Volume III, Chapter 3
Pacific Lamprey

TABLE OF CONTENTS

3.0 Pacific Lamprey (*Lampetra tridentata*)

The anadromous and parasitic Pacific lamprey (*Lampetra tridentata*) is a native inhabitant of the Pacific Northwest. Pacific lampreys, largest of the native lampreys, are an important part of the Columbia basin in a cultural, utilitarian and ecological sense. Native Americans harvested Pacific lamprey at numerous natural barriers throughout the Columbia basin for subsistence, ceremonial and medicinal purposes.

When European settlers arrived they began harvesting Pacific lamprey in great numbers at select locations such as Willamette Falls, where 7 tons of lamprey were harvested in 1913 (Close et al. 1995). In the mid-1900s, lamprey became commercially important with harvest at Willamette Falls approaching 200 tons in 1946 (Ward 2001). Lampreys were used for vitamin oil, protein food for livestock, poultry, fish bait and fish meal (Mattson 1949). Recent year harvest at Willamette Falls is primarily for tribal treaty, collection for anticoagulants, subsistence use, bait for sturgeon fishing, and teaching specimens (Close et al. 1995).

Two other species of lamprey, the river lamprey (*L. ayresii*) and western brook lamprey (*L. richardsonii*) coexisted with Pacific lamprey in the Columbia River basin (Kan 1975). Western brook lampreys have been observed on Oregon and Washington stream (Jackson et al. 1997). However, distinction of ammocoetes of these three species is difficult. Little is know about the river lamprey.

Pacific lampreys are ecologically important to the Pacific Northwest. As an anadromous species that dies after spawning, lampreys provide an important vessel for carrying marine-derived nutrients to the freshwater environment. Numerous marine species use lamprey as an important food item. Near the mouth of Klamath River, it was estimated that 82% of sea lion feeding observations were of Pacific lamprey (Jameson and Kenyon 1977). In fresh water, at least 7 aquatic and five avian species prey on lamprey.

Understanding of Pacific lamprey population status in the lower Columbia is hindered by lack of data. Very little research has focused on Pacific lamprey distribution, abundance, productivity, migration survival, and habitat association. However, limited available data suggest that Pacific lamprey populations in the Columbia basin have been declining since the construction of the hydroelectric network of dams on the mainstem Columbia River. Adult lamprey counts at each of the mainstem dams are markedly lower than counts during the mid-1900s, and growing evidence indicates that Pacific lamprey have great difficulty surviving downstream passage at dams and migrating upstream past dams (Close 2000).

3.1 Distribution

The parasitic Pacific lamprey is found primarily along the Pacific coast and near coastal islands. Its range in North America extends from Unalaska Island (Aleutians) to Baja California. From the Aleutians, the range of Pacific lamprey extends to the eastern Asian coast and as far south as the Uuhutu River, Japan (Scott and Crossman 1973). Pacific lamprey are common within the Columbia basin, and extend inland to Chief Joseph and Hells Canyon dams (Close et al. 1995), and their historicaldistribution is considered to be similar to that of Pacific salmonids (Close et al. 1995). Although populations currently exist in the Snake and Clearwater River drainages, Clair (2003) reported that Pacific lamprey may be nearing extinction in the Snake River basin.

The Pacific lampreys are anadromous and thus utilize both freshwater and marine environments. In fresh water, lampreys use small to mid-sized streams for spawning. Juvenile lampreys use these environments for rearing for up to 7 years before migrating to the ocean. Little is known of distribution of Pacific lamprey once they reach the ocean, but it is believed that they move off-shore quickly, and have been caught in high seas sampling (Kostow 2002).

There are some accounts of landlocked Pacific lamprey. Hubbs and Miller (1948) describe populations of landlocked Pacific lamprey in Oregon and California. Other landlocked populations include Cultus Lake (Vladykov and Kott 1979), and in Cowichan Lake (Hart 1973). In landlocked populations, it is reported that Pacific lamprey mature to the parasitic life stage and prey upon resident fish populations (Zanadrea 1961; Scott and Crossman 1973; McPhail and Lindsey 1970; Hart 1973).

3.2 Life History Characteristics

3.2.1 Freshwater Existence

The timing of the return of anadromous Pacific lamprey from the ocean to spawning grounds seems to be prolonged, but is poorly understood. Beamish (1970) reported that Pacific lamprey return to fresh water from May to September. In the lower Columbia River, Kan (1975) reported that returning adults have been seen as early as February. At Willamette Falls, peak numbers passing the falls occurred in May and June (Kostow 2002). In contrast, Scott and Crossman (1973) suggest that spawning migration from the ocean begins in July to September. Adult lampreys enter Cedar Creek in the Lewis River basin in southwest Washington between June and November (Stone et al. 2001; 2002).

Also in Cedar Creek, researchers found that movement of adults past traps occurred in two pulses, one in the late-spring/early summer and another in late summer/early fall (Stone et al. 2002). It is unclear whether lampreys from these two movements left the ocean at similar times, or if a portion of the fish held lower in the basin prior to moving past the traps in the fall. Starke and Dalen (1995) analyzed data from the Columbia River and determined that there are two Pacific lamprey runs past Bonneville Dam, with one occurring in late May to early June, and another in late July to early August. Stone et al. (2002) found that this movement pattern may be related to flow, but Starke and Dalen (1995) suggested that these movements indicate the existence of multiple sub-runs of lamprey. Feeding ceases during upstream migrations (Scott and Crossman 1973). Lampreys move into their spawning tributaries where they over-winter prior to spawning in the spring (Beamish 1980; Kostow 2002; Stone et al. 2001, 2002). During this time, they are dormant and hide within the substrate (Scott and Crossman 1973).

The length of lamprey upon return to fresh water depends on the length of time spent in the marine environment. Beamish (1970) reported that returning adults commonly range from 5 to over 28 in (13-72 cm). These measurements were taken at spawning, and likely underestimate lengths upon leaving the ocean. In Cedar Creek in the Lewis basin, the mean length of adult lamprey was 21 in (53 cm) with a range of 19 to 24 in (48 to 61 cm) in 2001 (Stone et al. 2002). The previous year, lengths were similar with a mean of 22 in (55 cm) and a range of 18-24 in (46-61 cm) (Stone et al. 2001).

Homing abilities and mechanisms of Pacific lamprey are not well understood. Sea lamprey (*Petromyzon marinus*) do not home to natal streams as salmon do (Bergstedt and Seelye 1995), but home based on response to pheromones released by larval lamprey (Bjerselius et al. 2000). Specific references regarding homing in Pacific lamprey are conflicting. Hardisty and Potter (1973) found no conclusive evidence that Pacific lamprey home to natal streams. Beamish (1980) reported, based upon lengths of Pacific lamprey returning to streams, that at least some adults return to native streams. These latter studies only comment on homing to natal streams, and do not consider the potential for homing similar to that of sea lamprey.

Spawning of Pacific lampreys occurs in the spring when temperatures approach 43°F (8.5°C) (Pletcher 1963; Carl et al. 1977; Lee et al. 1981; Kostow 2002). In the Willamette and on the Oregon Coast, spawning takes place primarily between February and May (Kostow 2002). In Cedar Creek, spawning of lampreys in both 2000 and 2001 occurred primarily from April through late June/early July. Average daily temperatures during this period in 2001 ranged from 45 to 61°F (7 to 16°C) (Stone et al. 2001; Stone et al. 2002). In British Columbia populations spawning may begin in April, and extend until late July (Beamish 1980).

Pacific lampreys spawn in low gradient streams in sandy gravel at the head of riffles and in pool tailouts (Kan 1975; Carl et al. 1977; Scott and Crossman 1973; Stone et al. 2002). Some authors have noted Pacific lamprey spawning in lentic environments. In Babine Lake, British Columbia researchers noted the presence of 14 lamprey redds and spawning lamprey pairs in shoreline environments (Russell et al. 1987). Redds are constructed by either moving rocks with body motions, or by grasping individual gravels and cobbles with their grasping mouthparts (Scott and Crossman 1973; *US v Oregon* 1997). Redds are 16-24 in (40-60 cm) in diameter, and are located in water depths less than 3 ft (1m) (Pletcher 1963; Kan 1975; Russell et al. 1987). Pacific lampreys are highly fecund, with females possessing up to 34,000 eggs. Most evidence indicates that lamprey die within 2 weeks of spawning (Moffet and Smith 1950; Scott and Crossman 1973; Beamish 1980). However, Michael (1980) reported evidence of seaward migration of adult lamprey after spawning, and repeat spawning on the Olympic Peninsula. Similar observations have been made by ODFW personnel for Oregon waters (Kostow 2002).

Egg incubation is influenced by temperature, and may last 10 to 14 days (Kostow 2002). After hatching but prior to the stage at which they begin to metamorphose into adults Pacific lamprey are known as ammocoetes. After hatching, ammocoetes burrow into sand/silt substrate downstream of their nests (Scott and Crossman 1973). Ammocoetes will spend approximately 6 years rearing in fresh water, during which time they remain burrowed in fine substrates filter feeding on algae (Kostow 2002). Although relatively little is known about Pacific lamprey rearing habitat requirements, Claire (2003) reported that ammocoetes density was not significantly correlated with water depth and coarse substrates but did increase with fine substrates and canopy cover (shading) of the stream reaches studies in Idaho. Ammocoete density also decreased with increasing water column velocity in this study.

Prior to the adult life stage, Pacific lamprey are not parasitic and do not have parasitic mouthparts. Ammocoetes possess an oral hood and their eyes are undeveloped. At hatching, ammocoetes are minute and grow to about 0.4 in (1 cm) in their first year (Scott and Crossman 1973). Survival and growth at early life stages are related to temperature. In laboratory experiments, survival decreased at temperatures of 72°F (22°C) compared to 50°F (10°C), 57°F (14°C), and 64°F (18°C) (Meeuwig et al. 2002). Juvenile Pacific lamprey were found in Idaho at stream temperatures up to 79°F (26^{o}C), however, interstitial space and substrate temperatures were generally 2 degrees cooler (Claire 2003). As ammocoetes grow, they move gradually downstream (primarily at night; Claire, 2003) and continue to burrow and feed in fine substrates (Kostow 2002). Older ammocoetes generally occupy the lower portions of river basins and flood plains.

As metamorphosis approaches, ammocoetes are typically 4.8 to 12 in (12 to 30 cm) in length and are known as macrothalmia (the physiological equivalent of a salmon smolt). Pacific lamprey transform from ammocoetes to macrothalmia in July to October (van de Wetering 1998, Stone et al. 2001, Stone et al. 2002). At the macrothalmia stage, Pacific lampreys begin their migration to the sea and develop parasitic features characteristic of the adults. During this transformation, lampreys survive on lipid reserves and do not feed (Kostow 2002). Downstream migration of ammocoetes and macrothalmia in Idaho's Clearwater River basin occurred primarily at night from mid-March to the end of May, with a limited number of out-migrant observed during September and October (Claire 2003). These results were similar to a study of the abundance and freshwater migrations of pacific lamprey in a tributary of the Fraser River in British Columbia (Beamish and Levings 1991).

There are some discrepancies in reports of downstream migration timing. In the lower Willamette River outmigration peaked in May, though no monitoring occurred in the winter (Kostow 2002). Studies in the Umatilla have shown that outmigration peaked in the winter and early spring (Kostow 2002). In Cedar Creek in the Lewis basin, peaks in macrothalmia movement occurred in February and June/July where macrothalmia movements were typically correlated to discharge (Stone et al. 2002). There was also a downstream movement of ammocoetes in February through July (Stone et al. 2002). Peak ammocoete movements in February were temporally correlated with high flows, but peak movements in late spring were not. Fish that moved during periods of increased river discharge were significantly shorter than those that did not (Stone et al. 2002). It is unclear if the difference in size between those whose movements were correlated to discharge were smaller because of discharge influences or smaller because their movement occurred earlier in the year. In landlocked populations, macrothalmia finish their metamorphosis into a parasitic adult and spend their adult life preying on resident fishes (Scott and Crossman 1973).

3.2.2 Marine Existence

Adult marine Pacific lampreys prey on fishes and marine mammals. Accounts of marine residence time differ with estimates ranging from 12 to 20 months (Scott and Crossman 1973) and others estimating up to 40 months (Kan 1975; Beamish 1980; Richards 1980; Lee et al. 1981). Feeding at sea is accomplished by attaching to fishes. The toothed tongue penetrates scales and skin and fluids are consumed. (An illustration of the mouth of the Pacific lamprey is provided below.) Feeding is supported by the production of an anticoagulant which prevents the host's blood from coagulating (Scott and Crossman 1973).

Pacific lamprey prey include salmon, steelhead, rockfish, cod, sable fish, halibut, flounder, Pacific ocean perch, pollock, hake, and whales (Pike 1950; Pike 1951; Beamish et al. 1976; Beamish 1980). Predation rates by lamprey on specific stocks can be extremely high. Beamish et al. (1976) reported that 10% of 145 pollock from Dixon Entrance in British Columbia had lamprey wounds. Prey are weakened by lamprey predation, but many survive as evidenced by survivors with lamprey scars (Carl et al. 1977). Williams and Gilhousen (1968) examined lamprey scarring on salmon entering the Fraser River and found that 20% of pink salmon and 66% of sockeye salmon sampled had lamprey scars. They estimated that mortality due to lamprey wounds after fish moved onto the spawning grounds was 1.6-1.8%.

Figure 3-1. Mouth of parasitic Pacific lamprey.

Little is known about marine movement of Pacific lamprey. Some authors have suggested that lamprey move considerable distances, and that migration distance may be correlated to lamprey length (Pletcher 1963; Beamish 1980). Larkins (1964) recorded catches of Pacific lamprey during high seas sampling, suggesting that lamprey move considerable distances off-shore.

3.2.3 Population Demographics

There is evidence that suggests Pacific lamprey populations occur in clusters. Observations on Clear Creek in the Clackamas River basin and in Bear Creek in the Rogue River basin showed that lamprey tended to congregate in certain areas. In both Clear Creek and Bear Creek, lampreys were found in high concentrations, but when using the same sampling method the same year in adjacent tributaries relatively few lampreys were found (Kostow 2002). This spatial pattern of population distribution would increase the susceptibility of lamprey to significant losses under localized disturbances such as landslides, chemical spills, forest fires, and other natural and anthropogenic perturbations.

3.3 Status & Abundance Trends

3.3.1 Abundance

The status of lamprey populations in the lower Columbia basin is not well understood for several reasons: 1) Many observations of lampreys in fresh water are of juveniles, and it is difficult to distinguish juveniles of the various lamprey species; 2) Data on lampreys is typically only collected incidental to research on salmonids, and thus data gathered regarding lampreys is typically not analyzed or presented and 3) There are very few historical data sets for lampreys (Kostow 2002).

Counts at mainstem Columbia River dams suggests that Pacific lamprey runs in the Columbia basin have declined considerably. However, counts at dams are considered unreliable for estimating lamprey abundance. In the past, counts were only conducted during the day, and evidence suggests that primary lamprey movement is at night. Recent fish counts that employed lights at counting windows indicated that lamprey display avoidance of these lighted areas (Ocker 2001). Also, lampreys often struggle passing fish ladders and are often seen floating downstream past viewing windows. Though today these fish are considered in daily passage counts, this has not have always been the case, and some lamprey may have been double counted (Kostow 2002).

Despite these limitations, lamprey counts at dams are one of the few long term consistent data sets available. Records of lamprey passage at Bonneville Dam are available from 1938 to 1969. Monitoring was discontinued until it began again in 1997 and continues to date. Average annual lamprey passage between 1938 and 1969 was 109,000 with Bonneville Dam counts ranging from 26,000 to 380,000. Since counts were reinitiated in 1997, lamprey passage has averaged 39,000 and ranged from 19,000 to 100,000. (Figure 3-2 shows annual counts of Pacific lamprey passing Bonneville Dam.) These counts indicate that abundances of lamprey moving to the interior Columbia basin are reduced from the mid-1900s. However, in 2002, lamprey counts at Bonneville were much higher than the previous 5 years, and similar to the average for the period of 1938–69.

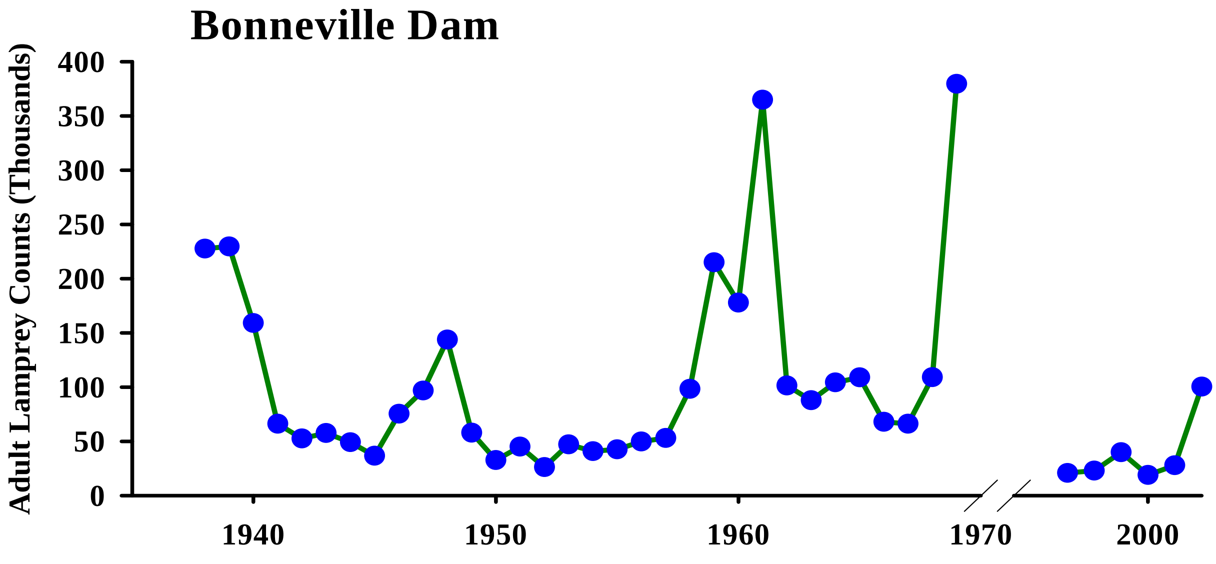

Figure 3-2. Annual counts of Pacific lamprey passing Bonneville Dam, 1938–69 and 1997–2002.

Counts at Bonneville reflect the variable nature of lamprey abundance. From 1967–69, counts expanded by 600% at Bonneville Dam, and wide fluctuations were common between 1938 and 1969. More recently, Bonneville passage increased from 19,000 in 2000 to just over 100,000 in 2002. These fluctuations suggest a cyclic survival pattern similar to salmonids, likely dependent on variable freshwater and marine environmental conditions.

Evidence from the lower Columbia River also suggests that lamprey abundances may be on the decline. Observations at Willamette Falls in the 1800s indicate that hundreds of thousands lamprey passed the falls annually (Kostow 2002). During the 1940s, nearly 400,000 pounds (18,140 kg) of lamprey were harvested in a single year. Recent year harvest opportunity at Willamette Falls has been reduced by time and area regulations compared to the 1940s and the fishing interest level has reduced. A significant reduction in recent year lamprey landings at Willamette Falls likely reflects recent year fishery restrictions, reduced fishing effort, and reduced lamprey abundance. (Figure 3-3 illustrates the Willamette Falls lamprey harvest.)

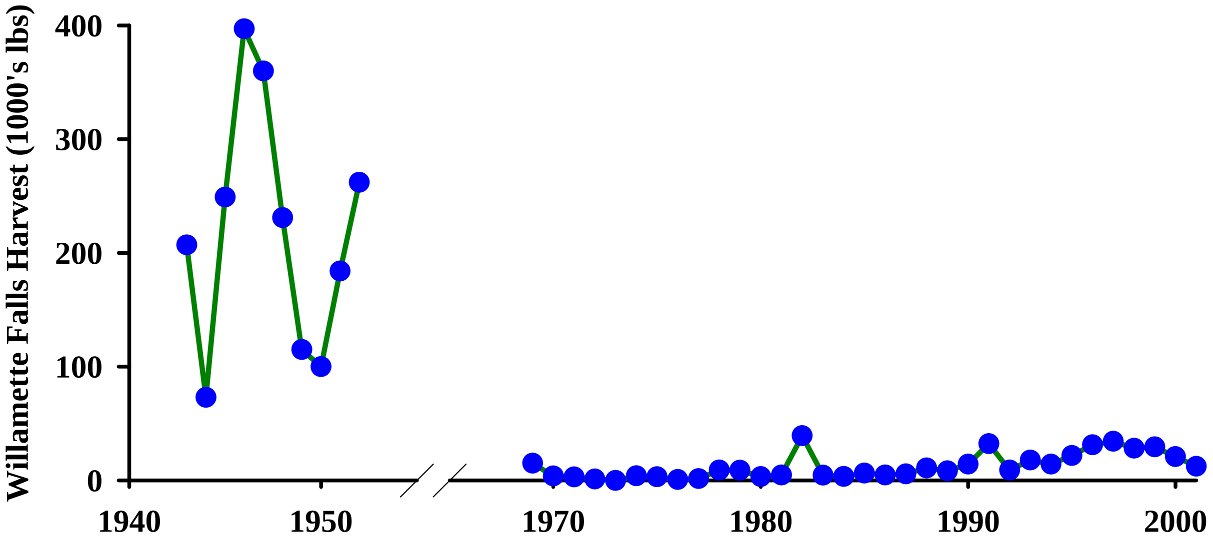

Figure 3-3. Harvest of adult Pacific lamprey at Willamette Falls, 1943–52 and 1969–2001. Data from Ward (2001).

Kostow (2002) compared Gnat Creek data from the 1950s and 1960s with recent data from Scappoose Creek and concluded a reduction in lamprey abundances. ODFW monitored an adult weir on Gnat Creek (tributary to the lower Columbia) in the 1950s and 1960s (Willis 1962). Each year, hundreds to thousands of adult lamprey were caught moving upstream and downstream past the weir along with thousands of juveniles. Willis (1962) noted additional adult lamprey moving upstream around the weir that were not being counted. Scappoose Creek is a slightly larger tributary to the lower Columbia, compared to Gnat Creek. Adult lampreys have been counted at a trap facility on Scappoose Creek since 1999, and fewer than 400 adults have passed during the 3 years of monitoring. This comparison suggests that abundance of adult lamprey in the lower Columbia may have declined since the 1960s.

Despite data indicating decreasing abundances, evidence suggests that Pacific lampreys are well distributed throughout the lower Columbia basin. In the last 2 years, WDFW personnel have observed adult lamprey in screw traps in Mill, Germany, and Abernathy Creeks in the lower Columbia River drainage (Patrick Hanratty, WDFW, personal communication). Populations successfully pass Willamette Falls, are still found in the Clackamas River, and

ODFW crews have encountered adult lamprey in various locations in the lower Columbia and Willamette River basins (Kostow 2002).

3.3.2 *Productivity*

Information regarding productivity of lower Columbia lamprey populations was unavailable.

3.4 Factors Affecting Population Status

3.4.1 *Harvest*

Historically, tribes in the Columbia basin harvested lamprey for food, ceremonial, medicinal, and trade purposes. Harvest occurred at natural barriers throughout the Columbia basin (US vs. Oregon 1997). With the addition of dams throughout the basin, and decreases in lamprey abundance, these conditions and opportunities are no longer present. Today, harvest occurs primarily at Willamette Falls and at Sherars Falls on the Deschutes River.

Since the early 1980s through 2000, harvest was allowed 7 days a week but restricted to June through August. The harvest period occurs at the tail end of the lamprey run , and its impact is inherently limited by the method and time of day of catch (*US v. Oregon* 1997). In 2001, in response to concern for the status of Willamette basin lamprey, the Oregon Fish and Wildlife Commission further reduced harvest by restricting the number of fishing days in the week and limited the season to 6 weeks (Ward 2001). Tribal subsistence opportunity also occurred within the same 6 week period. Landings of lamprey and the number of permits issued for harvest at Willamette Falls from 1980–2001 are displayed in Table 3-1.

Harvest of Pacific lamprey in the lower Columbia River basin is not regulated with the exception of Willamette Falls, and given its limited nature is not likely a major causal factor of decline for Pacific lamprey in the lower Columbia basin. At Willamette Falls, current regulations restrict harvest to certain portions of falls by hand or with hand operated tools, and only during the daytime (Kostow 2002), and in the late spring after the majority of the lamprey run has passed over the falls.

3.4.2 Supplementation

There are no Pacific lamprey supplementation programs in the lower Columbia basin.

Table 3-1. Lamprey harvest at Willamette Falls, 1980–2001 (Non-commercial landings are not known prior to 2001*) .

Year	Commercial Landings (lbs)	Value ($)	Number of permits		
			Commercial	Personal	Indian
1980	3,223	970	3	—	—
1981	4,666	2,008	2	—	—
1982	39,169	26,681	2	—	—
1983	4,482	582	4	80	70
1984	3,391	856	3	55	68
1985	6,381	2,233	3	43	54
1986	4,740	1,659	4	75	90
1987	5,633	1,100	10	28	40
1988	10,896	1,634	14	6	25
1989	8,366	2,950	7	9	27
1990	14,203	3,562	8	6	19
1991	32,221	9,017	13	13	11
1992	9,089	2,381	15	12	6
1993	17,858	4,028	12	26	9
1994	7,884[a]	2,819	4	20	21
	6,376[b]	1,734			
1995	14,097[a]	17,622	8	23	20
	7,800[b]	4,091			
1996	23,008[a]	23,008	4	13	11[c]
	8,256[b]	5,366			
1997	15,546[a]	15,870	3	22	23
	18,696[b]	13,823			
1998	14,580[a]	14,967	7	15	33
	13,638[b]	13,647			
1999	3,330[a]	3,516	7	22	7
	26,119[b]	27,598			
2000	4,314[a]	4,530	4	34	20
	16,624[b]	18,455			
2001	12,276[b]	14,608	8	16	12

* Table from Ward (2001). a = Indian landings and values, b = Non-Indian landings and values

3.4.3 Water Development

3.4.3.1 Dams

Despite evidence of sustained landlocked populations, the majority of evidence suggests that dams have significant deleterious effects on Pacific lamprey. The construction of a dam on the outlet of Elsie Lake, British Columbia caused the apparent extinction of Pacific lamprey above the dam. For 7 years after dam construction, occurrences of lamprey attacks on resident trout increased and then suddenly ceased. Since this is the estimated life span of ammocoetes, it was interpreted that the conversion from an anadromous life history to the resident form was unsuccessful (Beamish and Northcote 1989). Researchers have found that it is difficult to keep metamorphosed parasitic lamprey in fresh water (Potter 1970; Potter and Beamish 1977).

There is substantial evidence indicating that Columbia River dams have had a negative effect on Pacific lamprey populations. Hammond (1979) suggested that construction of hydroelectric dams in the Columbia system have caused a significant decrease in Pacific lamprey populations. Upstream passage efficiency of adult lamprey between 1997 and 2000 at Bonneville, The Dalles and John Day Dams have been estimated to be 38-47%, 50-82%, and 27-55% respectively (Moser et al. 2002). In the Clackamas River basin, data from several screw traps indicated that Pacific lamprey are not restricted to streams below North Fork Dam (Kostow 2002). Upstream passage efficiency is shown in Figure 3-4.

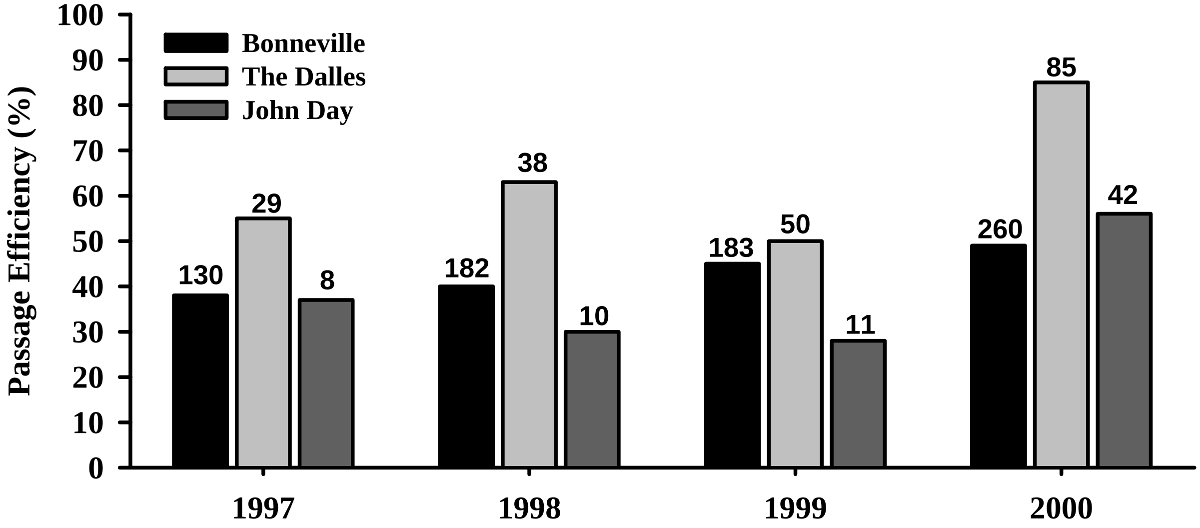

Figure 3-4. Overall passage efficiency for Bonneville, The Dalles, and John Day Dams in 1997–2000. Number of lampreys that approached the dam are shown above the bar. Graph adapted from Moser et al. 2002.

Pacific lamprey are weak swimmers, and passage at dams proves to be difficult. Areas of fish ladders that are most difficult include areas where gratings have to be crossed, where water velocity is high, and where there is lighting, as Pacific lamprey are nocturnally active and negatively phototaxic. Although Pacific lamprey were reported to have difficulty passing through hydropower facilities (Vella et al.1997), the preferred passage tactic of lamprey at hydropower dams is to grasp onto surfaces to rest, and then surge forward a short distance before resting again (Ocker et al. 2001). In areas where there is no surface to cling to (gratings), or where the water velocity is too high, passage may be impossible. Moser et al. (2002) concluded that the ability to find attachment sites is important to lamprey passage through areas of high velocities including fishways.

The lower Columbia basin may provide a critical refuge area for Pacific lamprey unable to access the interior Columbia basin due to poor passage efficiencies at mainstem hydropower projects (Kostow 2002).

Negative effects on downstream migrants have also been noted. Lamprey migrate downstream as macrothalmia and ammocoetes. They may pass under fish screens on dams (Long 1985) or may pass through bypass screens which have openings larger than the diameter of lamprey. Kostow (2002) suggested that the highest potential for mortality comes from the fish screens. Kostow (2002) states, "Anecdotal observations by biologists working on mainstem dams on the Columbia and Snake Rivers during the 1970s and 1980s indicated that juvenile lampreys impinged on the perforated plates that blocked various openings across the forebay faces of the dams and on the juvenile bypass screens in huge, but undocumented numbers." Such observations have been documented to some extent by Stark and Dalen (1995).

3.4.3.2 Other Migration Barriers

Other migration barriers may also contribute to the Pacific lamprey decline in the lower Columbia River basin. In Oregon's Alsea River basin, a presence/absence survey by van der Wetering showed that no Pacific lamprey were found above most road culverts (Kostow 2002). Other small barriers that may hinder lamprey populations include hatchery weirs, tide gates, or diversion structures (Kostow 2002).

3.4.4 Flow Alterations

As with other anadromous fish, lamprey undergo a metamorphosis as part of their migration to the sea. This metamorphosis takes place within a given physiological window. Dams in the Columbia River and its tributaries disrupt and slow river flow and alter thermal conditions. It has been observed that increased discharge initiates the downstream movement of macrothalmia (Beamish and Levings 1991; Stone et al. 2002). Lamprey are weak swimmers, and typically rely on flow to carry them towards the ocean. The reduction in velocity in reservoirs may delay migration for juvenile lamprey, and disrupt the synchrony of physiological development and downstream migration.

Dams and land use patterns have altered flow regimes to some degree in most Columbia basin tributaries. Kostow (2002) suggested that increased peak flows may mobilize cobble substrate disrupting Pacific lamprey nests. Increased flows may also flush fine sediments that have accumulated and provided habitat for ammocoetes.

3.4.5 In-Channel Habitat Conditions

3.4.5.1 Channel Maintenance & Dredging

Lamprey burrow in fine sediment river bottoms throughout their migration to the ocean (Kostow 2002). Dredging is common in the lower Willamette and Columbia Rivers, and may pose a threat to downstream migrating lamprey. Beamish and Youson (1987) discovered that they could find River lamprey by filtering through dredging spoils from the lower Fraser River. They estimated that only 3-26% of lamprey that passed through a dredge survived.

3.4.5.2 Floodplain Development

Stone et al. (2002) found that juvenile lamprey density was negatively associated with gradient and gravel substrate, and positively associated with percent fines in the substrate in Cedar Creek, Washington. This habitat preference suggests that juvenile lamprey likely favor lower basin, low gradient reaches for rearing. It is typically these portions of basins that experience the most development. With development may come flow alterations, water chemistry influences, channel morphology alterations, thermal alterations, and chemical pollution. With the lack of understanding of Pacific lamprey ecology, it is difficult to say how these alterations may influence lamprey populations. However, such changes are generally assumed to not benefit Pacific lamprey.

3.4.6 Water Quality

3.4.6.1 Temperature

Increased stream temperatures from land use practices and hydro modifications may also affect the survival of juvenile Pacific lamprey. Van de Wetering and Ewing (1999) found that lamprey mortality begins as temperatures reach 28°C, whereas Meeuwig et al. (2002) determined that survival begins to decrease as temperatures reach 22°C. Elevated temperatures may adversely affect lamprey survival through increased metabolic rates and decreased stream microbial activity (van de Wetering and Ewing 1999). However, increased temperatures increase growth rates of juvenile lamprey (Meeuwig et al. 2002), and at various times in the life cycle may benefit juvenile lamprey. In other fish species, increased size has been correlated to increased survival.

3.4.6.2 Dissolved Gas

Very little information is available regarding the effects of dissolved gases on Pacific lamprey. Stone et al. (2002) found that at the reach scale, lamprey presence was positively associated with dissolved oxygen in Cedar Creek, Washington.

3.4.6.3 Chemicals

From the late 1940s through the 1980s, the Oregon Fish Commission used rotenone in basins throughout the state to eliminate non-game species including Pacific lamprey (US vs. Oregon 1997). Kostow (2002) reported that lamprey in Oregon were easy to kill with rotenone. This practice no longer occurs today, but with up to 7 year-classes of Pacific lamprey present in fresh water at any one time, the intentional fish kills of the mid-1900s likely severely impacted Pacific lamprey populations.

Chemical spills in lower Fifteen Mile Creek and in the John Day River in Oregon killed thousands of lamprey, empirical confirmation of the susceptibility of lamprey to localized chemical accidents. Pacific lamprey juveniles likely use lower river basins including the Willamette and Columbia Rivers extensively. These habitats tend to accumulate toxins, and may potentially build up lethal concentrations in the substrate occupied by juvenile lamprey. The Environmental Protection Agency (EPA) recently detected high levels of PCBs in lamprey collected from the Columbia River (Kostow 2002).

3.4.7 Species Interactions

3.4.7.1 Competition

Little is known regarding competition between Pacific lamprey and other species. Scott and Crossman (1973) speculated that Pacific lamprey compete with other Pacific coast lamprey including River lamprey and Western Brook lamprey. However, Stone et al. (2002) showed that Pacific lamprey and Western Brook lamprey spawned in different habitats of Cedar Creek, Washington, with Pacific lamprey preferring larger substrate.

3.4.7.2 Predation

During feeding observations of Stellar sea lions near the mouth of the Klamath River, 82% were on Pacific lamprey. Two sea lions whose stomach contents were examined contained solely Pacific lamprey (Jameson and Kenyon 1977). Roffe and Mate (1984) revealed that the most abundant dietary component of sea lions and seals was Pacific lamprey. Other predators of lamprey have included sperm whale (Pike 1950), fur seals (Hubbs 1967), spiny dogfish and sablefish (Beamish 1980). Lampreys are a valuable source of nutrition for these predators. Caloric values for lamprey range from 5.92-6.34 kcal/g wet weight (Whyte et al. 1993) compared to 1.26-2.87 kcal/g for salmon (Stewart et al. 1983).

Adult Pacific lampreys have been targeted by avian and terrestrial predators as well (Roffe and Mate 1984). Beamish (1980) cites a report of a mink seen with a Pacific lamprey in its mouth.

The author of this report has witnessed the predation on juvenile lamprey by gulls at Willamette Falls. It is generally believed that predation on the juvenile lamprey life stages by salmonids is uncommon. Experiments have indicated that their low incidence in the diet of salmonids may result from secretions from the skin of the lamprey (Scott and Crossman 1973, Pletcher 1963). Juvenile rainbow trout prey on lamprey eggs and larvae. Non-salmonid freshwater piscivores include channel catfish, white sturgeon, northern pikeminnow, minnows, sculpin and logperch (Close et al. 1995). Close et al. (1995) suggested that the presence of abundant outmigrating juvenile lamprey may provide a buffer for predation by other species on juvenile salmon.

3.4.8 Ocean & Estuary Conditions

The abundance of Pacific lamprey may be positively correlated to their food base in the ocean. Recently, ocean conditions have improved as evidenced by increasing runs of salmonids in the Columbia basin as well as on the Oregon and Washington coasts. In addition, harvest of salmonids has been curtailed increasing the potential prey base in the ocean. In 2002, counts of lamprey were the highest seen in recent years at dams on the mainstem Columbia. Since lamprey feed on salmon, it would stand to reason that increases in adult lamprey populations would occur some years after increases in salmonid populations.

Increased ocean productivity and protection of marine mammals have resulted in increased populations of these species which prey on lamprey (Close et al. 1995; BioAnalysts 2000). Also, harvest on non-salmonid species in the ocean may be depleting a portion of the prey base of Pacific lamprey.

3.5 References

Beamish, R.J. 1980. Adult Biology of the River Lamprey (*Lampetra agresi*) and the Pacific Lamprey (*Lampetra tridentate*) from the Pacific Coast of Canada. Can. J. Fish. Aquat. Sci. 37: 1906-1923.

Beamish, R.J., M. Smith, R. Scarsbrook, and C. Wood. 1976. Hake and Pollock study, Strait of Georgia cruise G.B. REED, June 16-27, 1975. Fish. Mar. Serv. Data Rec. 1:174 p.

Beamish, R.J. and J.H. Youson. 1987. Life history and abundance of young adult Lampetra ayresi in the Fraser River and their possible impact on salmon and herring stocks in the Strait of Georgia. Can. J. Fish.Aquatic Sci. 44:525-537.

Beamish, R.J., and T.G. Northcote. 1989. Extinction of a population of anadromous parasitic lamprey, Lampetra tridentate, upstream of an impassable dam. Can. J. Fish. Aquat. Sci. 46: 420-425.

Beamish, R.J. and C.D. Levings. 1991. Abundance and freshwater migrations of the anadromous parasitic lamprey, *Lampetra tridentata*, in a tributary of the Fraser River, British Columbia. Can. J. Fish. Aquat. Sci. 48: 1250-1263.

Bergstedt, R.A., and J.G. Seelye. 1995. Evidence for lack of homing by sea lampreys. Trans. Am. Fish. Soc. 124: 235-239.

BioAnalysts, Inc. 2000. A Status of Pacific Lamprey in the Mid-Columbia Region. Rocky Reach Hydroelectric Project FERC Project No. 2145. Prepared for Public Utility District No. 1 of Chelan County, Wentachee, Washington.

Bjerselius R., L. Weiming, J.H. Teeter, J.G. Seelye, P.B. Johnsen, P.J. Maniak, G.C. Grant, C.N. Polkinghorne, and P.W. Sorenson. 2000. Direct behavioral evidence that unique bile acids released by larval sea Lamprey (*Petromyzon marinus*) function as a migratory pheromone. Can. J. Fish. Aquat. Sci. 57: 557-569.

Carl, G.C., W.A. Clemens, and C.C. Lindsey. 1977. The freshwater fishes of British Columbia. B.C. Prov. Mus, Handbook No. 5: 192 p.

Claire, C. W. 2003. Pacific lamprey larvae life history and habitat utilizatin in Red River subbasin, South Fork Clearwater River drainage, Idaho. Draft MS. Thesis, University of Idaho, 74 pp.

Close, D.A. 2000. Pacific lamprey research and restoration project, annual report 1998. Tribal Fisheries Program, Department of Natural Resources, Confederated Tribes of the Umatilla Indian Reservation. Prepared for Bonneville Power Administration, Project No. 94-026.

Close, D.A., M. Fitzpatrick, H.Li, B. parker, D. Hatch, and G. James. 1995. Status report of the Pacific lamprey (*Lampetra tridentate*) in the Columbia River Basin. Report (Contract 95BI39067) to Bonneville Power Administration, Portland, Oregon.

Hammond, R.J. 1979. Larval biology of the Pacific lamprey, *Entosphenus tridentatus* (Gairdner) of the Potlach River, Idaho. Masters Thesis. University of Idaho, Moscow, Idaho.

Hart. J.L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180:740 p.

Hardisty, M.W., and I.C. Potter. 1971. The general biology of adult lampreys. Pages 127-206 in M.W. Hardisty and I.C. Potter, editors. The Biology of Lampreys, vol. 1. London-New York Academic Press.

Hubbs, C.L., and R.R. Miller. 1948. The Great Basin. II. The zoological evidence. Bull. Univ. Utah 38(20): 17-144.

Hubbs, C.L. 1967. Occurrence of the Pacific lamprey, *Entosphenus tridentatus*, off Baja California and in streams of Southern California; with remarks on its nomenclature. Trans. Sand Diego Soc. Nat. Hist. 14: 301-312.

Jackson, A. D., D. R. Hatch, B. L Parker, M. S. Fitzpatrick, and H. Li. 1997. Research and Restoration Annual Report. US Department of Energy, Bonneville Power Administration 1997:91. Portland, Oregon.

Jameson, R.J., and K.W. Kenyon. 1977. Prey of sea lions in the Rogue River, Oregon. J. Mammal. 58(4): 672.

Kan, T.T. 1975. Systematics, Variation, Distribution and Biology of Lampreys of the genus Lamptera in Oregon. Dissertation for the Doctor of Philosophy, Oregon State University, Corvallis, Oregon.

Kostow, K. 2002. Oregon Lampreys: Natural history status and analysis management issues. Oregon Department of Fish and Wildlife.

Larkins, H.A. 1964. Some epipelagic fishes of the North Pacific Ocean, Bering Sea, and Gulf of Alaska. Trans. Am. Fish. Soc. 93: 286-290.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, J.R. Stauffer, Jr. 1981. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History.

Long, J.A. 1995. The Rise of Fishes. Johns Hopkins University Press. Baltimore. Pp 10-63.

Mattson, C.R. 1949. The lamprey fishery at Willamette Falls, Oregon. in Fish Commission of Oregon Research Briefs. 2(2): 23-27.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Bull. Fish. Res. Board. Can. 173. 381p.

Meeuwig, M, J. Bayer, J. Seelye, R. Reiche. 2002. Identification of Larval Pacific Lampreys (*Lampetra tridentate*), River Lampreys (*L. ayresi*), and Western Brook Lampreys (*L. richardsoni*) and Thermal Requirements of Early Life History Stages of Lampreys.

Michael, J.H. 1980. Repeat spawning of Pacific Lamprey. California Fish and Game Notes. p. 187.

Moffett, J.W., and S.H. Smith. 1950. Biological investigations of the fishery resource of Trinity River, California. US Fish and Wildlife. Serv. Spec. Sci. Rep. Fish. 12: 70p.

Moser, M.L., P.A. Ocker, L.C. Stuehrenberg, and T.C. Bjornn. 2002. Passage Efficiency of Adult Pacific Lampreys at Hydropower Dams on the Lower Columbia River, USA. Trans. Am. Fish. Soc. 131: 956-965.

Ocker, P.A., L.C. Stuehrenberg, M.L. Moser, A.L. Matter, J.J. Vella, B.P. Stanford. 2001. Monitoring Adult Pacific Lamprey (*Lampetra tridentate*) Migration Behavior in the Lower Columbia River using Radiotelemetry, 1998-1999. US Army Corps of Engineers, Portland, Oregon.

Pike, G.C. 1950. Stomach contents of whales caught off the coast of British Columbia. Fish Res. Board Can. Prog. Rep. Pac. Coast Stations 83: 27-28.

Pike, G.C. 1951. Lamprey marks on whales. J. Fish. Res. Board Can. 8(4): 275-280.

Pletcher, F.T. 1963. The life history and distribution of lampreys in the Salmon and certain other rivers in British Columbia, Canada. M.Sc. thesis, University of British Columbia, Vancouver, BC 195p.

Potter, I.C. 1970. The life cycles and ecology of Australian lampreys of the genus Mordacia. J. Zool. Lond. 161: 487-511.

Potter, I.C., and F.W.H. Beamish. 1977. The freshwater biology of adult and anadromous sea lampreys Petromyzon marinus J. Zool. Lond. 181:113-130.

Richards, J.E. 1980. Freshwater biology of the anadromous Pacific lamprey Lampetra tridentate. Master of Science, University of Guelph, Ontario, Canada. 99p.

Roffe, T.J., and B.R. Mate. 1984. Abundances and feeding habits of pinnipeds in the Rogue River, Oregon. Journal of Wildlife Management 48(4): 1262-1274.

Russell, J.E., F.W.H. Beamish, and R.J. Beamish. 1987. Lentic spawning by the Pacific lamprey, Lampetra tridentata Can. J. Fish. Aquat. Sci. 44: 476-478.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada, Ottawa.

Starke, G.M. and J.T. Dalen. 1995. Pacific Lamprey (*Lampetra tridentate*) Passage Patterns Past Bonneville Dam and Incidental Observations of Lamprey at the Portland District Columbia River Dams in 1993. US Army Corps of Engineers, Bonneville Lock and Dam, Cascade Locks, Oregon.

Stewart, D.J., D. Weininger, D.V. Rottiers and T.A. Edsall. 1983. An energetics model for lake trout, Salvelinus namaycush: application to the Lake Michigan population.

Stone, J., T. Sundlov, S. Barndt, T. Coley. US Fish and Wildlife Service. 2001. Evaluate Habiat Use and Population Dynamics of Lampreys in Cedar Creek. Annual Report 2000. Project No. 2000-014-00. Contract No. 00000014.

US v. Oregon. Technical Advisory Committee. 1997. 1996 All species review. Columbia River Fish Management.

Van de Wetering, S.J. 1998. Aspects of life history characteristics and physiological processes in smolting Pacific lamprey, *Lampetra tridentata,* in a central Oregon stream. MS thesis, Oregon State University.

Van de Wetering, S.J. and R. Ewing. 1999. Lethal temperatures for larval Pacific lamprey, *Lampetra tridentata*. Confederated Tribes of the Siletz Indians, Siletz, Oregon.

Vella, J. J., L. C. Stuehrenberg, and T. C. Bjornn. 1997. Migrsation patterns of Pacific lamprey *Lampetra tridentata* in the lower Columbia River. Annual report of Research, US Army Corps of Engineers.

Vladykov, V.D. and E. Kott. 1979. A new parasitic species of the holarctic lamprey genus *Entosphenus* Gill, 1862 (Petroyzonidae) from Klamath River in California and Oregon. Can. J. Zool 57: 808-823.

Ward, D.L. 2001. Lamprey Harvest at Willamette Falls, 2001. Oregon Department of Fish and Wildlife, Clackamas, Oregon.

Whyte, J.N.C., R.J. Beamish, N.G. Ginther and C.E. Neville. 1993. Nutrtitional condition of the Pacific lamprey (*Lampetra tridentate*) deprived of food for periods of up to two years. Can. J. Fish. Aquat. Sci. 50: 591-599.

Williams, I.V., and P. Gilhousen. 1968. Lamprey parasitism on Fraser River sockeye and pink salmon during 1967. Int. Pac. Salmon. Fish. Comm. Prog. Rep. 18:22 p.

Willis, R. 1962. Gnat Creek Weir Studies. Oregon Fish Commission, Portland, Oregon.

Zanadrea, G. 1961. Studies on European lampreys. Evolution. 15:523-534.