Pacific Lamprey Habitat Restoration Guide

METHOW SALMON RECOVERY FOUNDATION

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www.nwasco.com/FISHERIESCOMPENSATIONCOMMITTEE.cfm.

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This guide is intended for educational purposes. Please contact John Crandall at john@methowsalmon.org with any questions or comments about the guide. All restoration elements presented in the guide are for reference purposes only. Any instream or riparian restoration actions implemented should be developed with site specific information and with input from trained professionals. Guide development has relied upon the generosity of numerous photographers - please respect their copyrighted material.

Cover photo credits: Freshwaters Illustrated / US Fish & Wildlife Service Mid-Columbia River Fishery Resource Office (adult Pacific Lamprey), Michael Durham (Nez Perce Elder Elmer Crow), J. Crandall (ammocoete), Simon Wray (lamprey pasage structure).

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Pacific Lamprey are amongst the oldest living vertebrates and an integral component of aquatic food webs.

Section 1- Introduction

A Call to Action

Over the past 150 years, and coincident with European settlement, anadromous salmon populations in the Columbia River Basin have declined dramatically with several runs now extinct. The factors responsible for these declines are well documented and are related, in large part, to hydropower development, overharvest, predation by non-native fish, and urban and agricultural development. Stemming from a clear acknowledgement of the cultural, economic, and ecological importance of these fish, efforts to restore the dwindling stocks of salmon and steelhead have been initiated throughout the Columbia River Basin.

Unfortunately, not all imperiled anadromous species in the Columbia River Basin share such widespread appreciation and recognition as salmon and steelhead. A lack of public awareness and understanding of Pacific Lamprey – one of the most ancient animals on Earth - has allowed Pacific Lamprey in the Columbia River Basin to decline to only a small fraction of their historical abundance.

Yet it is has not been just a lack of understanding and appreciation that has led Pacific Lamprey to the brink of extirpation from some portions of the Columbia River Basin. The suite of factors that have caused salmon and steelhead populations to decline have also impacted Pacific Lamprey. Furthermore, due to their unique biology and ecology, Pacific Lamprey have often been adversely affected by the very steps taken to address the specific needs of salmonid populations. For example, insallation of fish ladders to allow for salmonid passage may prevent passage by lamprey. If we desire to obtain viable populations of Pacific Lamprey we must act now to conserve and restore the ecological niche of lamprey in the Columbia River Basin.

A fossilized lamprey estimated to be 300 million years old.

Purpose of the Guide

While the ecological and cultural importance of Pacific Lamprey has become increasingly acknowledged over the past decade, efforts to protect and restore lamprey have often been hampered by a lack of accessible, science-based information on natural history, ecology and restoration treatments. This guide is intended to provide habitat restoration practitioners, permitting agencies, and policy makers in the Columbia River Basin with a summary of current biological and ecological knowledge about Pacific Lamprey, creating a foundation for the use of best management practices and the implementation of informed habitat improvement projects.

Restoration efforts that consider lamprey-specific habitat requirements during project planning, design, implementation and monitoring phases will be more successful at promoting recovery of this imperiled species. Using the information in this guide, project sponsors will also be able to minimize harm to lamprey during implementation of salmonid-based habitat restoration projects. To this end, this guide will highlight best management practices and design elements of habitat restoration projects that have been implemented around the Columbia River Basin to illustrate on-the-ground actions that have been shown to benefit lamprey.

Throughout the Columbia River Basin, numerous salmonid-based restoration actions are currently underway, and more are planned for implementation. There is a valuable opportunity to incorporate lamprey-friendly project design elements into these instream and riparian habitat restoration efforts. In order for this to occur, restoration planners and practitioners must possess knowledge of lamprey ecology as well as project elements that could be incorporated into these restoration efforts to benefit lamprey.

Although several species of lamprey inhabit the Columbia River Basin, the focus of this guide will be on Pacific Lamprey restoration in tributaries to the Columbia, Snake, and Willamette Rivers. Pacific Lamprey are the most widespread lamprey species in the Columbia River Basin, and recent scientific studies, as well as historical information, have focused on this species. Nevertheless, other native species including River, Western, Brook, and Pacific Brook lamprey have similar habitat needs and are adversely affected by many of the same factors as Pacific Lamprey. Therefore much of the information provided here on habitat needs, potential threats, and possible restoration treatments should generally be applicable to other species of lamprey in the region.

Salmon habitat restoration projects, such as this installation of large wood, can also help with recovery of Pacific Lamprey.

A Valuable Cultural Resource

Native Americans of the Columbia River Basin have valued Pacific Lamprey, referred to as "eels", as a resource for cultural, spiritual, ceremonial, medicinal, and subsistence needs since time immemorial. Native cultures realize the important ecological role played by Pacific Lamprey in the streams of their homelands and honor their connections with these ancient fish to this day.

Declines in Pacific Lamprey have significantly affected native cultures and traditions. For millennia, harvest of lamprey has provided native people with a highly valued and significant subsistence food. The high caloric content and relative ease of capture makes lamprey a prized food. Although opportunities for harvest of lamprey still exist, they have decreased dramatically. As a result, younger generations are losing connection to the cultural strands that bind them to lamprey.

A dramatic reduction in harvestable lamprey, coupled with a sincere interest in their ecological health, has spurred Columbia River Basin tribes to initiate actions to restore declining lamprey populations. Members of the Columbia River Inter-Tribal Fish Commission, including Nez Perce, Umatilla, Warm Springs, and Yakama tribes have sponsored studies on the status of the species along with on-the-ground restoration actions to assist in their recovery. Tribes have partnered with federal and state resource managers to develop management plans and guidelines aimed at reducing threats and increasing funding for habitat restoration targeting Pacific Lamprey. Tribes have also intiated reintroduction efforts in some watersheds.

Drying lamprey along the banks of the Umatilla River. Lamprey have long been a valued resource for native peoples in the Pacific Northwest.

A Northwest tribal ceremonial meal with Pacific Lamprey cooking alongside salmon.

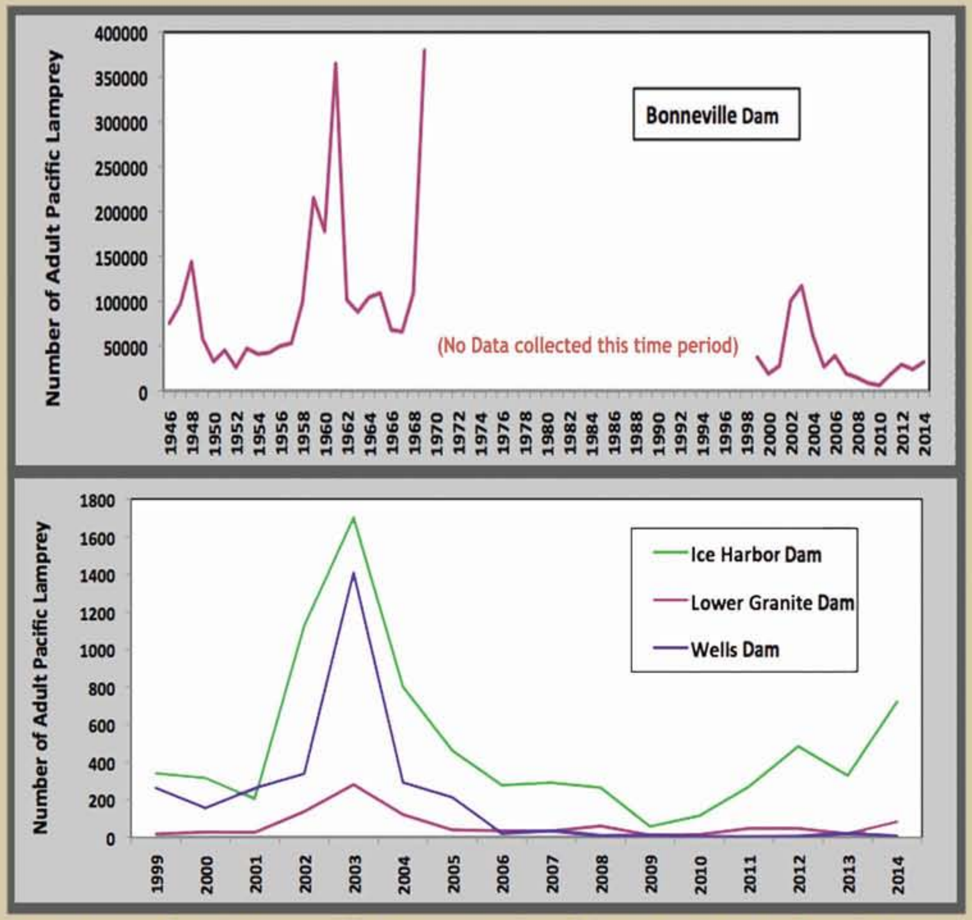
A Species in Decline

Pacific Lamprey within the Columbia River Basin, and elsewhere across their range have declined dramatically over the last century. Though scant data are available to precisely determine population abundance of Columbia River Pacific Lamprey prior to 1938, a sense of ithe magnitude can be gleaned from historical observations. Commercial harvest was significant. In the late 1800s, 100,000-500,000 adult Pacific Lamprey were harvested annually at Willamette Falls. These fish were harvested for a variety of uses including as a feed for hatchery salmon.

Early accounts for the Columbia River describe traditional lamprey harvest areas in the lower Columbia being "completely covered with the eels" - sometimes three layers deep. The first recordings of Pacific Lamprey abundance at Columbia River hydroelectric facilities began in 1938 at Bonneville Dam. Between 1938 and 1969, the annual adult Pacific Lamprey passage through Bonneville Dam ranged from 50,000-400,000 adult fish. Additional counts from the 1960s include 300,000-350,000 adults counted further upstream at the Dalles Dam, 25,000 from McNary Dam, and 17,500 at Rocky Reach Dam located 500 miles up the Columbia River. However, Pacific Lamprey often migrate at night, and these early counts were often conducted during the day, likely underestimating the actual total.

After 1969, adult lamprey counts at mainstem Columbia River dams were not reported again until the early 1990's. Dam passage counts from 1994-present reveal overall declines at all major dams on the Columbia and Snake Rivers where passage data have been collected (see page 7). More recent counts at some of the dams have included nighttime passage in an effort to increase accuracy. Up-to-date lamprey passage data can be obtained through the Fish Passage Center at http://www.fpc.org/lamprey/lamprey_home.html.

Columbia and Snake River Dam Passage



Dam passage data for Bonneville Dam was gathered from 1946-1970 and again from 1999-present. Other dams within the Columbia and Snake River Basins have only gathered data from 1999-present. While some locations have seen recent increases in abundance other locations remain severely depressed.

In 2004, the U.S. Fish and Wildlife Service launched the Pacific Lamprey Conservation Initiative to facilitate opportunities to increase our knowledge of Pacific Lamprey, address threats, and restore habitat. This collaborative effort is intended to improve the distribution and abundance of lamprey by proactively engaging in a concerted conservation effort.

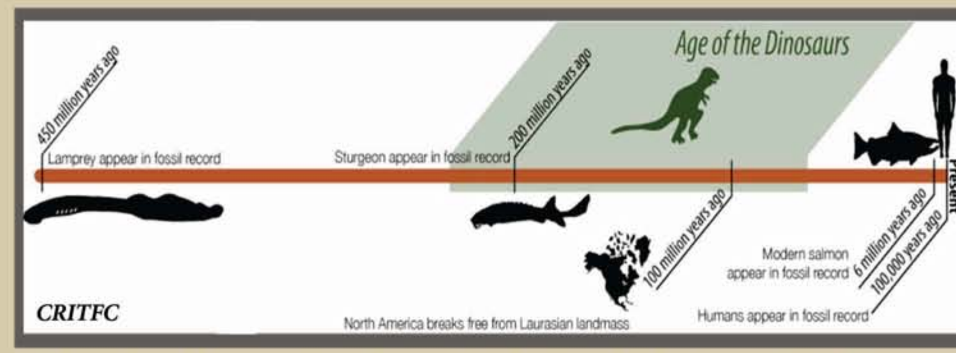
Recent efforts have also been made to sample populations of larval lamprey within tributaries of the Columbia, Willamette, and Snake Rivers. Ammocoete abundance and distribution data from these efforts parallel the declining trend demonstrated by adult passage. Monitoring within numerous rivers, including the Snake, Walla Walla, Tucannon, Grande Ronde, Deschutes, John Day, Clearwater, and Methow revealed ammocoetes to be either depressed or absent from historical habitat.

Section 2- Biology and Ecology

Lamprey Taxonomy

Lamprey are members of the ancient class of vertebrate fish Agnatha. Agnatha means "without jaws," and all lamprey lack this common fish characteristic. In place of jaws, lamprey have a toothed oral disc. Lamprey lack bones, but possess cartilaginous skeletons that provide structural support. Lamprey also lack several other characteristics commonly associated with other fishes including scales and paired fins.

Fossil evidence suggests that lamprey have existed for over 450 million years, making them among the oldest of living vertebrate group on Earth. This longevity means that lamprey preceded and survived the coming and going of the dinosaurs, and have been around much longer than modern humans which are believed to be approximately 100,000 years old.



The fossil record for ancestors of present day lamprey dates back over 450 million years.

Pacific Lamprey and Pacific Salmon - A Relationship of Balance

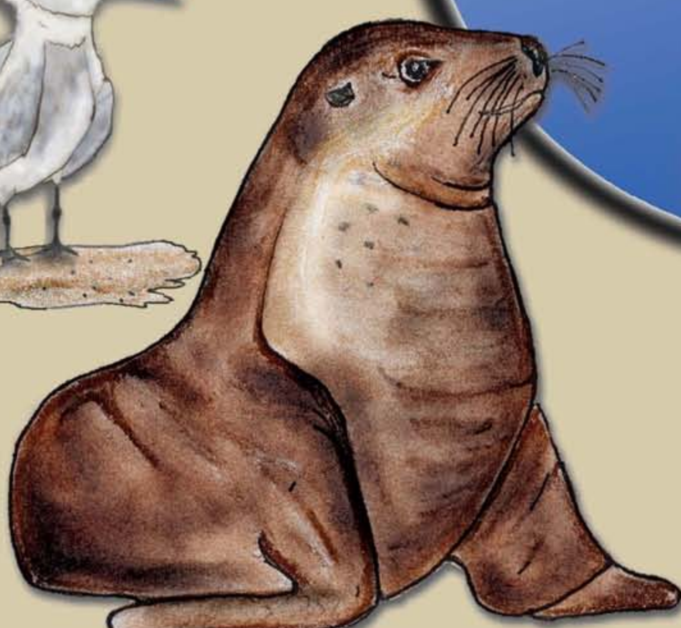
Pacific Lamprey evolved for tens of thousands of years in association with the various species of Pacific salmon. During this period, these anadromous species have developed a mutualistic relationship through transfers of energy.

For example, lamprey eggs provide a high calorie food source for young salmonids as well as other native fish species such as trout and sculpin. Ammocoetes are also a food source for young salmon. As filter feeders, ammocoetes play a vital link in the aquatic food chain, turning plankton and detritus into nutrient rich fats and proteins, and improving water quality in the process. As bioturbators, ammocoetes keep bottom sediments mixed. Adult lamprey in the ocean feed on salmon and steelhead and are a food source for numerous species of fish and marine mammals. See pages for 9-10 for more information.

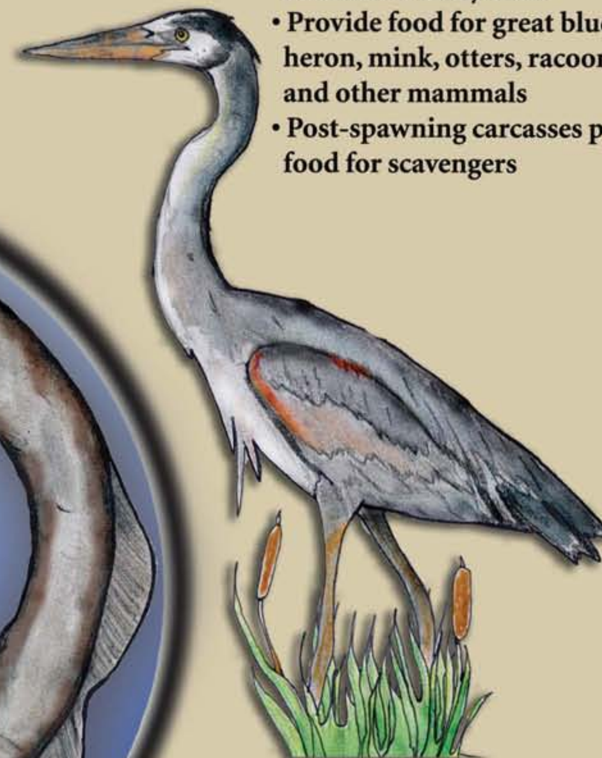
Ecological Roles of Pacific Lamprey

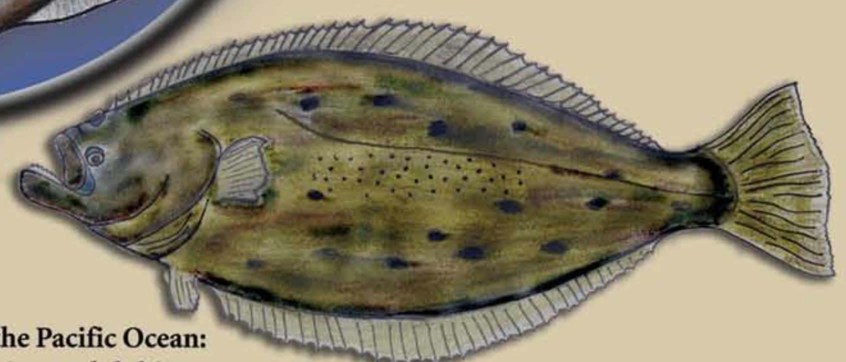
Ammocoetes in freshwater:
- Incorporate diatoms, detritus, algae, and other organic material into food web
- Food for small salmonids and other fish

Macrophthalmia during migration:
- Food for sturgeon and resident trout
- Food for terns, gulls, and other birds
- Shield for migrating salmon



Adults in freshwater:
- Bring marine nutrients to freshwater ecosystems
- Provide food for great blue heron, mink, otters, racoons, and other mammals
- Post-spawning carcasses provide food for scavengers





Adults in the Pacific Ocean:
- Food for Orcas, dolphins, porpoises, sea lions, and seals
- Food for other fish
- Parasitize hosts including salmon, halibut, pollock, herring, flounder, cod, and some aquatic mammals

A Confused Identity

For decades, Pacific Lamprey have been considered by many as a parasitic nuisance best eradicated to minimize their negative effects on salmon and other native fish populations. This misunderstanding may be due, in part, to the negative impacts of invasive sea lamprey on native fish in the Great Lakes region. Sea Lamprey were unintentionally introduced to that ecosystem through manmade canals, where they quickly feasted on native lake trout causing significant population declines. Lake trout are an important cultural and economic species in the Great Lakes and, not surprisingly, all species of lamprey were uniformly labeled as an unwanted nuisance to be eradicated.

In contrast to the situation in the Great Lakes, Pacific Lamprey in the Columbia River Basin do not feed on anything after they return to the river from the ocean and have evolved alongside other native species of fish, mammals, and birds as well as human populations for tens of thousands of years. This co-evolution has integrated Pacific Lamprey into a variety of roles within the ecological web of the Columbia River Basin (see pages 9-10).

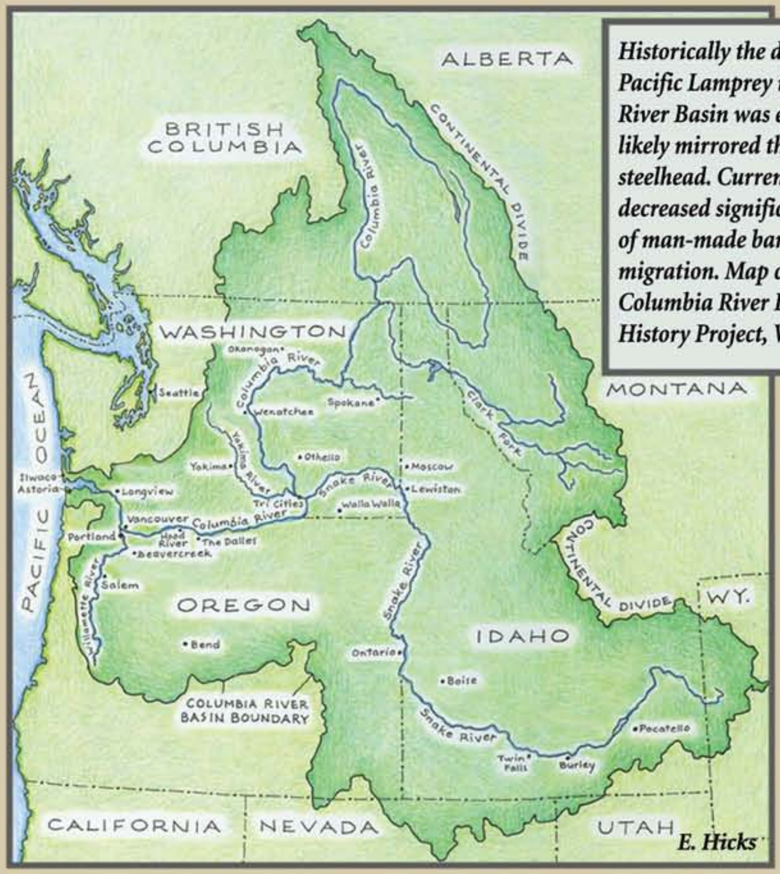
Sea Lamprey, a nuisance species in the Great Lakes, have contributed to a negative perception of native lamprey species in the Columbia River Basin and elsewhere in the Pacific Northwest.

Pacific Lamprey occupy several distinct ecological niches during their lives. They are parasitic during their adult phase in saltwater and are a prey species for a number of animals in both fresh and saltwater. Pacific Lamprey utilize the same migratory corridors as salmon and steelhead, and their presence alongside these fish provides a type of shield for predation on salmon during this migratory journey, as predators may focus their efforts on consuming lamprey.

Pacific Lamprey Distribution

Pacific Lamprey, *Entosphenus tridentatus*, are anadromous and exhibit a broad distribution centered around the Pacific Rim, including stream networks flowing into the Pacific Ocean from northern Mexico up to Alaska and extending across the Bering Sea to portions of Russia and Japan. Their historical range within the Columbia River Basin included most tributary streams throughout the basin. It is hypothesized that within the Columbia River Basin, Pacific Lamprey may have historically occupied a similar distribution to that of salmon and steelhead, but they probably reached even further since they can pass some natural barriers such as steep cascades and waterfalls that stop salmonids.

Current distribution of Pacific Lamprey has been curtailed in many portions of the Columbia River Basin by hydropower development that prevents fish passage. In the mainstem Columbia River, passage for lamprey is completely blocked by Chief Joseph Dam at river mile 545. In the mainstem Snake River, lamprey are blocked by Hells Canyon Dam at river mile 247. There are over 400 dams in the Columbia River Basin, many of them impassable to lamprey, and it is estimated that habitat availablity for lamprey has decreased by 40% simply as a result of these passage barriers.



Historically the distribution of Pacific Lamprey in the Columbia River Basin was extensive and likely mirrored that of salmon and steelhead. Current distribution has decreased significantly as a result of man-made barriers to upstream migration. Map courtesy of Columbia River Basin Ethnic History Project, WSU Vancouver.

Pacific Lamprey Life Stages and Habitat Use

The physical characteristics of Pacific Lamprey change considerably throughout their lives. These changes trigger shifts in habitat use, so it is important to understand characteristics of key life stages and their associated habitat requirements. The following is a general description of each life stage.

Egg Phase

Pacific Lamprey begin life as eggs deposited into streambed gravel nests akin to redds constructed by salmon and steelhead. Lamprey redds can be differentiated from those of salmon and steelhead based on size, shape and configuration. Lamprey redds are generally smaller and rounder, but will vary depending on site specific substrate and flow characteristics. The number of individuals constructing the redd is another factor that can influence size, and individuals may construct multiple redds. Redds are commonly constructed in the tail of pools in smaller gravel and cobble substrates than those used by salmon and steelhead. Another identifying feature is that lamprey redds may lack the characteristic tailspill deposits found on the downstream end of salmon and steelhead redds. This is because lamprey selectively excavate the redd by picking up individual stones with their sucker mouths and placing them around the redd to create a suitable area for resting and egg laying.

Lamprey eggs are round, approximately 1.5mm in diameter, and clear with an off-white to pinkish center. Eggs will incubate in redds for approximately 16-20 days prior to hatching. Duration of incubation is influenced by water temperature and will be shorter at warmer temperatures.

Top Left- Fertilized lamprey eggs.

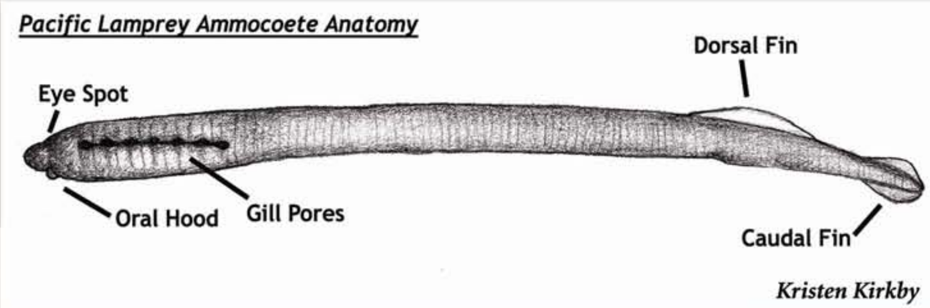
Top Right- Early developing eggs show visible tail and head.

Right- A recently hatched lamprey larvae called an ammocoete. At emergence ammocoetes will be about 10mm long.

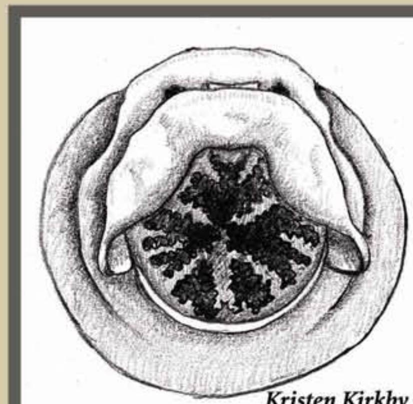
Credit- Northwest Fisheries Science Center Mukilteo Research Station.

Ammocoete (Larval) Phase

At hatching, larval lamprey are called prolarvae and remain in the redd for up to 15 days. After this time, they "swim up" and are then referred to as ammocoetes. Recently emerged Pacific lamprey ammocoetes are tiny (approximately 10mm long) and look like little pale grey eyelashes. A notable feature of ammocoetes is that they lack eyes and remain blind throughout their 5-7 year larval phase. They also lack a sucking disk and teeth, instead they have an oral hood which contains their filter-feeding structures. Other identifying features include a series of seven small round gill openings on the side of the head, eye spot, a light-sensitive pineal gland in their forehead, and two low dorsal fins. As ammocoetes grow their color shifts to a characteristic brown with a lighter belly. During their protracted larval phase, Pacific lamprey ammocoetes can grow to lengths approaching 200mm, but more commonly will reach lengths between 130-180mm.



Ammocoetes consume algae, plankton, and detritus by filter feeding from their burrows. They accomplish this by placing their oral hood near the substrate-water interface and filtering the water. Their ability to filter feed serves to improve local water quality. They also have an important role as bioturbators, mixing the sediments, much as earthworms do in a garden. Ammocoetes are preyed upon by a multitude of aquatic and terrestrial species and serve as a vital link in the aquatic food web.



Mouth of an ammocoete, showing filtering apparatus (oral cirri) used to capture small particles from the water column. They also filter fine sediments and as such help to maintain water quality.

Ammocoetes remain in close association with stream substrates for up to seven years before they transform and begin their migration to the ocean. Although fine sediment is their preferred habitat type, ammocoetes will also use small gravel and cobble substrates. Accumulations of fine sediments, and thus ammocoetes, are usually associated with areas of low water velocity found in eddies, alcoves, pools and along stream margins. This type of habitat often occurs in discreet patches within a given stream. However, while ammocoetes prefer fine sediments, they do not tolerate anoxic sediments, such as found in areas of high extremely organic content (e.g. cattails), without current (e.g. isolated backwaters), or thick algae covering on the bottom. Depositional areas downstream of boulders, logs, and other obstructions can also provide accumulations of suitable ammocoete habitat.

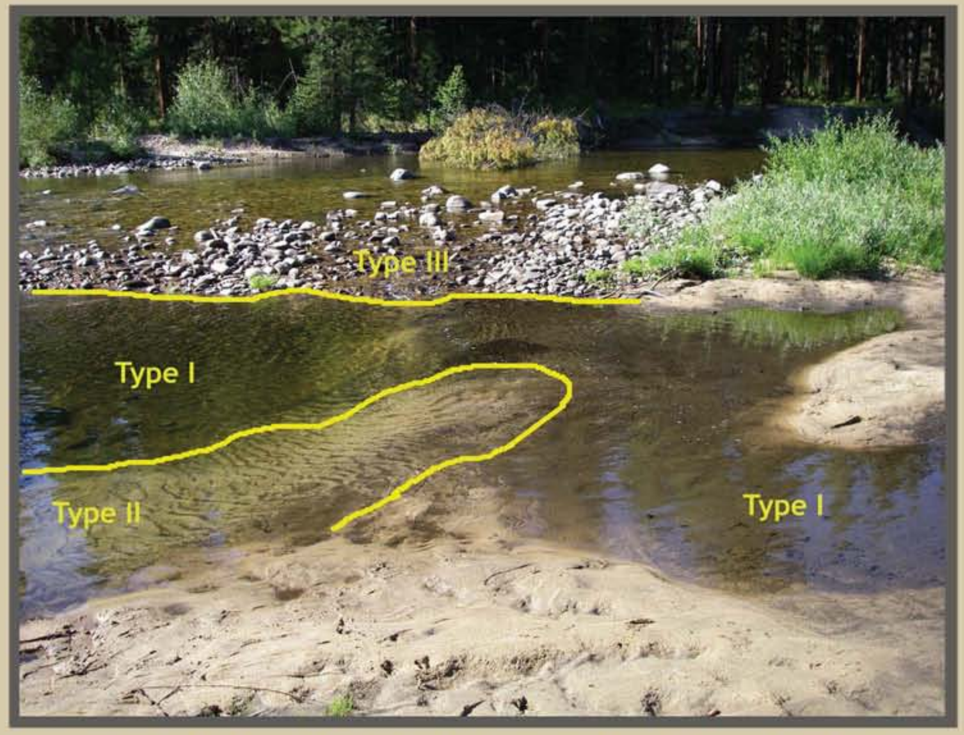
While ammocoetes may remain in one area for extended periods, they can move between habitat patches, generally at night, but the extent of these types of instream movements are not well documented. It is not uncommon to have several year classes of ammocoetes residing within the same habitat patch. Ammocoetes often move downstream, both passively and actively, during periods of high flow, such as during spring freshets.

The prefered habitat of Pacific Lamprey ammocoetes consists of fine silts and sands. They will also use coarse sand and small gravels but almost always will be more abundant in finer substrates as long as they contain adequate oxygen and water velocity.

Pacific Lamprey Ammocoete Habitat Classification

Type	Use	Substrate Composition
I	High	Fine Sediment including silt, sand, and detritus; medium-high organic matter
II	Medium	Shifting coarse sand, small gravel; low organic matter
III	Low	Bedrock, boulders, cobble, large gravel; low or no organic matter

A classification scheme for ammocoete habitat has been developed to standardize presence and distribution surveys. Habitat type is referred to as Type I, Type II, and Type III habitat (see above). Ammocoetes generally inhabit Type I habitat and to a much lesser degree Type II. They are only rarely found in Type III. Assessments to determine ammocoete presence within a stream should concentrate search efforts in Type I habitat.



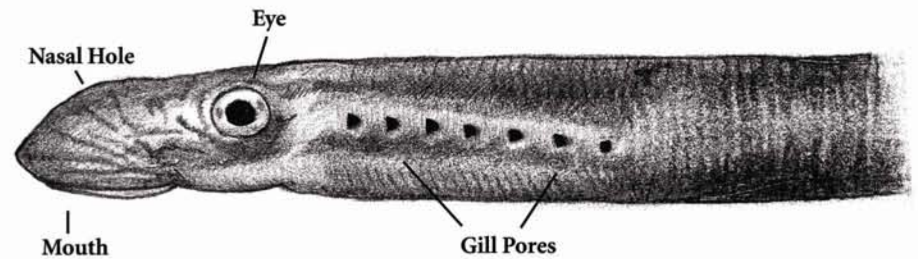
Ammocoetes prefer fine substrates, including silt and sand, throughout their freshwater residence period which can last up to seven years. This Type I habitat commonly occurs in discreet patches that can persist in the same locations from year to year or develop in new locations depending on annual patterns of sediment deposition. Quality of Type I rearing habitat varies and patches with accumulations of organic material may be preferred as long as adequate oxygen and water velocities are present. As seen above, Type I habitat is often interwoven within larger patches of Type II or Type III habitat.

Macrophthalmia Phase

Towards the end of the larval phase, ammocoetes undergo morphological and physiological changes during transformation to a macrophthalmia phase, preparatory to emigrating to the ocean. This transformation typically happens from July to November, but likely varies with environmental variables such as geographic location and water temperature.

The earliest visible physical transformation for macrophthalmia begins when the oral hood develops into a mouth and eyes begin to appear. Gradually, the mouth becomes rounder in shape and the eyes complete development. After approximately one month of transformation, a tongue and soft teeth will develop. In the final stages of external metamorphosis, the teeth harden and take on a yellow color. Internal changes, such as to organs and blood chemistry, occur during this time to prepare the juvenile lamprey for saltwater residence and parasitic feeding. During this transition period, feeding is temporarily halted as internal organs and the mouth transform to allow for parasitic feeding, and energy is garnered from stored lipid reserves.

Pacific Lamprey Macrophthalmia Anatomy



Kristen Kirkby

In preparation for the deeper water habitat encountered as they move downstream and into the ocean, macrophthalmia take on a countershaded coloration, with a dark blue back and bright silvery sides. Since they stop feeding at transformation and use their stored energy reserves, macrophthalmia can be slightly smaller than mature ammocoetes, typically measuring 130-180mm. Fully transformed macrophthalmia possess increased swimming ability, and the rate of migration to salt water accelerates at this time. For most macrophthalmia, migration to the Pacific Ocean typically begins in late fall or with the spring freshet.

During river migration, macrophthalmia are preyed on by larger fish and seabirds. Although most parasitic feeding initiates upon reaching the estuary, macrophthalmia may begin to feed on a variety of freshwater fish as they make their way downstream towards the Pacific Ocean, particularly if delayed by the slow water currents found in dam impounded reservoirs.

Adult Phase

Information about Pacific Lamprey behavior and habitat use in the ocean is very limited. They are thought to spend between 18-40 months in the ocean prior to their return to freshwater. They may move into deep water soon after entering the ocean and have been found throughout the water column to over 500 meters deep.

During their marine phase, Pacific Lamprey are parasitic, feeding on a variety of fish, such as pollock, hake, and salmon, as well as whales. Pacific Lamprey may not inflict a great deal of harm to some of their hosts, as evidenced by the numerous otherwise healthy fish captured with lamprey attachment scars. Pacific Lamprey also occupy a role as prey within the marine food web, providing a food source for fish and marine mammals, such as seals, sea lions, and killer whales. Lamprey are rich in fats and oils, making them a good source of nutrition for their predators.

In the ocean, Pacific Lamprey grow to a size of 60-90cm (24-36") and weigh between 200-500 grams when they begin their return journey to freshwater spawning grounds. Migration out of the marine environment and into the lower Columbia River typically begins in April (see Life History Timing Chart pages 21-22).

Historical accounts describe migrations occurring in large groups with movements typically under the cover of darkness. Pacific Lamprey use their sucking mouth to attach to substrates as they migrate upstream. They are unable to jump like many other fish, making some anthropogenic barriers like dams, weirs, and fish ladders especially challenging. However, as long as there are rounded edges that allow their mouth to maintain suction, they are able to scale vertical features, including waterfalls, that salmon cannot pass.

J. Crandall

An adult steelhead showing scars from lamprey parasitization.

Pacific Lamprey do not home to natal streams for spawning as salmonids do, and therefore lack the site-specific genetic diversity exhibited by salmon. In fact, genetic data collected from Pacific Lamprey suggest that the populations along the Pacific Rim are well mixed. Pheromone-like compounds released by ammocoetes provide adult lamprey with attractive olfactory cues, and adults may be drawn to rivers and streams with high concentrations of ammocoetes. If so, absence of ammocoetes in a particular stream may limit the number of returning adults and hamper recovery of Pacific Lamprey in that stream.

Adults make their way up tributary streams of the Columbia River in late summer through early fall, depending on location. Adults may spend 6-12 months in freshwater prior to spawning, and they may hold for extended periods in one location as they prepare to spawn. Adults hold under boulders or logs, buried in coarse gravel, or in other cover features. No feeding occurs during this holding period while energy is shifted in preparation for reproduction. Adults may lose up to 20 percent of their body weight prior to spawning.

Spawning for Pacific Lamprey in the Columbia River Basin generally occurs between March-July, but varies geographically and with environmental cues, such as water temperature and stream discharge. Adults will move to spawning grounds from winter holding locations during this time. Once suitable spawning habitat is located in gravel substrates, Pacific Lamprey will either pair up or gather in small aggragations, commonly one female with multiple males. Adults may construct multiple redds in the same area.

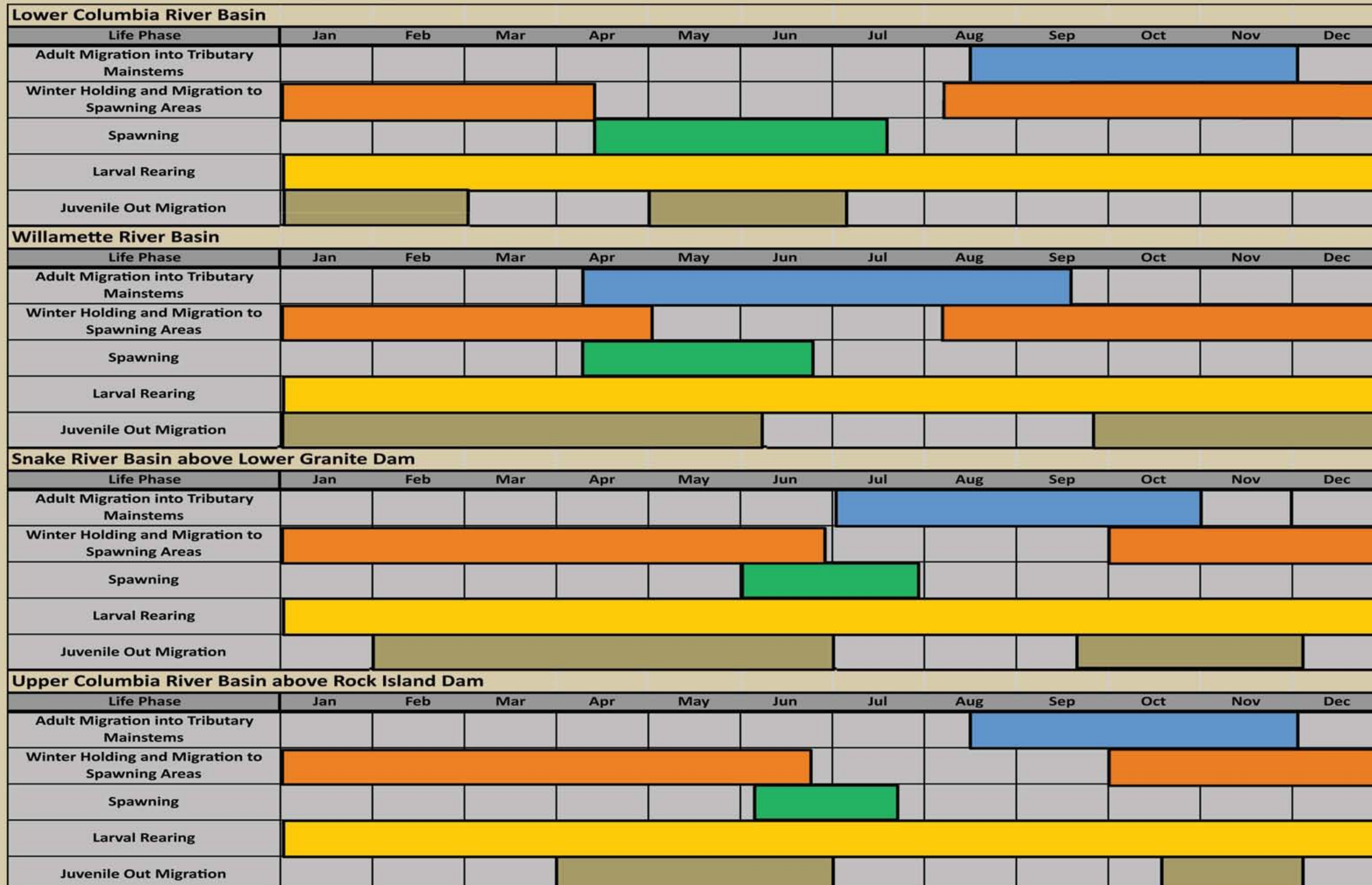
Pacific Lamprey construct redds in small gravels similar to salmon.

To prepare the redd adults use rapid undulations of their bodies and use their sucking mouths to pick up and move gravels . Mating occurs as the pair intertwine their eel-like bodies. Eggs are released from the female and externally fertilized by the male. Eggs are deposited in the redd to begin their incubation in the interstitial spaces amongst the gravels. Adult Pacific Lamprey are extremely fecund, with a mature female capable of producing between 100,000-230,000 eggs.

Like salmon, adult Pacific Lamprey die after spawning. Their decaying carcasses provide a considerable food source for many organisms and increase freshwater supplies of marine derived nutrients.

Pacific Lamprey provide freshwater ecosystems with valuable supplies of marine derived nutrients.

Pacific Lamprey Life History Timing By Region



Life history information is provided as a general description of the seasonal timing of distinct Pacific Lamprey life stages in different portions of the Columbia River Basin. The charts represent a summary of various data sources including adult dam passage, adult radio tracking, ammocoete monitoring (electrofishing and screw traps), and field observations collected from across the Columbia River Basin. It is recognized that gaps in our knowledge of life history timing exist, and some degree of behavioral variation within the life stages should be expected depending on local conditions that vary across time and location. This variation should be kept in mind when planning instream activities in lamprey habitat, and project stakeholders are strongly encouraged to contact regional biologists for more information specific to a

Section 3- Threats to Pacific Lamprey

Pacific Lamprey have undergone significant declines in abundance throughout their range within the Columbia River Basin. Similar to declines seen in numerous runs of Columbia River salmon and steelhead, the factors contributing to the precipitous and rapid decline in Pacific Lamprey are believed to be both numerous and pervasive. Although Pacific Lamprey abundance is expected to fluctuate as the population responds to natural variations in ecological conditions such as climate, streamflow, habitat, and prey populations, the extent and rapid pace of the decline over the past century suggests that anthropogenic influences are involved and threaten the future persistence of the Pacific Lamprey in the Columbia River Basin.

Recent research and field observations indicate that both current and past anthropogenic actions are working in concert to adversely affect all life stages Pacific Lamprey populations throughout their distribution. While this guide is focused on tributaries to the mainstem Columbia, Willamette and Snake Rivers, the nature and impact of factors within these mainstem rivers, the Columbia River estuary, and the Pacific Ocean are extensive and warrant consideration to provide context to the more detailed discussion of tributary threats.

While Pacific Lamprey are subjected to the same threats as other members of the Columbia River Basin native fish community, their response differs due to their unique biology and ecology.

Ocean and Estuary Conditions

Habitat conditions (i.e. ocean currents, water quality, productivity) within the Pacific Ocean and the Columbia River estuary play a significant role in determining Pacific Lamprey productivity. However, very little is known about the effects these conditions have on lamprey populations. It is well documented that ocean conditions are a powerful driver of anadromous salmonid productivity, and it is likely that this also applies to Pacific Lamprey. Declines in marine prey abundance, particularly species targeted by large commercial fisheries, have probably impacted lamprey by decreasing feeding opportunities and adult returns at Bonneville Dam may correlate with marine prey species abundance.

Mainstem Passage

The large hydropower dams of the mainstem Columbia, Snake and Willamette Rivers pose significant passage challenges for both adult and juvenile Pacific Lamprey. Upstream migrating adults have a difficult time navigating through the fish ladders at many of these large dams. In most cases, fish ladders were engineered to facilitate passage of adult salmon and were not specifically engineered to assist lamprey. High water velocities, grating, screens, right angled steps, and lighting associated with these passage structures may impede or prevent adult passage. At some dams passage success for adult lamprey can be as low as 30%.

Migrating Pacific Lamprey face many challenges including man made obstacles. Here lamprey macrophthalmia became entrapped on extended length bar screen at John Day Dam. Modification of fish screens can help reduce this threat to lamprey.

Even with successful passage, travel through the dams is energetically costly for adult lamprey as it slows migration and saps valuable energy reserves, which are needed for further migration, winter holding, and spawning. These challenges are compounded as many adult lamprey must past through multiple dams on their spawning migration.

Downstream migrating macrophthalmia also encounter passage challenges at the dams. Juvenile migrants approaching dam infrastructure often encounter water velocities that exceed their swimming ability, putting them at high risk of being impinged upon, or entrained into fish screens and turbines, which can inflict high mortality.

Predatory fishes and birds often concentrate below dams where they feed on disoriented and damaged macrophtalmia. Similar to adults, macropthalmia may use valuable energy reserves to navigate the dam infrastructure.

Downstream passage features at most dams were also designed to facilitate salmon passage and not necessarily adapted for lamprey. Improved passage conditions at mainstem dams has been recognized as an extremely critical element of the overall restoration strategy for Columbia River Basin Pacific Lamprey.

Tributary Passage-Water Diversions and Fish Screens

Similar to the large hydropower dams of the mainstem rivers, diversion dams and culverts in smaller tributary streams can negatively affect Pacific Lamprey by creating conditions that can disrupt and delay migration. The vertical drops associated with diversions and culverts may lack suitable surface area and texture for lamprey to attach to. Adults are also not adept at attaching to the right-angled steps present at many structures. Pools downstream of the structures may not provide suitable habitat where the adults can rest and prepare for the climb over the structure, preventing them from accessing upstream habitat. Additionally, diversions and culverts can create zones of high water velocity that exceed the swimming ability of adults.

Entrainment of lamprey, especially ammocoetes, into irrigation diversion canals is a major threat to lamprey within most Columbia River tributaries. Ammocoetes and juvenile lamprey that enter open diversion canals may not have suitable opportunities to ever re-access the stream channel. Once isolated in the canals, they face stranding and desiccation when diversions are shut-off and drawn down, as well as the potential to be harmed or killed during dredging activities associated with canal maintenance.

Lamprey that pass through fish screens can become stranded and face dessication when the canals are drained or dredged.

Fish screens, either within diversion canals or adjacent to stream channels, are another pervasive threat to larval and juvenile lamprey, which lack strong swimming ability. Water velocities approaching fish screens can easily exceed their escape ability. When this occurs, and young larvae may become impinged upon, or entrained into, the fish screen. This can severely harm or kill the lamprey, or allow them access into habitat to which there is little potential for escape. The screen material is also a consideration as juveniles may become impinged more easily on some materials such as wire cloth.

Dewatering

Rapid drops in water inundation levels associated with water management in streams, reservoirs and irrigation canals can strand and desiccate lamprey inhabiting those areas. Dewatering is also associated with reaches of stream undergoing restoration such as during installation of engineered log structures. While the impacts of dewatering most likely affect rearing ammocoetes, adults and redds can also be impacted depending on the habitat and seasonal timing of the dewatering.

Irrigation ditches with fine sediments often make great habitat for ammocoetes, but ammocoetes are vulnerable to stranding during dewatering or dredging.

Dredging

Dredging of stream and lake/reservoir beds directly removes or disturbs substrates occupied by lamprey, especially ammocoetes. Dredging is usually accomplished via heavy machinery, thus lamprey are susceptible to injury (i.e. crushing) as well as desiccation when they are removed from the water. Activities that may involve dredging include irrigation ditch maintenance, road construction, shipping channel maintenance and stream restoration.

Instream placer mining is perhaps the most pervasive dredging activity that may affect lamprey in the Columbia River Basin. This type of mining often uses suction dredging techniques to remove stream substrates for processing. Not surprisingly, placer mining can greatly impact lamprey, and myriad other aquatic organisms through direct mortality and alterations to habitat.

Habitat Degradation

Past and present activities that diminish the availability and quality of instream and floodplain habitats pose a continued threat to lamprey. Residential and agricultural development, road construction and maintenance, flood control measures, and numerous other activities have conspired to limit the availability and quality of habitats critical to lamprey. Connectivity between mainstem streams and associated side channels, floodplains, and other off-channel habitats are critical to healthy, functional lamprey habitat. Diminished habitat connectivity and complexity generally results from a reduction in the formative geomorphologic processes that create complex stream habitat.

Habitat degradation has the potential to affect the whole instream life cycle of lamprey from egg to adult. Ammocoetes spend a prolonged period instream and may be the life stage most significantly affected, but the effects on other life stages may be equally or more significant, depending on the location and degree of functional impairment.

Development within a river floodplain can contribute to habitat degradation in many ways, including loss of riparian cover, sediment loading, pollution from home and yard chemicals, and contamination from septic tanks.

Water Quality

Degraded water quality often stems from a multitude of sources, such as the clearing of riparian forests, residential and agricultural development, road construction and maintenance, mining, as well as many other point and non-point sources. Diminished water quality may harm lamprey on numerous fronts by upsetting normal physiological patterns and forcing movements from preferred habitat to less productive areas. Water quality, especially temperature, plays a large role in the reproduction and egg-larval development stages of lamprey. Thus, activities that increase water temperature can have negative impacts to lamprey productivity.

Water quality can also be severely degraded when chemicals spill or drift into waters occupied by lamprey. Depending on the degree of exposure (acute or chronic) and chemical composition, pesticides, herbicides, or other chemicals may cause direct mortality in lamprey or other physiological and behavioral harm. Once instream, these chemicals can persist in sediments for decades. Ammocoetes, because they also reside in the sediment for years, have been shown to bioaccumulate toxins such as mercury, pesticides, and flame retardants.

As ammocoetes live in the substrate, sediment conditions are crucial to their success. Ammocoetes are not found in anoxic sediments, so maintaining suitable instream flows, reducing nutrient inputs, and limiting excess algal growth are critical to maintaining healthy ammocoete populations.

Non-point source pollutants from a varity of sources can build up in aquatic environments causing harm to lamprey and other species.

Section 4- Best Management Practices

Lamprey are unique fish. Their atypical body shape, swimming methods and ability, and natural history require special consideration when planning activities that have the potential to disturb stream habitats. Actions related to water diversion, road construction and maintenance, riparian development, mining, and recreation all have potential to adversely impact lamprey (See Section 3). Where these actions occur, the needs of lamprey should be considered by employing the Best Management Practices (BMPs) outlined below.

Negative impacts to lamprey and their habitat may also be associated with actions resulting from the implementation of instream, riparian and off-channel habitat restoration projects. Currently, the majority of habitat restoration projects funded and implemented in the Columbia River Basin are intended to improve habitat conditions for salmonids. These efforts seek to enhance the productivity of salmon and steelhead through improvements in habitat quality and availability. Yet, because these actions are focused on salmonids, they may not be planned, designed, or implemented in such a fashion to maximize potential benefits to Pacific Lamprey and may inadvertantly harm lamprey. Recent efforts by the U.S. Fish and Wildlife Service and Natural Resources Conservation Service provide guidelines for the implementation of Pacific Lamprey-centric BMPs.

Poorly designed and maintained roads can alter watershed hydrology and degrade water quality.

The extensive geographic scope and overall scale of salmonid-based habitat restoration efforts within the Columbia River Basin present habitat restoration practitioners, land use planners, and funding entities with unique and valuable opportunities to simultaneously improve habitat conditions for Pacific Lamprey.

These BMPs can be included with the development and execution of activities that may disturb stream and riparian habitats occupied by lamprey. This guide presents a brief overview of BMPs as well as a listing of local biologists that can be consulted prior to any activities (page 51).

Adherence to BMPs for habitat disturbances within or adjacent to streams occupied by lamprey that alter instream flow, stream substrate, and water quality is especially important as disturbances to these habitat attributes have a high potential to harm lamprey across all life stages. Consider that even if the activities do not occur in habitats occupied by lamprey, disturbance effects may extend up or downstream into occupied habitats. If lamprey presence within a project area is uncertain, consult with local biologists for guidance (refer to contact information on page 51), or carry out a local survey (see Monitoring Section on page 47).

The timing of the disturbance is another important aspect to consider for instream activities. Adults, redds, and macrophthalmia are present for portions of the year, while ammocoetes are typically present year-round. Thus, the type and timing of activities are critically important to minimizing or eliminating potential harm to lamprey. If possible, restrict project activities to work windows that will not conflict with lamprey presence. If this is not possible or practical, employ relevant BMPs throughout all phases of the project. Refer to pages 21-22 for generalized Columbia River Basin Pacific Lamprey life history timing.

Instream Flow

Activities that alter the availability of instream flow over both the short- and long-term can impede adult spawning, adult and macrophthalmia migration, and ammocoete movement. Alteration to instream flow can also desiccate and isolate habitat, including redds and adult holding habitat. Ammocoetes and holding adults are especially susceptible to desiccation and stranding because they are burrowed into the substrate and may react slowly to changes in water levels.

Short-term alterations to instream flow, such as dewatering an area for stream habitat restoration or to make repairs on a diversion structure, should be avoided in lamprey habitat if possible. If dewatering is necessary, it should occur slowly, ideally ramped down incrementally over several days, rather than rapidly, which leaves little opportunity for lamprey, especially ammocoetes, to move out of the area. During dewatering, care should be taken to create low spots in the work area for ammocoetes to congregate. Sufficient staff should be on hand to assist with lamprey removal from-the work area. Dewatering should never occur in a spawning area.

Electrofishing during dewatering can be an effective technique to remove ammocoetes from instream work areas, but this should not be viewed as a method to remove all ammocoetes, as many more may escape capture. Repeated efforts over several days will likely remove more lamprey from the area. An effective strategy for excluding, dispersing and salvaging ammocoetes from instream work areas has not been developed. New and innovative removal methods are an on-going need.

The removal of ammocoetes from instream work areas requires planning and patience. De-fishing efforts may require multiple passes over several days.

Long-term modifications to instream flow, such as irrigation diversions, should allow for adult and juvenile passage and reduce the potential for juvenile entrainment into canals. More information on design and installation of Lamprey Passage Structures at diversions is presented in Section 5.

Impingement onto diversion screens and entrainment into diversion canals is a well documented source of mortality for juvenile lamprey. Approach velocities at screens should be less than 0.4 feet/second (0.12 meters/second) for active screens (e.g. rotating drum and belt screens) and 0.2 feet/second (0.06 meters/second) for passive screens (e.g. standard pump screens, vertical bar). Screen design and material is also a consideration when used in areas inhabited by lamprey. See Section 5 for more details of screen design and operation.

Water Quality

Lamprey require a high degree of water quality to thrive. Water temperature is a major consideration and any actions that result in warmer stream temperatures may be deleterious to lamprey and should be avoided. At temperatures above 22°C (71°F), mortality may occur in incubating eggs and young ammocoetes. Spawning may also be impacted at temperatures that exceed this 22°C threshold. Activities that may result in increases to water temperatures include removal of riparian vegetation, water diversion, stream channelization, and habitat alteration.

Lamprey can also be negatively impacted by toxins, such as pesticides and herbicides, that are present in the water and accumulate in stream sediments. Recent studies have shown that ammocoetes can accumulate detrimental levels of flame retardants, mercury, and pesticides. Herbicides can impair the olfactory and migratory behavior of adult lamprey. Activities that involve use of toxic chemicals should be avoided in and around streams.

Pacific Lamprey are similar to other Columbia Basin fish species in that they require cold clean water, free of pollutants, in order to survive.

Stream Substrate

Without thoughtful and informed planning, activities that disturb stream substrates have the potential to negatively affect Pacific Lamprey and their habitat. Dredging, mining, and habitat restoration projects all have a high potential to impact lamprey, as they commonly disturb substrate types preferred by lamprey for spawning (gravels) and larval rearing (oxygenated fine sediment). During implementation, care must be used to minimize effects to lamprey.

Similar to instream flow activities, the timing of substrate disturbing activities is an important consideration, especially for adult lamprey. Pacific Lamprey spawning in the Columbia River Basin occurs March–July, and care must be taken to never disturb redds or spawning adult lamprey (or other fish species). See pages 21-22 for regional life history timing charts.

For disturbances in ammocoete habitat (fine substrates such as silt and sand), the timing is less of a concern as ammocoetes reside in these habitats year-round. Activities occuring in fine substrate at any time have the potential to impact ammocoetes. Multiple year classes of ammocoetes often occupy the same habitat patch, so disturbances in fine sediments have the potential to disrupt several age classes of lamprey. Activities that impact stream substrate should follow the BMPs for instream flow.

Section 5- Restoration and Passage Design

The abundance and viability of Pacific Lamprey in the Columbia River Basin are threatened by habitat conditions in tributary streams. Impeded passage and diminished instream habitat complexity and water quantity negatively impact all life stages through direct mortality, loss of access to preferred habitat, migration delays, and diminished growth and survival.

These threats are widespread and persistent throughout the range of Pacific Lamprey in the Columbia River Basin. Due to the steep declines in abundance there is an urgent need to ameliorate threats to promote their recovery and persistence. Restoration actions designed to improve aquatic and riparian habitat conditions provide a means to assist Pacific Lamprey recovery.

The collective movement to restore salmonid habitat in the Columbia River Basin presents a valuable opportunity to restore habitat for Pacific Lamprey. By considering lamprey from the onset of project developement it may be possible to include lamprey specific project elements at little or no additional cost.

Currently, there is an extensive and resource-intensive effort underway to restore salmonid habitat in the Columbia River Basin. A portion of these projects also have the potential to improve habitat conditions for lamprey, but in order to do so most effectively, the unique life history traits and habitat needs of lamprey must be considered throughout the life of the project from planning through implementation. By addressing the needs of lamprey in salmonid-based restoration efforts, project sponsors and managers will increase the overall ecological value of their project with potentially minimal additional cost. Those involved with salmonid-based restoration are encouraged to review the lamprey-specific restoration approach described in this section.

A Restoration Approach for Pacific Lamprey

Habitat restoration for Pacific Lamprey must include consideration of the short- and long-term effects of actions. Lamprey will benefit in the short-term from projects that remove an immediate threat (i.e. "limiting factor"), such as improvements to irrigation diversion screens to reduce direct mortality. They will also benefit from projects that promote habitat-forming processes over the long-term (i.e. decades), such as those designed to increase availability side channels and other off-channel habitats.

Ideally, a restoration approach within a given stream or watershed should include projects to address identified threats across multiple time scales. Keep in mind that each geographic setting will be unique in relation to fish presence, habitat conditions, limiting factors, available resources and social context. One key to successful restoration is to develop a strategy tailored to site-specific conditions.

While it is likely that many of the salmon-based restoration efforts that address habitat limiting factors in the Columbia River Basin also improve habitat conditions for lamprey, these projects may have the potential to increase their benefit to lamprey by simply considering their ecology and habitat needs. Some approaches to salmon restoration, for example reduction of fine sediment and gravel/cobble augmentation, can adversely effect lamprey by eliminating ammocoete rearing habitat.

For this reason, before initiating instream and riparian restoration actions, project sponsors, managers, and other stakeholders are encouraged to gather as much information as possible related to the distribution, status, and threats faced by Pacific Lamprey in the project area. In many cases, this information will be available from local state and tribal fisheries biologists. If no information is available locally, project proponents should contact regional offices of the U.S. Fish and Wildlife Service. A contact list for the entire Columbia River Basin is available on page 51 with annually updated versions available at *www.methowsalmon.org.*

After lamprey distribution and status information has been gathered, the threats to lamprey should be identified and, if possible, prioritized based on their severity and prevalence within the project area. From this point, the project can proceed through a standard management pathway including the steps of 1) planning and design, 2) permitting, 3) contracting, and 4) construction. Project-level monitoring may also be applicable (see Section 6).

It is crucial to develop a site specific treatment that includes as much local environmental and biological information as possible. Habitat restoration to benefit Pacific Lamprey is a relatively recent development, and project sponsors are encouraged to seek out as much information as possible to assist with project development and also to develop other innovative solutions to benefit lamprey.

In the Columbia River Basin, several threats to Pacific Lamprey have been identified as particularly pervasive and harmful. These include physical barriers to migration, entrainment, diminished habitat complexity, low water volume, and high water temperatures. In the sections that follow, these threats will be summarized in the context of restoration efforts that can be employed to ameliorate them.

Physical Barriers to Migration

Barriers to instream movement of lamprey are a regional concern as they are widespread throughout the Columbia River Basin. While fish passage barrier assessments have been completed for many watersheds, most assessments focused on passage of salmonids and may not have considered the needs of lamprey in their analyses. However, the data and observations collected at the various sites can be useful in determining if they pose passage challenges for lamprey. Efforts to collect as much site-specific information as possible is highly recommended to assess potential for a barrier to impede lamprey passage. Local biologists, irrigators, and water masters are good sources for site-specific information and should be contacted.

Perched culverts (top) and culverts with an elevated apron (bottom) are common passage barriers for all life stages of Pacific Lamprey. Replacing these culverts with larger stream bed simulating culverts can assist Pacific Lamprey as well as salmon and other fish species.

Once remediation areas are selected, site-specific treatment designs based on local conditions need to be developed. Where possible, barrier culverts should be replaced with a bridge or open bottom culvert with a stream simulating design.

Of particular interest for lamprey at any barrier are the water velocities and depths through the structure. Compared to salmon, lamprey are not strong swimmers. They use undulatory movements for swimming, and cannot swim through long patches of high water velocity. Lamprey use their oral discs to attach to substrate as they ascend and move through barriers. Once attached, lamprey can rest and recover for further movement. They will then use quick bursts of energy to move up to a new attachment point where they rest before bursting again. This “attach and burst” type of travel allows lamprey to scale vertical barriers and short sections of high water velocity.

Adult Pacific Lamprey will be unlikely to pass through barriers with water velocities exceeding 8.8 feet/second (2.7 meters/second). They will also be challenged to pass longer distances (>15 feet) with sustained velocities exceeding 2.8 feet/second (0.86 meters/second), especially if attachment points for resting are lacking along the way. Minimum water depths in and around the structure of at least 0.1 feet(3 cm) are needed for adequate passage. Water depths less than this pose a significant passage issue for lamprey, even though they are capable of moving short distances in shallow water.

Juvenile lamprey are much less accomplished swimmers than adults and the velocity values listed above likely greatly exceed their swimming abilities. Overall, velocity is less of a threat for migrating juveniles, as they primarily move within the current in a downstream direction. However, passage barriers can cause bodily harm via transport over spillways or through other bypass structures.

The physical construction of barriers is also of importance when assessing lamprey passage. Again, fish passage assessments focused on salmonids may be inadequate to determine if the structure is a passage challenge for lamprey. Lamprey will move best along relatively flat, non-porous (i.e. no mesh or grating), and slightly rough surfaces that are large (wide) enough to securely attach to with their oral disc. Lamprey will attach most securely when their oral disc can form a tight seal on the substrate and they will achieve the best passage success when broadly rounded surfaces are available (4-6" minimum radius). Surfaces such as fish ladders, culverts, and weirs that have sharp (i.e. ~90°) angles will hamper attachment and impede or prevent passage. Passage success over structures with perched drops on the downstream side can be very problematic for adult lamprey passage, as these structures lack vertical attachment surfaces, and lamprey cannot jump barriers like salmon.

Overall lamprey will benefit from remediation efforts that minimize turbulent flows, provide gradual transitions from low to high velocity areas and provide rounded surfaces and rest areas for attachment. Where replacement of a culvert is not possible or cost prohibitive, consider installation of a lamprey passage structure (see pages 37-38).

Lamprey Passage Structures

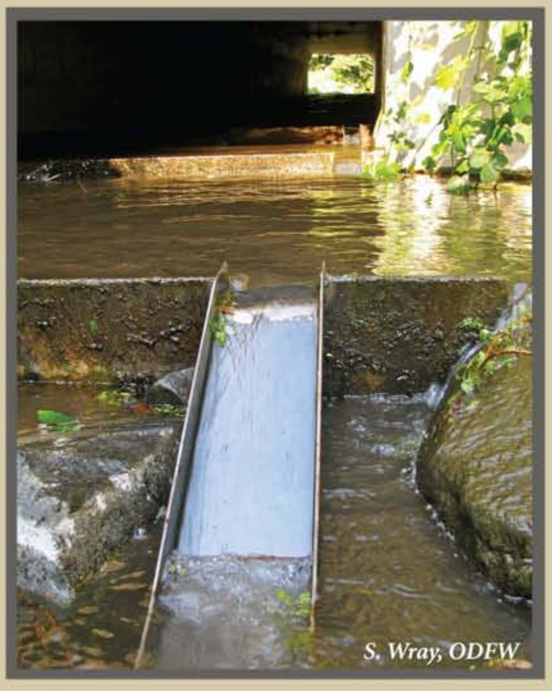
Identifying passage barriers is an important first step in the restoration of habitat access for lamprey. Once a structure has been identified as a potential barrier, restoration actions to ameliorate this threat can be implemented. Recently, the installation of Lamprey Passage Structures (LPS) at barriers has emerged as a restoration technique that has successfully improved conditions for migrating adult lamprey in several watersheds in the Columbia River Basin where other restoration options were not possible.

In their simplest configuration, LPS are inclined ramps that connect the downstream portion of a barrier with the upstream elevation. These structures are usually custom fabricated stainless steel plates designed to meet site specific conditions. They can be installed on the downstream side of a barrier to allow for passage over the lip of the upstream side (photo upper left). They can also be installed in series across a set of small step barriers such as would be found in a culvert with multiple baffles along the length of the culvert (photo upper right). LPS can also be attached as a verticle plate (photo lower right). The attachment method of these small ramp LPS depends on the material of the structure but commonly use bolts.


S. Wray, ODFW

Lamprey Passage Structures (LPS) can be an effective tool to restore upstream passage beyond barriers where other restoration options, such as barrier removal, are impractical.


S. Wray, ODFW


S. Wray, ODFW

LPS can be installed as ramps or verticle plates. Water depths and velocities should be considered and may dictate the exact installation location.


S. Reid

LPS installation at large or more structurally complex barriers, such as low head dams, is more complex and may require more sophisticated engineering (see page 39). The LPS may feature a series of ramps interspersed with benches in order to achieve the desired gain in elevation and to provide adequate resting areas for adults. Additional features such as fish traps and video monitoring can be installed within these LPS, which are similar in design to the LPS being installed on mainstem dams on the Columbia and Willamette Rivers.

A key consideration for any LPS installation is assessing the flow velocities and depths through the structure during the periods of the year when lamprey use would be expected. The LPS should be engineered to provide adequate passage velocities and depths throughout the migration window. The LPS should be configured and installed to be locatable and accessible to migrating fish. Care should be taken not to install the LPS in a location that would impede passage for other fish such as in the center of a downstream holding pool. For more information, refer to the water velocities and depth guidance provided in this guide (page 36) and contact local biologists for more information.

Lamprey Passage Structures

LPS for more complex barries require a higher level of planning and engineering, It is best to consult with local experts prior to the implementation this type of project.

Entrainment and Impingement

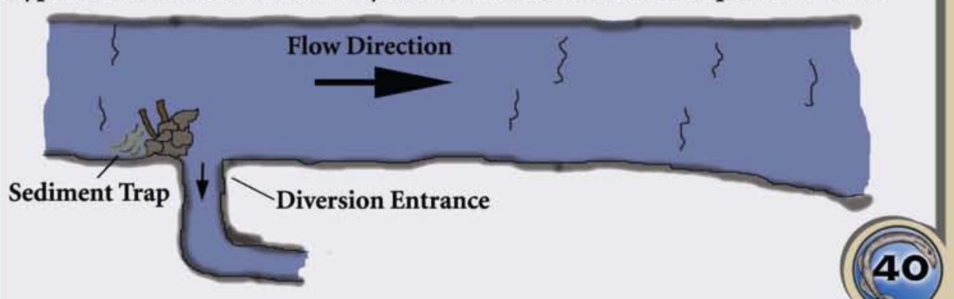
Irrigation diversion canals, pumps, and associated infrastructure pose a major threat to Pacific Lamprey populations in the Columbia River Basin due to their prevalence and the harm they can inflict. Lamprey interaction with diversion infrastructure, including entrainment into canals and impingement on fish screens, may result in direct mortality, injury, or increased susceptibility to predation. If they occur in stream reaches where lamprey reside, these types of structures should be evaluated for their impact to lamprey and, if warranted, improved to minimize negative effects.

While entrainment and impingement are a threat to all life stages of Pacific Lamprey, the threat is certainly most acute for juveniles and ammocoetes. The slender, elongated body shape, poor swimming ability and small size of juveniles makes them highly susceptible to both entrainment and impingement. Young ammocoetes are especially small (10-20mm), which increases their chances of entering diversions and screens.

Many diversions canals have slow current velocities that promote sediment deposition, which are habitat attributes attractive to ammocoetes. Ammocoetes that enter diversion canals and locate suitable habitat conditions may reside there for extended periods of time. When the diversion is closed for the season, intake flow will cease. As the canal dewaters, there is a high potential to strand and desiccate ammocoetes (and other fish) if they do not have adequate access to the fish return or if the canal is dewatered too quickly. Utilization of several operational BMPs, such as a gradual draw down, will minimize negative effects (see section 4), but depending on the configuration of the canal, restoration of infrastructure may also help alleviate harmful effects on lamprey.

Modification of the orientation of the canal headgate to the stream current is one potential action than can be taken to reduce entrainment of lamprey. Headgates that are oriented parallel to the stream current may promote intake of streamflow and sediment as well as downstream moving lamprey. Modifying the headgate to an orientation perpendicular to the streamflow (i.e. thalweg) may reduce sediment deposition and ammocoete access into the canal, thereby reducing overall use and potential negative effects.

Hypothetical Diversion Intake Layout to Reduce Sediment Transport Into Canal



Fish Screens

Almost all fish screens in the Columbia River Basin were designed to curtail entrainment and impingement of salmonids, yet current salmonid-based screen design criteria may not adequately protect lamprey. Lamprey mortality and injury associated with screens is likely one of the most significant regional threats to lamprey and is the source substantial amounts of direct mortality. Reducing this threat should be a high priority wherever it has been identified.

Screen Types and Material

Rotary Drum Screen

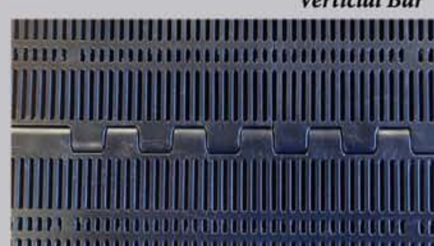
Vertical Plate Screen

Vertical Belt Screen

Wire Cloth

Perforated Plate

Verticlal Bar



Interlock

Of particular concern are the screen mesh size, screen material and the current velocities approaching and along the face of the screen. The mesh size may be the most important factor in determining potential impacts to lamprey, especially ammocoetes. A good rule of thumb is that the larger the mesh size the larger threshold size for entrainment and impingement. Current criteria for salmonids allows for mesh openings of 2.38mm (<3/32") for round and square mesh and 1.75mm for rectangular mesh. Screens with larger mesh size should be considered unacceptable to prevent impingement and should be replaced with smaller mesh. Small ammocoetes (<70mm long) are susceptible to harm with any mesh sizes currently in use in the Columbia River Basin; thus, there is a need to develop screen alternatives that reduce this potential.

Screen material is another important consideration. Currently, there are four common types in use including perforated plate, vertical bar, wire cloth, and interlock (see page 41). Observations have shown that perforated plate is perhaps the best mesh type for lamprey to reduce impingement, with both interlock and vertical bar slightly less effective. Wire cloth appears to provide more opportunities for ammocoete impingement, thus is less desirable for use in streams occupied by lamprey. Unfortunately, wire cloth is one of the most widely used screen material in the Columbia River Basin. The replacement of this material with something more lamprey-friendly, such as perforated plate, will take significant effort and resources, but is recommended as it will help improve survival of lamprey over the long-term.

Screen type may also influence lamprey survival. Observations on rotary drum and belt screens indicate that when ammocoetes become entrained into the mesh they are subsequently transported up and over the screen and into the downstream waters where mortality is likely. Passive screen designs may be better suited for lamprey. One such design is the Farmers Screen, a horizontal, flat perforated plate screen that is a new design with good potential for reducing effects on lamprey.

Water movement associated with passive screens may reduce entrainment and harm to ammocoetes.

Fish screens should also be examined to assess their associated water current velocities. Present salmonid-based criteria call for velocities approaching (i.e. perpendicular) the screen to not exceed 0.4 feet/second (0.12 meters per second) for active screens (e.g. rotating drum, travelling belt) and 0.2 feet/second (0.06 meters per second) for passive screens (e.g. pump screens, vertical panels). Sweeping velocities, those that run parallel to the screen face and promote fish movement across, not into, the screen, should at least exceed the approach velocities. While not conclusive, observations have shown that ammocoetes can effectively swim through these velocities, thus these criteria may be appropriate as a high end for screen velocities until further research findings become available. Fish screens should have functional fish bypass that allow for passage back into the stream. Screens oriented at a 90º angle to the approach current will promote fish movement into the bypass.

Thousands of fish screens are in use throughout the Columbia River Basin. Each is unique in its deployment, including stream and water current characteristics, screen type and material, and fish bypass configuration. Screens opperating in lamprey habitat should be evaluated for their impacts. Monitoring for lamprey presence downstream of the screen can determine if the screen poses an entrainment risk. If a screen is determined to pose a risk to lamprey, it should be modified to minimize any negative impacts.

Instream Habitat

Lack of instream habitat complexity and connectivity to off-channel habitats are pervasive limiting factors for ESA-listed salmonids in the Columbia River Basin. Anthropogenic influences such as mining, timber harvest, and urban and agricultural development have reduced the potential for instream and riparian habitat forming processes. As a result, fish populations and their associated aquatic communities are threatened by stream channelization, low supplies of large wood, diminished instream flows, and a lack of connectivity to off-channel habitat, especially floodplains, side channels, and alcoves.

Although the extent to which these changes have impacted Pacific Lamprey is not well understood, it is probable that they have also negatively impacted the stream and riparian habitat processes lamprey depend on for survival and production. Compared to the direct effects of passage barriers and entrainment/impingement, the effects of these habitat changes on lamprey are more indirect and subtle in their expression.

Currently, there is a significant amount of salmonid-based habitat complexity restoration underway in the Columbia River Basin. While not focused on lamprey by design, these restoration efforts provide an opportunity to simultaneously improve habitat to sustain viable populations of lamprey over the long-term.

A key to maximizing the benefits to lamprey of salmonid-based restoration is to integrate the specific habitat needs of lamprey into the project planning and design phases. A key first step is to develop a basic understanding of lamprey use of a proposed restoration site or reach including: 1) lamprey presence/absence, and if present, what life stages, 2) how they are using the habitat (i.e. spawning, overwintering, rearing), and 3) the timing of use.

This information can be combined with the life-stage specific habitat requirements provided in this guide in order to determine how the proposed restoration may benefit or influence lamprey. For example, a simple modification of a proposed action, such as the placement location or orientation of large wood to the streamflow to promote sediment deposition may be effective at developing habitat suitable for larval rearing.

In the Methow River watershed, a salmonid-based instream complexity restoration effort at Whitefish Island was implemented with the habitat needs of lamprey as a design consideration. Several engineered wood structures were placed in locations deemed appropriate to develop accumulations of sediment. Within one year post-construction, ammocoetes were observed in Type I habitat that formed around the installed wood.

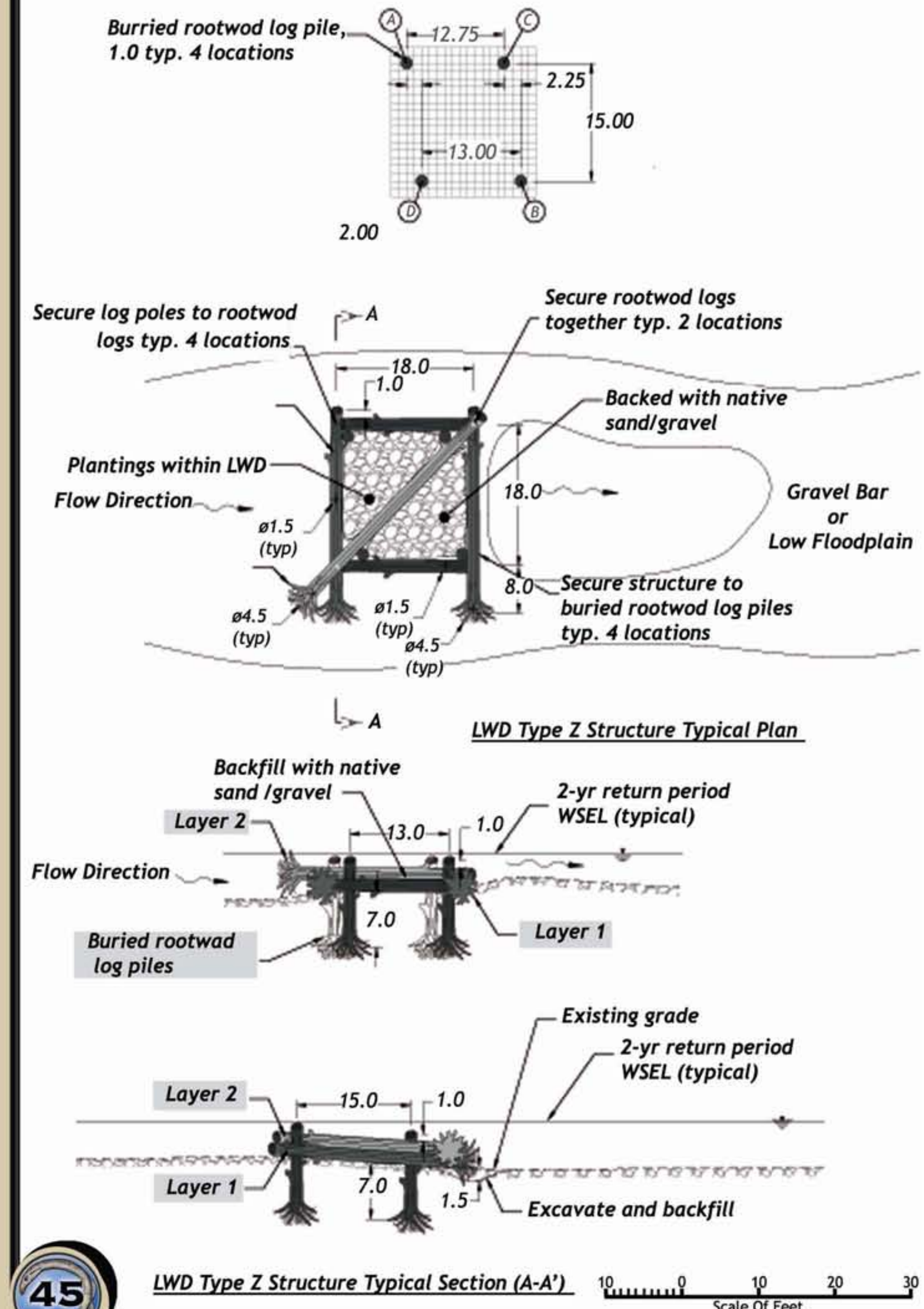
Engineered wood structures, like this example at the Whitefish Island Project in the Methow River, can promote sediment deposition that helps create attractive habitat for ammocoetes.

Another approach to installation of large wood uses existing riparian trees to secure installed wood. Logs are installed between standing trees that "pinch" them into place in a sort of log mesh. Once secured into these locations the lateral forces of stream flow will work against the natural buoyancy of the installed wood to lock the wood in place.

This type of restoration requires thoughtful planning and implementation. Many instream restoration efforts experience challenges as the project takes shape, from permitting hold-ups to unforeseen site characteristics and weather. It is important to maintain as much flexibility as possible while adhering to project goals, best management practices and permit requirements.

Wood Structure Design Elements From Whitefish Island Project Methow River

See USBR's Methow Subbasin-Whitefish Island Habitat Improvement Project report for complete engeneering design.



Instream Flow

Many streams in the Columbia River Basin suffer from diminished instream flows that reduce the extent and availability of fish habitat. Low flows also commonly lead to increases in water temperature, algal growth, and reduced sediment oxygen which are detrimental to lamprey. Where possible, restoration of instream flow with a goal to develop a more natural hydrograph is an action that will benefit lamprey.

Several different approaches to instream flow restoration have been used in the Columbia River Basin. The placement of irrigation water rights into instream trust flows (i.e. water banking) is a method that has gained widespread stakeholder approval. There exists a great deal of flexibility in how these trust flow agreements are constructed and they can be used to gain flow during critical low flow periods that may impact lamprey. More information on water savings programs can be found at: http://www.tu.org/tu-programs/western-water.

Another example of how instream flow can be used to benefit lamprey involves instream restoration techniques to re-connect side channels with perennial flow. The Whitefish Island project in the Methow watershed re-established perennial flow into a side channel adjacent to the Methow River. This effort re-established hydrological functions to a backwater alcove that now provides suitable ammocoete rearing habitat with perennial connection to the river. A key to this type of restoration for lamprey is ensuing that adequate flow and oxygen are available for rearing ammocoetes.

Alocating water for instream purposes can increase habitat availability for lamprey and other aquatic species.

Section 6 - Monitoring

Monitoring of Pacific Lamprey can be a useful tool in the development of restoration projects and the assessment of their effectiveness. Monitoring can also be used to determine lamprey presence in an area where their status is uncertain. The simple knowledge of lamprey presence within a given stream is a critical first step in developing restoration projects and other actions to benefit them. Monitoring can also be used to document distribution and abundance to track population status and trends.

As with any monitoring program, the goals and objectives should be determined prior to heading out in the field. Well defined objectives will lead to the development of a monitoring plan that can meet goals in an efficient manner. Those interested in monitoring for lamprey are strongly encouraged to consult with local biologists prior to initiating any monitoring activities, as well as with federal, state, and tribal permitting agencies, as a valid scientific collection permit is required to handle Pacific Lamprey.

Adult Pacific Lamprey can be difficult to detect in many streams, but potential spawning areas and around passage barriers are good locations to perform visual surveys. The timing charts on pages 21-22 can help determine the general windows of time when adults or redds would be expected in a given stream. Adult lamprey in winter holding habitat may be especially difficult to locate as they commonly hide under large boulders, bedrock and other hard to reach places. In many locations, spawning of Pacific Lamprey may coincide with steelhead spawning. Pacific Lamprey redds are much smaller compared to steelhead and generally lack the defined tailspill present in steelhead redds. Additional information to assist with the development of a monitoring program can be found on page 53.

Locating redds is a technique for determining lamprey distribution in some streams, but spawning adults and areas can be difficult to locate.

Searching for ammocoetes is perhaps the easiest method to determine lamprey presence in a given stream or reach. If ammocoetes are detected, it can be assumed that adult lamprey are seasonally present nearby or upstream of that location. Thus, determining the upstream extent of ammocoete presence is one method than can be used to develop an understanding of the extent of adult distribution. Searching for ammocoetes downstream of (behind) a fish screen can provide valuable information on the ability of the screen to prevent entrainment.

Ammocoetes are relatively easy to detect with electrofishing techniques that effectively remove them from their burrows so they can be captured in nets. While conventional electrofishers can be used to sample for ammocoetes, they typically use higher voltages and frequencies that can be harmful to ammocoetes and other fishes. Ammocoetes are best sampled using a two-stage backpack-style electrofisher equipped with a “tickle” setting that coaxes ammocoetes from the substrate and a second “stun” setting that is used to immobilize them for capture in dip nets after they have emerged from the substrate. Models of this type of electrofisher include the AbP-2 from ETS Electrofishing and the “lamprey setting” of the LR-24 made by Smith-Root.

Electrofishing is a common technique used to assess ammocoete presence.

In the Columbia River Basin, it has been useful for those involved with lamprey monitoring to use standardized electrofisher settings when monitoring ammocoetes, so that monitoring efforts are generally comparable across sites. It is recommended that individuals monitoring for lamprey utilize the settlings provided on page 49. When a dual setting electrofisher is not available, turning down the voltage output on a standard electrofisher to 100-200 volts can be an effective substitute. Keep in mind that the effectiveness of electrofishers is related to stream conductivity, thus site specific conditions must be assessed.

Parameter	Primary Wave Form Burst Slow Pulse "Tickler"	Secondary Wave Form Standard Fast Pulse "Stun"
Voltage	125v	125v
Pulse Frequency	3Hz	30Hz
Duty Cycle	25%	10-15%
Burst Pulse Train	3:1	n/a

Typical electrofisher settings for ammocoetes sampling. These should be used as a starting point but may require adjustment to account for variations in conductivity.

The electrofishing techniques used will influence monitoring results, as will site characteristics such as streamflow, substrate, conductivity and water temperature. Adopting an occupancy type sampling protocol will provide a probabilistic estimate of the confidence in determining presence or absence (see Reid and Goodman 2015, page 53). The development of a standardized approach for the determination of ammocoete habitat preferences and abundance is currently under development.

Ammocoetes are most commonly found in Type I habitat (page 16), thus monitoring that concentrates effort in that type of habitat stands the highest probability of locating ammocoetes. Due to operator and equipment safety, backpack electrofishing will be most effective in water less than about 3 feet (1 meter) deep. A two person monitoring crew is helpful with one person operating the electrofisher and one person netting. The netter or a third staff person should carry a bucket to hold captured ammocoetes. The pace of electrofishing for ammocoetes should be relatively slow and methodical within a given habitat patch, but care should be taken to limit the overall time that ammocoetes are exposed to the electrical field to reduce the risk of injury to them. Ammocoetes tend to recover rather quickly from electrofishing, but release back into the water should be delayed if they show any signs of lethargy.

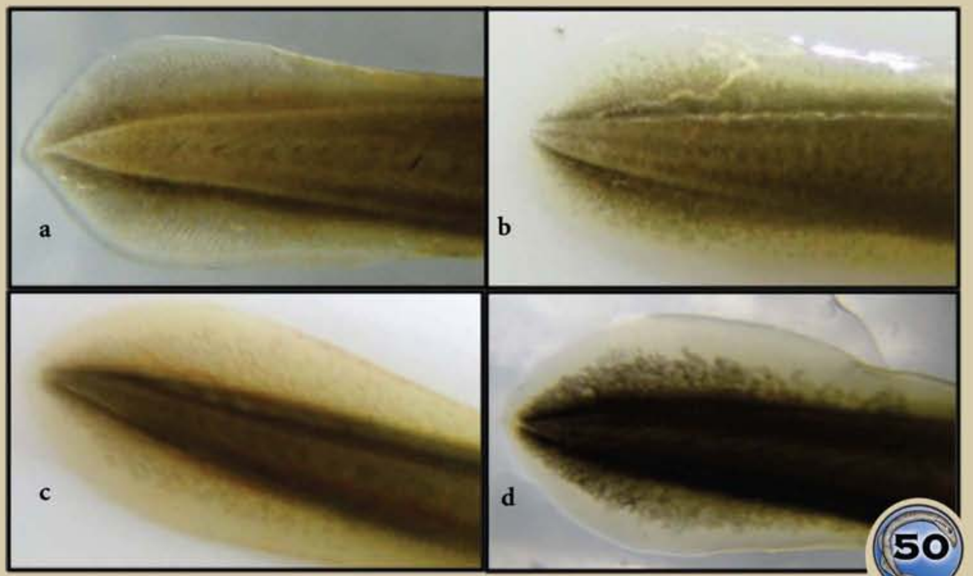
It is important to note that the direction of sampling should generally proceed upstream to minimize sediment disturbance to water clarity, which can affect visual detection of ammocoetes as they emerge out of the substrate. Keep in mind that when eddies and other current anomalies are encountered, the direction of sampling may actually be downstream but into prevailing currents.

Upon capture, ammocoetes should be handled carefully and gently. They are very tricky to handle and having trained staff on hand to assist is highly recommended. Ammocoetes may be most easily handled when anesthetized. If possible ammocoetes should be indentified to species (see page 50), and measured to the nearest millimeter. Specific handling gear such as a V-shaped board, Ziplock bag, or Wild Fish Conservancy photarium for lengths are extremely useful. Other data can be collected at this time, if necessary, such as tissue clips for genetic analysis. It is also possible to mark ammocoetes with visible elastomer tags, but this should only be done by experienced personnel.

A Photarium can be used to help safely hold ammocoetes underwater for species identification and length measurement.

Species Identification

Caudal (tail) fin morphology is a helpful feature in the identification of ammocoetes and can be used in the field to distinguish Pacific Lamprey from Western Brook and River lamprey. The caudal fin of Pacific Lamprey has a band of dark pigmentation that extends out from the caudal ridge of the body which is predominantly lighter in color (a and b). The caudal fin of Western Brook or River lamprey is either entirely translucent (c) or has a narrow band of pigment near the base with a translucent border (d); in both cases the color of the tail is about the same as the body. Additional resources for identification can be found on page 53.



Section 7 - Resources

Rangewide				
Stewart Reid	Western Fishes	Ashland, OR	westernfishes@opendoor.com	(541)890-1669
Bianca Streif	USFWS	Portland, OR	bianca_streif@fws.gov	(503)231-6978
Mary Moser	NOAA	Portland, OR	mary.moser@noaa.gov	(206)860-3351
Lower Columbia River				
Christina Wang	USFWS	Vancouver, WA	chritina_wang@fws.gov	(360)604-2583
Carrie Cook-Tabor	USFWS	Lacey, WA	Carrie_Cook-Tabor@fws.gov	(360)753-9440
Brian McIlraith	CRITFC	Portland, OR	mcib@critfc.org	(503)731-1284
Wilamette River				
Luke Schultz	OSU	Corvallis, OR	Luke.Schultz@oregonstate.edu	(541)737-1964
Mid-Columbia River				
R.D. Nelle	USFWS	Leavenworth, WA	RD_Nelle@fws.gov	(509)548-7573
Ralph Lampman	Yakama Nation	Toppenish, WA	lamr@yakamafish-nsn.gov	(509)388-3871
Aaron Jackson	Umatilla Tribes	Hood River, OR	aaronjackson@ctuir.org	(541)276-3447
Snake River				
Jody Brostrom	USFWS	Salmon, ID	jody_brostrom@fws.gov	(208)756-5162
Christopher Peery	USFWS	Orofino, ID	chris_peery@fws.gov	(208)476-2257
Upper Columbia River				
R.D. Nelle	USFWS	Leavenworth, WA	RD_Nelle@fws.gov	(509)548-7573
John Crandall	MSRF	Twisp, WA	john@methowsalmon.org	(509)341-4341

Additional Resources by Section

Section 2 Biology and Ecology

Beamish, R.J. 1980. Adult biology of the River lamprey (*Lampetra ayresi*) and the Pacific lamprey (*Lampetra tridentata*) from the Pacific Coast of Canada. Canadian Journal of Fisheries and Aquatic Science 37:1906-1923.

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Keefer, M.L., M.L. Moser, C.T. Boggs, W.R. Daigle, and C.A. Perry. 2009. Variability in migration timing of adult Pacific lamprey (*Lampetra tridentata*) in the Columbia River, U.S.A. Environ Biol. Fish 85:253–264.

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Section 3 Threats

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Natural Resources Conservation Service. 2011. Pacific Lamprey and NRCS: Conservation, Management and Guidelines for Instream and Riparian Activities. Biology Technical Note No. 51. 30p.

Section 4 Best Management Practices

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Streif, B. 2009. Considering Pacific Lamprey when implementing instream activities. In Biology, Management, and Conservation of Lampreys in North America. Brown, L.R., S.D. Chase, M. G. Mesa, R. J. Beamish, P. B. Moyle, editors. 321 pages. Published by the American Fisheries Society. ISBN: 978-1-934874-13-4.

U.S. Fish and Wildlife Service. 2010. Best management practices to minimize adverse effects to Pacific Lamprey (*Entosphenus tridentatus*). Compiled by: Jody K. Brostrom and Christina Wang Luzier, U.S. Fish and Wildlife Service and Katherine Thompson, U.S. Forest Service. 25p.

Section 5 Restoration

CRITFC (Columbia River Intertribal Fish Commission). 2011. Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin. Access: http://www.critfc.org/wp-content/uploads/2012/12/lamprey_plan.pdf.

Moser, M.L. and M.G. Mesa 2009. Passage Considerations for anadromous lampreys. In Biology, Management, and Conservation of Lampreys in North America. Brown, L.R., S.D. Chase, M. G. Mesa, R. J. Beamish, P. B. Moyle, editors. 321 pages. Published by the American Fisheries Society. ISBN: 978-1-934874-13-4.

Section 6 Monitoring

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U.S. Fish and Wildlife Service. 2010. Best management practices to minimize adverse effects to Pacific Lamprey (*Entosphenus tridentatus*). Compiled by: Jody K. Brostrom and Christina Wang Luzier, U.S. Fish and Wildlife Service and Katherine Thompson, U.S. Forest Service. 25p.

Web Links

Pacific Lamprey Restoration Guide
http://www.methowsalmon.org/

Columbia River Inter-Tribal Fish Commission Lamprey Restoration
http://www.critfc.org/salmon-culture/columbia-river-salmon/columbia-river-salmon-species/the-pacific-lamprey/lamprey-plan/

USFWS Lamprey Homepage
http://www.fws.gov/pacific/Fisheries/sphabcon/lamprey/index.cfm

Pacific Lamprey Data Clearing House (USGS)
https://www.sciencebase.gov/catalog/folder/53ad8d9de4b0729c15418232

Pacific Lamprey Mapping Interface
http://nplcc.databasin.org/datasets/fb4c6a49a017424b8c78e81ec55a1927

Pacific Lamprey Habitat Restoration Guide

Pacific Lamprey throughout the Columbia River Basin have declined at an alarming rate over the past decades and have been extirpated in many Upper Columbia and Snake River subbasins. These ancient fish are also at risk of becoming extirpated from more streams in the near future. The reasons for this are complex and intertwined, but include such threats as habitat loss, reduced passage success at dams, historic overfishing, non-native predators, and ocean conditions.We must act now to identify and understand the habitat needs of Pacific Lamprey and incorporate this knowledge into habitat restoration, water management, and education programs in the Columbia River Basin.

Thoughtful instream and riparian habitat restoration projects can assist with recovery of Pacific Lamprey.

Similar to Pacific Lamprey, many salmon and steelhead populations in the Columbia River Basin have also declined, and a significant effort to restore habitat conditions for these salmonids is currently underway. Salmonid-based habitat restoration projects in the Columbia and Snake Rivers are based on addressing limiting factors and ecological needs of these important fish. While the majority of these projects are focused on salmonids, there is a unique opportunity to incorporate the habitat needs of Pacific Lamprey into this salmonid-based habitat restoration effort.

One reason for a lag in the development of lamprey-specific restoration has been a lack of an accessible source for technical information related to enhancement of lamprey populations. The *Pacific Lamprey Habitat Restoration Guide* provides a detailed description of the biology, ecology, and cultural significance of Pacific Lamprey as well as summary of the threats they face and best management practices that can implemented to benefit them. It provides a blueprint for the enhancement of Pacific Lamprey habitat in order to restore these imperiled and vital populations of fish.

Methow Salmon Recovery Foundation views lamprey as an integral component of healthy watersheds and supports efforts to restore its habitat.