WESTERN BROOK LAMPREY
Lampetra richardsoni (Vladykov and Follet)

Status: Moderate Concern. Western brook lampreys are still present in the least disturbed portions of many watersheds but all populations are likely small, isolated and declining.

Description: Western brook lampreys are small, usually less than 18 cm TL, and nonpredatory (Moyle 2002). They have poorly developed tooth plates in the oral disc and tooth plates in spawning adults may be missing from the anterior field. The supraoral plate is wide with one cusp at each end. The infraoral plate has 6-10 toothlike cusps and 3 circumoral plates on each side of the mouth. The middle circumoral plate has 2 or 3 cusps. Cusps on the transverse lingual lamina are inconspicuous. The oral disc is narrower than the head with a length that is less than 6 percent of the total length. Both adults and ammocoetes have trunks made up of 52-67 myomeres (52-58 in California populations). Body coloration is dark on the sides and back, and light (yellow or white) on the underside. Ammocoetes have dark tails and heads above the gill opening (Richards et al. 1982).

Taxonomic Relationships: The western brook lamprey was determined to be a species, *L. richardsoni*, distinct from the European brook lamprey, *L. planeri*, in 1965, but closely related to the predatory river lamprey, *L. ayersi* (Vladykov and Follett 1962). Later, populations in Oregon and California were described as belonging to *L. pacifica* by Vladykov (1973). C. Bond, in an unpublished study, determined that differences in myomere counts that were thought to distinguish *L. pacifica* from *L. richardsoni* did not do so when populations throughout their range were sampled, so the name was quashed without further review by the American Fisheries Society (Robins et al. 1991, Stewart et al. 2011). Stewart et al. (2011) determined it is, indeed, a valid species but confined to the Columbia River basin. Boguski et al. (2012) examined nominal river and brook lampreys from the entire Pacific Coast and found that, for the most part, the non-predatory brook lampreys conformed to *L. richardsoni*, on the basis of both morphology and genetics (mitochondrial DNA). However, there were some notable exceptions:

- The Kern brook lamprey was confirmed to be a distinct species, with a possible additional population in Paynes Creek, Tehama County (see the Kern brook lamprey account in this report for further information).
- A very distinctive population (based on mitochondrial DNA) was found isolated in Kelsey Creek, Lake County, a tributary to Clear Lake. Further investigation is needed to determine if this is another endemic species in the Clear Lake watershed.
- The population in Mark West Creek, a tributary to the lower Russian River, was found to be genetically distinct, perhaps indicating a distinct lineage in the Russian River.

The western brook lamprey is very similar to the river lamprey, based on mitochondrial DNA analysis (Docker et al. 1999). The nonpredatory brook lampreys in many coastal streams are, therefore, potentially derived from river lamprey through a series of independent evolutionary events, found in other “pair species” of lampreys as well (Docker 2009). Brook lamprey adults are not known to migrate although, in British Columbia, some streams contain both predatory and nonpredatory adults, with the predatory form able to migrate to salt water (Beamish 1987, Beamish et al. 2001). River and brook lampreys hybridize in the laboratory but hybridization in the wild has not been observed (Beamish and Neville 1992). Docker (2009) suggested that the distinctness of members of species pairs of lampreys depends on how recently the non-predatory form developed. Long isolation leads to speciation, as in the Kern brook lamprey. It is clear that further research on the systematics of the brook lamprey is required; however, mounting evidence indicates that California populations are distinct.

Life History: Most published studies relating to western brook lampreys were done outside of California (Schultz 1930, McIntyre 1969, Kostow 2002, Gunckel et al. 2009), with the exception of a study by Hubbs (1925). It is assumed, however, that differences in biology between California populations and those elsewhere are minor, based on unpublished observations (cited below).

Spawning adult brook lamprey build nests in gravel riffles that are slightly smaller in diameter than their body lengths. In Mark West Creek, during April, 1994, they were observed building nests 15-20 cm wide in gravel riffles at a depth of about 15 cm (M. Fawcett, pers. comm. 1998). In the Smith River, Oregon, most nests are about 12 cm (length) by 11 cm (width) by 3 cm (depth) and are located in low velocity (ca. 0.2 m/sec) water averaging 13 cm depth (Gunckel et al. 2006, 2009). Median gravel size in nests is 24 mm and most nests are associated with cover (boulder, wood, vegetation). Sixty-eight percent of nests in the Oregon study were found in either pool tail-outs or low gradient (<2% slope) riffles. Spawning begins when water temperatures exceed 10°C (Schultz 1930, Kostow 2002). However, in Cedar Creek, Washington, spawning occurred at temperatures ranging from 8.6 to 17.4°C (Stone et al. 2002). In California's North Fork Navarro River, spawning begins in early March, peaks between mid-April and mid-May, and may continue through the first week of June (S. Harris, pers. comm. 2011). In Outlet Creek (Eel River watershed), spawning begins slightly later (mid-March), peaks in late-April to late-May, and continues through mid-June (S. Harris, pers. comm. 2011).

Spawning behavior is similar to that of Pacific lamprey (Schultz 1930, Morrow 1980). In Cedar Creek, 3 to 12 lampreys were observed working together to move large rocks out of the nest prior to spawning (Stone et al. 2002). Upon completion of the nest, adhesive eggs are deposited and covered with sand and gravel (summarized in Kostow 2002). Adults die after spawning. Length of the spawning season varies from 6 months in Washington (Schultz 1930), where flow conditions are more constant, to 2 months (March-April) in Coyote Creek (Alameda County) (Hubbs 1925). Fecundity ranges from 1,100 to 5,500 eggs per female (Wydoski and Whitney 1979, Kostow 2002). Eggs hatch in about 30 days at 10°C, 17 days at 14°C, 12 days at 18°C and 9 days at 22°C (Meeuwig et al. 2005). Speckled dace (*Rhinichthys osculus*) and salmonids (*Oncorhynchus* spp.) have been observed to feed on eggs in and around lamprey nests (Brumo 2006).

After hatching, embryos and larvae (ammocoetes) may spend another week to a month in the nest (summarized in Kostow 2002). Once they reach about 10 mm, ammocoetes leave the nest and move downstream, usually at night, to burrow tail first into deposits of fine sediment; their mouths are located near the substrate surface so that they can filter feed. Movement of ammocoetes occurs year-round, mostly at night (Kostow 2002), but is primarily associated with increases in discharge (Stone et al. 2002). Ammocoetes move further downstream into deeper water as they grow (Kostow 2002). Ammocoetes are most common in sandy and silty areas of backwaters and pools, occurring in aggregations as dense as 170 per square meter (Schultz 1930). However, densities in two sites of the South Fork Walla Walla River, Washington and Oregon, were 5 and 37 individuals per square meter, respectively (Close et al. 1999). Western brook lampreys live as ammocoetes for 3-4 years in California and Oregon, and 4-6 years in British Columbia (Hubbs 1925, Schultz 1930, Pletcher 1963, Wydoski and Whitney 1979). California populations grow the fastest and largest (13-18 cm) by feeding on algae (especially diatoms) and organic matter (Wydoski and Whitney 1979). Ammocoetes begin transforming in the fall and mature by spring. Individuals develop eyes and an oral disc and undergo physiological changes in the gills and nasopineal gland (Kostow 2002). They become dormant in burrows during the transformation stage and do not feed as adults.

Where western brook and Pacific lamprey co-occur, there can be some degree of overlap in spawning habitat; in some cases western brook lamprey will spawn within Pacific lamprey nests (Stone et al. 2002, Luzier and Silver 2005, Brumo 2006, Gunckel et al. 2006, 2009). However, western brook lamprey generally spawn further upstream in smaller tributaries than Pacific lamprey. The bile acid, petromyzonol sulfate, may be used as a chemical cue between conspecifics (Yun et al. 2003), perhaps influencing in-river distribution.

Habitat Requirements: Western brook lampreys have habitat requirements similar to those of salmonid species, with which they co-occur. They need clear, cold, water in little disturbed watersheds, as well as clean gravel near cover (boulders, riparian vegetation, logs, etc.) for spawning. Additional habitat requirements include areas with low flow velocities and fine sediments for rearing that are not excessively scoured under high flows. Habitat utilization surveys of spawning western brook lamprey in Cedar Creek, Washington, found that adults avoided areas with deep, fast water and large substrates, suggesting specific habitat needs for spawning (Luzier and Silver 2005). Lamprey presence was positively correlated with temperature, percent fine substrate and dissolved oxygen and negatively correlated with stream gradient, velocity, percent bedrock and percent large gravel (Stone et al. 2002). In the Tualatin River basin, Oregon, western brook lampreys were most commonly found in shady glides or riffles with relatively fine substrates (soil or rock), in stream reaches without obvious signs of habitat degradation (Leader 2001). Optimum temperatures for embryo and larval development are 10-18°C (Meeuwig et al. 2005).

Distribution: Western brook lampreys occur in coastal streams from southeastern Alaska south to California and inland in the Columbia and Sacramento-San Joaquin River drainages (Vladykov 1973, Morrow 1980). California populations are primarily found in the Sacramento River watershed, including remote areas such as Kelsey Creek, upstream of Clear Lake (Lake County), and St. Helena Creek (Lake County), a tributary to upper Putah Creek. They are also found upstream of Pillsbury, Morris and Centennial reservoirs in the Eel River drainage (Mendocino County) (Brown and Moyle 1996, S. Harris, pers. comm. 2011) and in tributaries to the Russian River, such as Mark West Creek (Sonoma County) (M. Fawcett, pers. comm. 1998) and Austin Creek (J. Katz, pers. obs. 2009). Spawning adults have been collected from the Navarro River, Mendocino County (J.B. Feliciano, pers. comm. 1999). Ammocoetes were once collected from the Los Angeles River (Culver and Hubbs 1917) but they have been extirpated from this highly degraded system (Swift et al. 1993, Swift and Howard 2009). Hubbs (1925) also collected ammocoetes from Coyote Creek, Santa Clara County. They likely occur in other coastal rivers systems as well (Moyle 2002). Boguski et al. (2012) note that isolated populations they examined (e.g. from Kelsey Creek) are often genetically distinct and may deserve recognition as separate taxa.

Trends in Abundance: Western brook lampreys are probably more common than survey data indicate because they are difficult to observe and to distinguish from other species (Kostow 2002, Moyle 2002). In Oregon, they are assumed to occur in less than half of their historic habitats in the Columbia River and Willamette River subbasins (ODFW 2006). Consequently, they are considered to be "at risk" due to habitat loss, passage barriers and pollution. However, they are still common in other parts of Oregon such as the Smith River (tributary to the Umpqua River), where an estimated 4,692 (2004) and 4,265 (2005) western brook lamprey nests were observed (Gunckel et al. 2006). Abundance data for California populations are not available and there are no records of spawning numbers such as those observed in Oregon.

Nature and Degree of Threats: Little is known about the factors limiting abundance or distribution of western brook lamprey in California. Threats to western brook lamprey in Oregon include pollution, logging, degraded water quality, changes to natural hydrographs (including rapid reduction in flows, scouring), dredging and development in floodplains and low gradient stream reaches (Kostow 2002). It is likely that some, if not all, of these stressors also affect populations in California streams. In particular, brook lamprey populations are exceptionally vulnerable to single transitory events (pollution, dewatering) that can kill relatively immobile ammocoetes. Local extinctions caused by such events are likely to go unnoticed.

Major dams. Many streams occupied by western brook lampreys are dammed and/or diverted to some extent; small diversions are more prevalent than large dams in most portions of their range. Major dams on coastal and Central Valley rivers have likely fragmented habitats and isolated populations in upstream areas, as has been documented elsewhere (Close et al. 1999). Where altered flow regimes below dams have changed habitats (e.g. reduced backwaters, increased summer temperatures) brook lamprey are generally absent.

Agriculture. Western brook lamprey tend to occur in low gradient reaches of California streams that are impaired, to varying degrees, by local agriculture, both legal and illegal (e.g., marijuana cultivation). Such streams may be less suitable for all lamprey life stages as the result of diversions, pollution and poor water quality from agricultural return waters. For example, the rapid expansion of vineyards in coastal watersheds has likely reduced habitat quality and quantity for lampreys in many areas.

Grazing. Livestock grazing in headwater streams favored by brook lampreys alters channel morphology (stream bank degradation, widening and shallowing of stream channels), increases sedimentation (potentially degrading spawning habitats but also potentially increasing abundance of fine sediment deposition areas utilized by ammocoetes), reduces riparian vegetation (stream shading and water temperature moderation) and may cause localized impacts due to pollution input from animal wastes.

	Rating	Explanation
Major dams	Medium	Dams block passage, alter natural flow regimes and sediment budgets
Agriculture	Medium	Many populations affected by polluted water and reductions in flows from diversions
Grazing	Medium	Grazing occurs throughout species' range
Rural residential	Medium	Rural development increasing within species' range; may cause localized pollution and habitat degradation in many areas
Urbanization	Medium	Lampreys are absent from heavily urbanized areas
Instream mining	Low	Dredging formerly impacted many areas occupied by lampreys; dredging currently prohibited in CA
Mining	Low	Legacy toxic effects of mine drainage may still affect populations; may be particularly acute to ammocoetes, due to filter feeding in substrates where mercury accumulates
Transportation	Medium	Roads (particularly unsurfaced roads in headwater areas) can increase sediment delivery and fragment and degrade habitats
Logging	Medium	Most streams in species' range are affected by logging and logging roads
Fire	Medium	Forest fire frequency and intensity are increasing in species' range
Estuary alteration	n/a	
Recreation	n/a	Recreational impacts to lamprey populations are unknown
Harvest	n/a	
Hatcheries	n/a	
Alien species	Medium	Unknown impacts but co-occurrence likely throughout much of range

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of western brook 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 "medium" 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.

Rural residential. Rural communities are common throughout the species' range and rural development in many areas is increasing rapidly. Development (e.g., road building, building site preparation, water and power delivery), along with pollution from septic tanks and household wastes, can degrade aquatic habitats and water quality.

Urbanization . Urban development along streams (e.g., Mark West Creek in Santa Rosa) decreases the abundance of rearing habitats, while pollutants can kill adults and ammocoetes. Channelization simplifies stream morphology and often eliminates edge habitats needed by ammocoetes. Lampreys are usually absent from urban streams, such as the Los Angeles River and Coyote Creek, in which they were historically present, indicating that urban development adjacent to streams has a significant impact on their persistence.

Mining. Eggs, embryos and ammocoetes may have been negatively affected by suction dredging in the past; however, there is currently a moratorium on suction dredging in California. Nonetheless, dredging is still considered an important threat in Oregon (Kostow 2002) and could become so again in California if the moratorium is lifted. Legacy effects from widespread historic hard-rock mining (e.g., for mercury) may have eliminated or reduced populations in many areas. Toxins (e.g., heavy metals) from mostly historic mining operations may still persist in stream substrates, causing direct and prolonged exposure to ammocoetes with unknown effects on this life history stage. Instream gravel mining operations may contribute to removal of important spawning habitats or disruption of habitat utilization by all life stages.

Transportation. Culverts can create barriers and limit longitudinal movements within streams, especially for fishes with limited burst-speed swimming or jumping capabilities (e.g., lampreys). Roads along streams, especially unsurfaced roads in headwater areas (logging, recreational or other unimproved roads), often contribute to increased fine sediment or pollutant delivery to streams. Higher sediment loads are associated with degradation of spawning gravels and may contribute to excessive deposition in backwater or edgewater areas required for ammocoete rearing.

Logging. Timber harvest has been widespread and historically intensive throughout the range of western brook lamprey in California. Many areas have been logged multiple times, with resultant changes in forest vegetation composition, alteration to streams (e.g., geomorphology, annual hydrograph) and degradation of aquatic habitats (e.g., increased siltation, lack of canopy cover for shading and stream temperature moderation). Logging can reduce lamprey numbers after timber harvest occurs due to stream alteration (Moring and Lantz 1975), while extensive road networks created to facilitate logging continue to contribute sediments and increased surface run-off into streams.

Fire. Under predicted climate change scenarios, wildfires are expected to become more frequent and intense in many portions of the western brook lamprey's range, potentially leading to more extensive forest and aquatic habitat damage and longer recovery periods for these habitats. Fires can result in landslides that smother spawning gravels and removal of vegetation from riparian areas. Fire retardant reaching streams may cause localized areas of low dissolved oxygen, to which western brook lampreys are sensitive (Stone et al. 2002).

Alien species. Alien fishes (e.g., smallmouth bass) feed on ammocoetes and adults but the extent of impacts on lampreys from alien species predation and/or competition is not known. Alien fishes, however, are widespread throughout the western brook lamprey's range, so the potential for negative interactions is considerable.

Effects of Climate Change: The most noticeable and widespread impacts from climate change on lamprey habitats in California will be continued increases in water temperatures and changes to the frequency and timing of drought and flooding events. Water temperature increases may reduce the individual fitness of brook lampreys by decreasing growth, decreasing reproductive potential and increasing susceptibility to disease. The early life history stages (embryo to larva) are particularly sensitive to temperature increases. Both survival to hatch (~60%) and to the larval stage (~50%) significantly decreased at 22°C as compared to all other temperatures (10, 14 and 18°C; Bayer et al. 2001, Meeuwig et al. 2005). Survival to hatch and larva was about 90% from 10-18°C. Furthermore, physical deformities (e.g. deformed egg or yolk, fragmented yolk, bent or deformed prolarvae) occurred at all temperatures (<7%, Bayer et al. 2001) but was significantly higher at 22°C (~35%, Meeuwig et al. 2005). In general, most western brook lamprey populations are found in streams where temperatures are not likely to exceed 18°C during incubation or early rearing during spring months.

Elevated air temperatures associated with climate change will change the periodicity and magnitude of peak and base flows in streams, due to a reduction in snow pack levels and seasonal retention, particularly in watersheds at low elevations (< 3000 m) (Hayhoe et al. 2004). Predictions are that stream flow will increase in the winter and early spring and decrease in the fall and summer (Knox and Scheuring 1991, Field et al. 1999, CDWR 2006), perhaps changing the spawning ecology of fishes. If increased winter and spring flows make floodplain habitats accessible, western brook lamprey ammocoetes may benefit by rearing in highly productive habitats. Ammocoetes, however, can become stranded when flow decreases too quickly (Kostow 2002). If adults and ammocoetes spawn and rear in main channels, increased winter and spring flows may shift stream sediments to the detriment of nests and eggs. Because of their early life history stages' particular sensitivity to increased water temperatures, as well as their general immobility, Moyle et al. (2013) rated the species "highly vulnerable" to extinction within the next 100 years due to the added effects of climate change.

Status Determination Score = 3.0 - Moderate Concern (see Methods section Table 2). NatureServe lists western brook lamprey as globally secure (G4) but vulnerable in California (S3). In Oregon, they are considered a species "at risk." In 2003, a petition to list western brook lamprey in the Pacific Northwest and California under the Federal Endangered Species Act was received by the U.S. Fish and Wildlife Service (USFWS) (Nawa 2003). The petition cited habitat degradation and loss as major threats to the species. The USFWS determined the petition did not warrant further review based on insufficient scientific or commercial information (50 CFR Part 17). The high concern status in this report is driven by multiple interacting factors that have degraded many of the streams brook lampreys inhabit, combined with lack of information about their actual distribution or relative abundance within California (Table 2).

Metric	Score	Justification
Area occupied	5	Most historic watersheds are apparently still occupied
Estimated adult abundance	2	No population size information is available for California, but populations are assumed to be small
Intervention dependence	4	Persistence requires habitat improvements and stream protection
Tolerance	3	Moderately tolerant of warm temperatures; intolerant of low dissolved oxygen, pollution, low flows and disturbances to stream sediments
Genetic risk	2	Isolation and apparent small size of most populations increases vulnerability to genetic risks
Climate change	2	Populations are vulnerable to changes in natural flow regimes and increased temperatures
Anthropogenic threats	3	Multiple interacting threats exist (Table 1)
Average	3.0	21/7
Certainty (1-4)	2	Poorly known in California; better data available on populations in other states

Table 2. Metrics for determining the status of western brook 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: One of the greatest challenges to management of western brook lamprey is the lack of basic information on its status and biology in California; data are needed on distribution, abundance, genetics, environmental tolerances and population structure. In particular, research is needed to determine the status of isolated, distinctive populations such as those in Kelsey Creek and the Russian River; such forms may merit further taxonomic recognition (Moyle 2002, Boguski et al. 2102). Baseline surveys are needed to establish the relative abundance of this species within its range. Monitoring surveys (every 5 years) should be implemented in order to determine trends in distribution and abundance. Studies are also needed to establish the environmental tolerances of brook lampreys in California, especially to factors affected by land use and climate change, including temperature, turbidity, sedimentation, flows and water velocity.

Streams known to support brook lamprey populations, as well as those with the potential to do so, should be managed in ways that favor native fishes in general, including maintaining cool temperatures, spawning riffles and complex habitat structure using active management of water and land use practices or restoration actions, where necessary. For example, management of flow releases from hydroelectric projects should take into account the habitat requirements of native aquatic fauna, including western brook lamprey. Dam releases, in general, should mimic natural flow regimes in scale and periodicity. Grazing and logging activities should be buffered from riparian areas to protect riparian vegetation, limit nonpoint source pollution and minimize stream bank destabilization and excessive fine sediment inputs.

Figure 1. Assumed distribution of western brook lamprey, *Lampetra richardsoni*, in California. Actual distribution is largely unknown and distribution shown may include undescribed taxa.