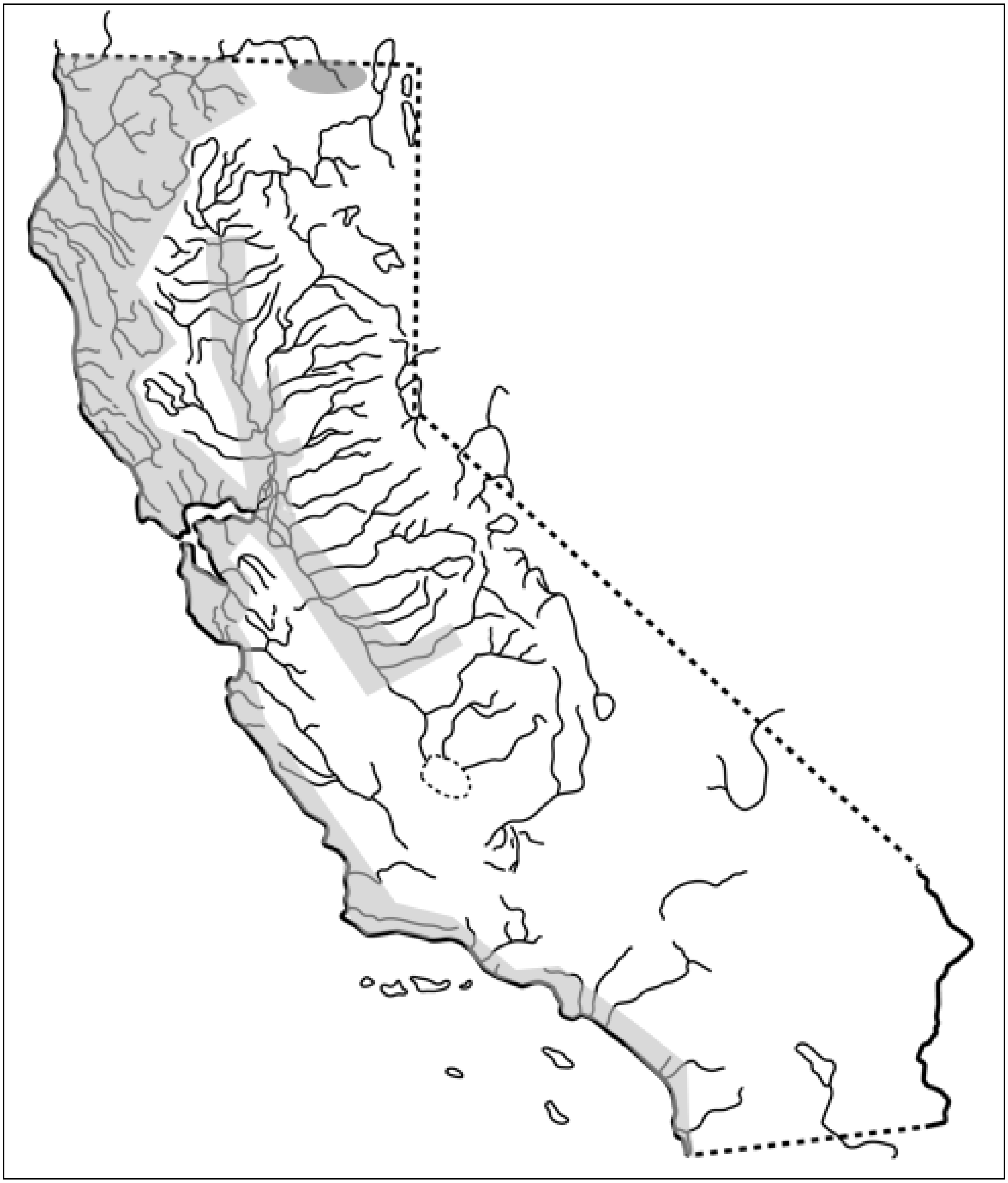

Figure 1. Generalized distribution of Pacific lamprey, *Entosphenus tridentatus***,** in California. Current distribution is reduced and fragmented, although recolonization of depleted areas may occur periodically.