Best Management Guidelines for Native Lampreys During In-water Work

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Lamprey Technical Workgroup

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Questions? *Email info@pacificlamprey.org*

TABLE OF CONTENTS

APPENDICES

Goals

The goals of this document are to provide guidelines to: 1) minimize impacts to native lampreys during in-water work and 2) improve instream habitat restoration projects to benefit native lampreys. In-water work refers to human activities that can disturb lampreys and their habitats. This includes dewatering, habitat restoration, culvert installation, and dredging, which are often implemented with little to no protections for lampreys. The guidelines are intended to help all entities incorporate lampreys into their in-water work plans, and the design and implementation of instream habitat restoration, regardless of the target fish species. Additional guidance is mentioned throughout this document for native freshwater mussels, another often overlooked ecologically important species in decline. Mussels are included to increase awareness and conservation efforts of these species in the restoration community, and help support a multi-species approach to restoration. For more complete information on freshwater mussels, we strongly encourage readers to review Blevins et al. (2017, 2019; see also Appendix A).

1. Introduction

Consideration of lampreys in the early planning, implementation, and post-monitoring phases of in-water work activities can be beneficial, with little added effort or cost (Streif 2009); this also applies to freshwater mussels. Because the state of the science of lampreys is changing rapidly, these guidelines are a "living document" that will be updated periodically: these guidelines should not be viewed as rigid prescriptions of what should be carried out in every in-water work activity. In all situations, coordination with local biologists and site-specific monitoring prior to in-water work will help to understand which lampreys, life stages, and mussels are likely to be encountered.

This document updates and combines information from some aspects of the 2010 Best Management Practices (USFWS and USFS 2010) and the Pacific Lamprey Habitat Restoration Guide (Crandall and Wittenbach 2015). These guidelines cover lamprey biology and habitat use, considerations for in-water work planning and implementation, salvage techniques, handling, and short-term holding procedures for lampreys. The guidelines are primarily informed by work on Pacific Lamprey in the Columbia River Basin, and may need modification for less studied lamprey species and locations.

Awareness of Pacific Lamprey has increased as their abundance and distribution has declined over the last several decades. Primary factors contributing to this decline include impeded passage at artificial obstructions, altered flows, degraded water quality, degraded stream and floodplain habitats, and establishment of non-native fishes that prey on lampreys (CRITFC 2011; Clemens et al. 2017; USFWS 2019).

Guidelines that consider Pacific Lamprey will *generally* benefit other native lampreys, as they share several life histories and habitat requirements. However, information on lesser known lamprey species is lacking. Knowledge gaps for other lampreys and locations may be filled by seeking advice from local biologists and conducting pre-project monitoring. The same guidance applies to freshwater mussels. Case studies and additional information follow in the appendices. More information on status assessments, limiting factors, and biology of Pacific Lamprey and freshwater mussels can be found in the References cited and Appendices. Questions may also be submitted to info@pacificlamprey.org.

2. Lamprey Biology and Habitat Use

Fourteen species of lampreys occur along the west coast of North America (Table 1; Potter et al. 2015). Pacific Lamprey, Western Brook Lamprey and Western River Lamprey are the most widely distributed. Six of the 14 lampreys are freshwater residents that do not feed after transforming from filter-feeding larvae. Five of the 14 are freshwater residents that, as juveniles, parasitize other fishes in streams and lakes. The remaining three species are anadromous and parasitize fishes and other animals in the estuary and ocean. Rivers within northern California and southern Oregon exhibit the most diversity: six species are endemic to the Klamath River Basin (Renaud 2011; Potter et al. 2015). A generalized life history description follows, with additional information specific to Pacific Lamprey mentioned throughout (see Figures 1 and 2).

Larval lampreys are 8 – 203 mm, whereas adults are 76 – 838 mm (Renaud 2011). The largest species are parasitic as adults. Transformed individuals of parasitic lampreys have eyes and mouths that are relatively large compared with their body sizes. The sucker disc mouths of parasitic lampreys possess sharp teeth and other adaptations for feeding on the blood, body fluids, or flesh of host species. All lampreys are nocturnal. During the day, larvae tend to stay in burrows at the bottom of the streambed and upstream migrating adults tend to conceal themselves with some form of cover. Larvae and juveniles enter the water column to migrate or relocate downstream; adults migrate upstream at night (Clemens et al. 2010; Moser et al. 2015a, 2015b).

Recently hatched larvae with a yolk sac (prolarvae) remain in the nest (redd) for 2 – 3 weeks after hatching (Lampman et al. 2016). About 3 – 5 weeks after egg fertilization, larval lampreys (~8 mm) disperse downstream into suitable burrowing habitat and begin to feed. Typical burrowing habitat is soft, silty, depositional areas (Schultz et al. 2014). The larval life stage lasts up to 8+ years and are present in nearshore habitats year-round. Within their burrows, larvae orient with their funnel-shaped mouths towards the substrate/water interface, and they filter feed on fine particulate matter; they also deposit feed within substrate. Larval lampreys may exit the substrate at night to move upstream or downstream and re-burrow in new locations. Larval lampreys migrate throughout the year, often facilitated by high river flows (Dawson et al. 2015; Moser et al. 2015a).

Physiological and environmental cues trigger transformation in larval lampreys, and larvae of parasitic species transition from filter feeders to parasitic juveniles over ~ 100 days (McGree 2008). For Pacific Lamprey, transformation typically begins during the summer months. During

Table 1. Lampreys of the West Coast of North America (excludes Mexico). "A" = anadromous; "R" = resident; "P" = parasitic; "NF" = non-feeding (do not feed as adults). (*) = unresolved taxonomy.

Scientific name	Common name	Life history	Distribution
Anadromous Species			
Entosphenus tridentatus	Pacific Lamprey	A, P	Widely distributed between CA & AK
Lethenteron camtschaticum	Arctic Lamprey	A, P	Rivers entering the Arctic and North Pacific oceans (AK)
Lampetra ayresii	Western River Lamprey	A, P	Southern CA to Southeast AK
Resident Species			
Entosphenus macrostomus	Vancouver Lamprey	R, P	Lake Cowichan Basin, Vancouver Island, BC
Lethenteron alakense	Alaskan Brook Lamprey	R, NF	Brooks and Chatanika river basins, AK; Mackenzie River, Canada
Lampetra pacifica	Pacific Brook Lamprey	R, NF	Lower Columbia (WA & OR) and Willamette River Basin (OR); Coastal rivers (OR)
Lampetra richardsoni	Western Brook Lamprey	R, NF	Northern CA to Southeast AK
Lampetra hubbsi	Kern Brook Lamprey	R, NF	Merced River and Friant – Kern Canal, CA
Klamath Basin Resident Species			
Entosphenus minimus	Miller Lake Lamprey	R, P	Upper Klamath River Basin, OR
Entosphenus similis	Klamath River Lamprey	R, P	Klamath River Basin, OR & CA
Entosphenus folletti	Northern California Brook Lamprey	R, NF	Klamath River Basin, CA
Entosphenus lethophagus	Pit-Klamath Brook Lamprey	R, NF	Klamath River Basin, OR; Goose Lake, OR & CA; Pit River, CA
Entosphenus spp. *	Klamath Lake Lamprey	R, P	Klamath River Basin (Upper Klamath Lake), OR
Entosphenus spp.*	Goose Lake Lamprey	R, P	Goose Lake, OR & CA

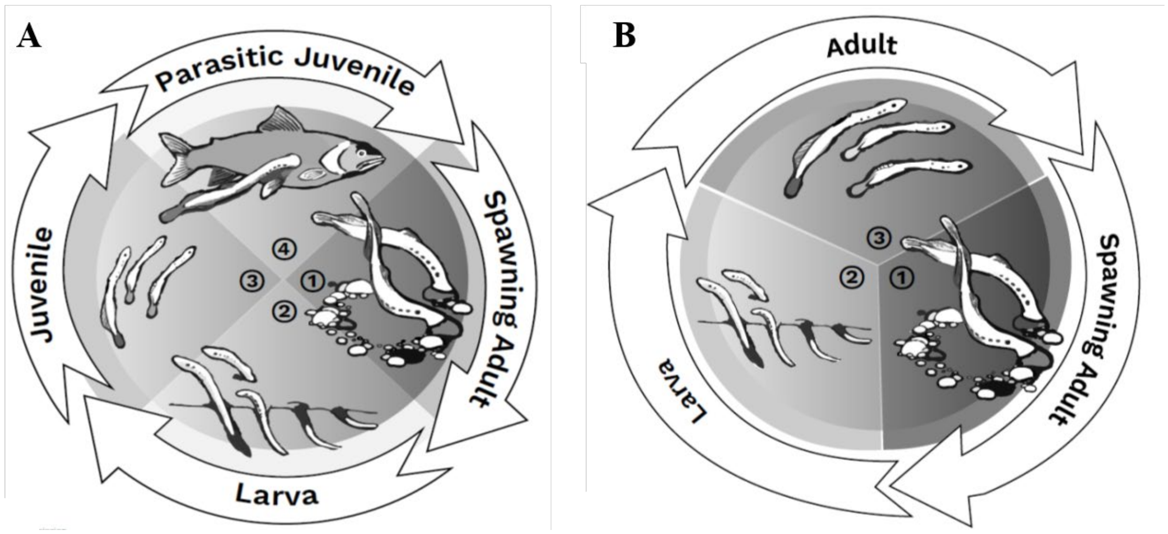

Figure 1. Lamprey life cycles for parasitic lampreys (A) and resident lampreys (B). The numbers "*1*" and "*2*" refer to spawning adult and larval rearing life stages, respectively, for both A and B. For A, "*3*" or *"juvenile"* represents the outmigrant life stage, and "4" represents the parasitic life stage. Original graphic courtesy of the Great Lakes Fishery Commission, modified from Hansen et al. (2016) by Rinee Merritt, Oregon Department of Fish and Wildlife.

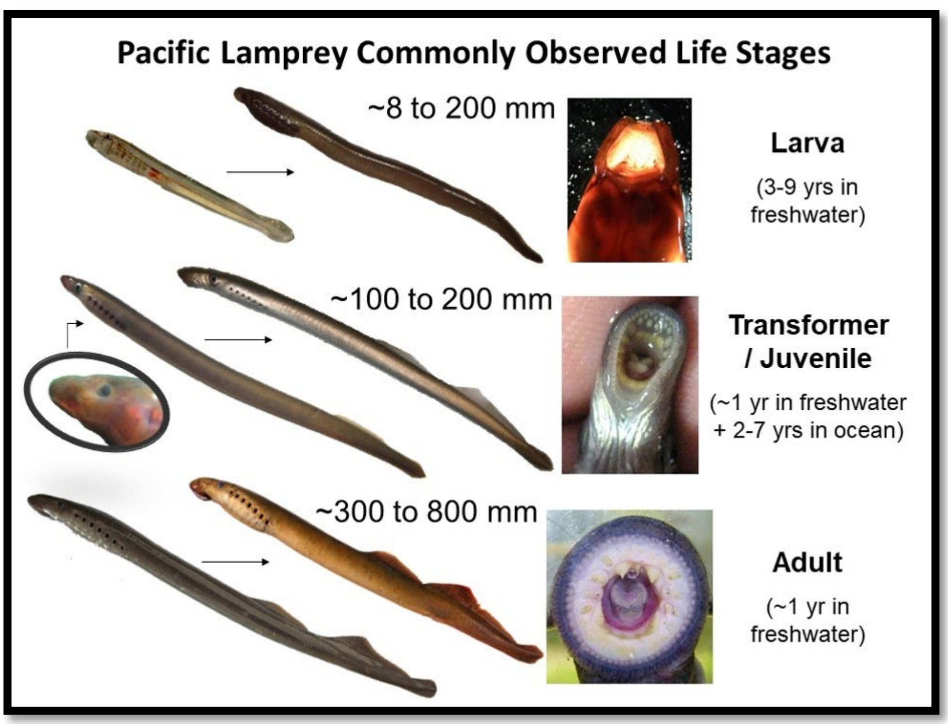

Figure 2. Pacific Lamprey life stages. From top to bottom, larva (first feeding to larger size), transformer (with two stages of emerging eye), juvenile (fully transformed silver body), and adult (migrant recently re-entering freshwater to sexually mature). Credit: R. Lampman.

transformation, larvae undergo color changes, develop eyes, and their mouths change from a funnel-shaped opening to a sucker disc (Manzon et al. 2015). Fully transformed juveniles tend to be found in or near the surface of the substrate, and can be associated with gravel and cobble (Dawson et al. 2015). Anadromous juvenile lampreys have a protracted downstream migration, moving in association with increasing flow and/or high streamflow events (Moser et al. 2015a). The timing of this outmigration varies by the location and size of river systems along the West Coast (Clemens et al. 2019).

Spawning generally occurs in the spring and summer, but depends on the species, latitude and local hydrograph (Stone et al. 2006; Gunckel et al. 2009; Clemens et al. 2010). Resident lampreys will spawn almost one full year after transformation begins, whereas parasitic lampreys will spend 1 – 7 years feeding prior to spawning. Relatively low flows and warm water temperatures are associated with earlier spawning; relatively high river flows and cool water temperatures are associated with later spawning periods (Brumo et al. 2009); timing will vary geographically. Spawning adults may remain active during the day. Lampreys excavate redds by attaching their mouths to rocks and moving them to the perimeter of a circular depression. Lampreys may spawn in pairs, as with larger species, or they may spawn in groups (all species; Johnson et al. 2015). All lampreys die after spawning (Johnson et al. 2015; Clemens 2019).

Habitats

Larval lampreys are burrowed in the fine sediments year-round, often in depositional areas along stream margins. As lampreys grow and transform, they gradually shift from fine sediments, defined as Type I habitat, to coarser substrates, defined as Type II / III habitat (Table 2; Figure 3; Dawson et al. 2015). In general, larval lampreys are more abundant in Type I habitat.

Habitats used by larval and juvenile lampreys year-round include:

- Depositional areas with low consistent velocities that recruit fine sediment (sand, silt, and clay) and organic matter provide ideal larval lamprey rearing habitat (Type I; Table 2).
- Larval lampreys primarily use fine sediment (Type I), whereas juveniles use coarser substrate (Type II habitats; Table 2).
- Larval lampreys have also been documented anecdotally using dense branches of submerged conifer trees as refuge habitat (Clackamas Basin).

Habitats used by adult lampreys (primarily Pacific Lamprey) include:

- Coarse substrates (large cobble, boulders, and bedrock) and large wood that create crevices in deeper waters with steady flow generally provide quality holding habitat for pre-spawn adults.
- Adult Pacific Lamprey have also been found burrowed in loose sand.
- Spawning habitat: Low gradient pool tail-outs and deeper riffles with a diversity of substrate (primarily gravel and cobble with some coarse sand) provide ideal spawning habitats for lampreys (Gunckel et al. 2009). Lamprey can also spawn in small pockets of coarse substrate in predominantly bedrock, boulder, or fine sediment areas.

- Pacific Lamprey redds are typically round and 20 – 60 cm in diameter with substrates deposited on the edges containing large gravels and small cobbles (Figure 4a and b). Redds with several spawners are much larger and spawning can also occur in bedrock or boulder dominant habitat (Figure 4d). In contrast, steelhead redds are typically larger, oval-shaped with larger tail-spill mound only on the downstream end.

Table 2. Lamprey habitat types and associated life stages (after Slade et al. 2003).

Habitat type	**Description**	**Associated life stage**
Type I	Depositional areas with low, consistent velocities, fine sediments (sand, silt, and clay) and organic matter: often in off-channel habitats (e.g. channel margins, backwater eddies, alcoves, perennial side channels, Figure 3).	Larvae
Type II	Areas with fine sediments mixed with coarse substrate (gravel, cobble, boulder), or shifting sand with no organic matter; often slightly higher velocities than Type I habitats (Figure 3).	Larvae and juveniles (eyed)
Type III	No fines; various combinations of hardpan clay, coarse substrate, and bedrock (Figure 3).	Juveniles (eyed) and adults
Spawning	Commonly spawn in pool tail-outs with gravel and cobble substrates, but variation occurs (Figure 4).	Adults

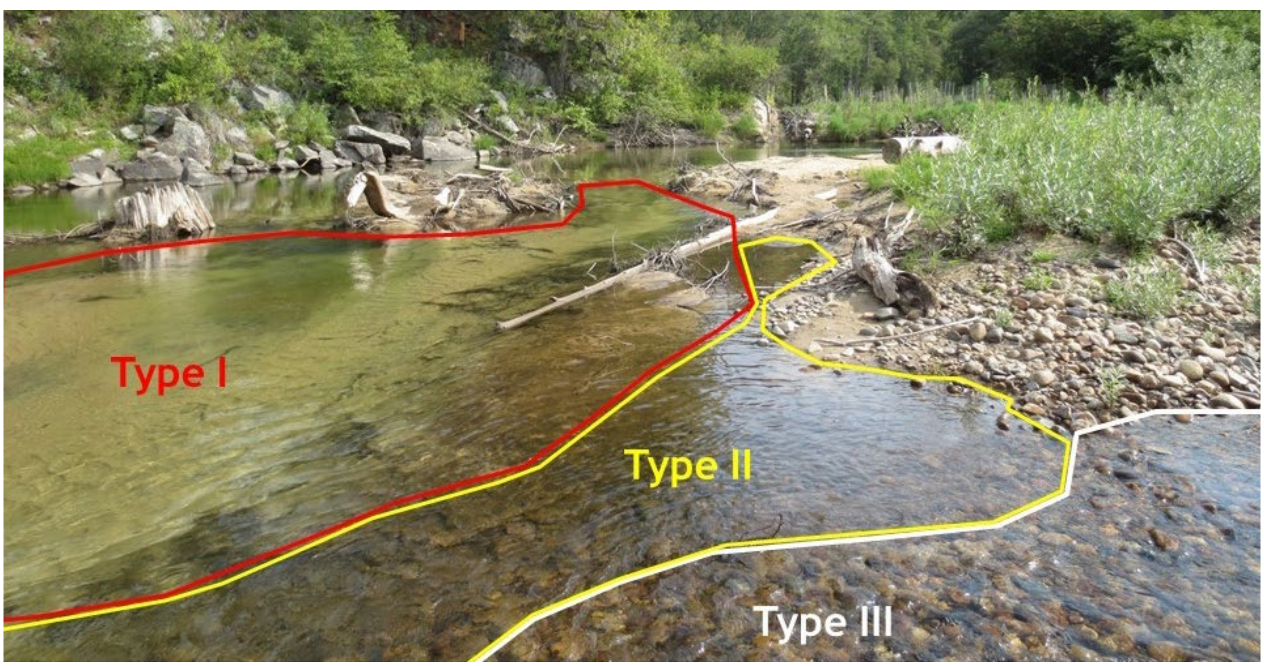

Figure 3. Example of Type I, II and III habitats used by lampreys. Credit: R. Lampman.

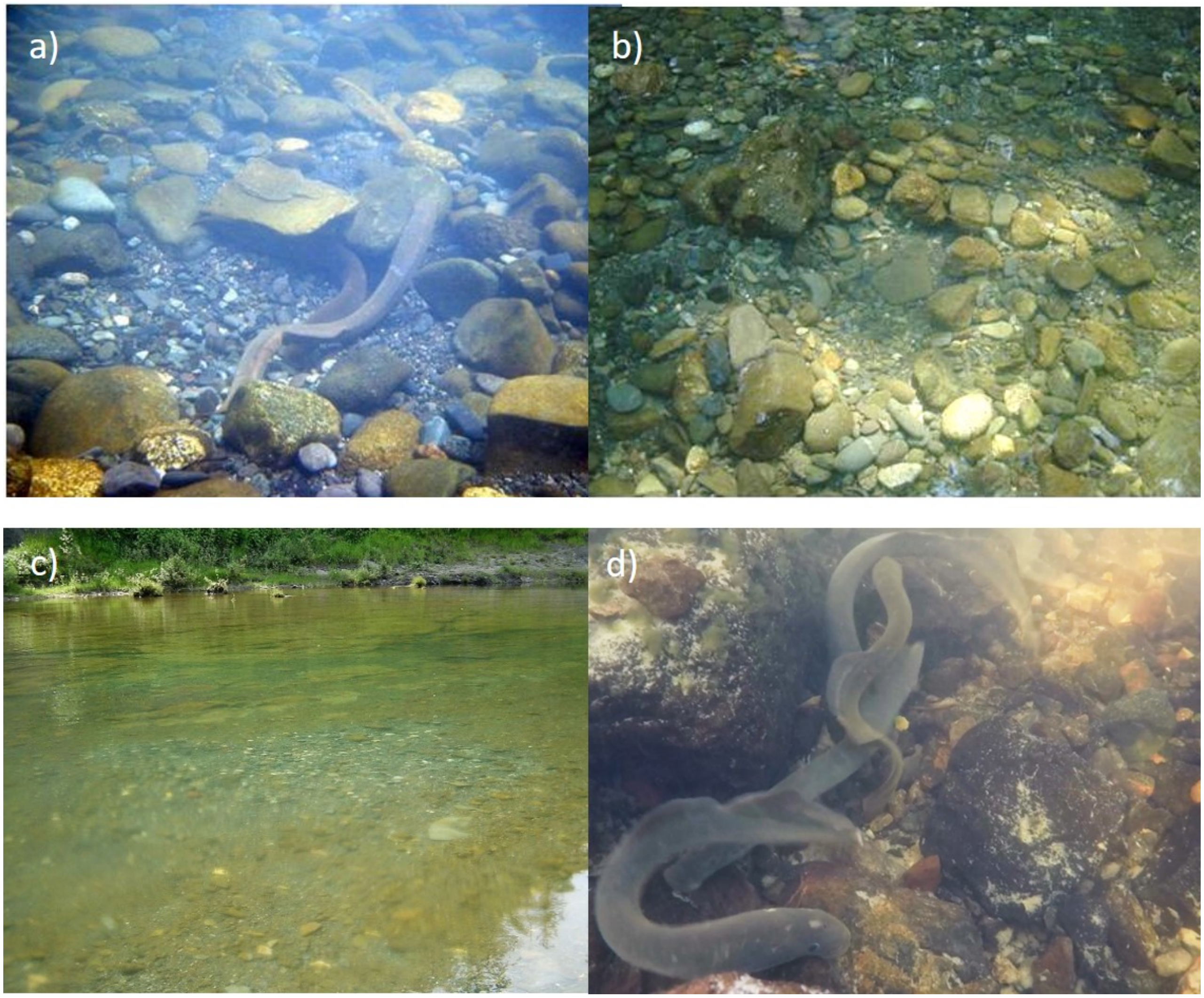

Figure 4. Examples of Pacific Lamprey redds. Photos a) and b) represent typical Pacific lamprey redds. Photos c) and d) are examples of atypical or less easily detected redds. Photo credit: A. Brumo (a –c); R. Litts (d).

3. Planning for In-water Work

All in-water work activities can impact lampreys and mussels and their habitats. Consideration of these species in the early planning, implementation, and post-monitoring phases of in-water work activities can benefit them considerably, often with little added effort or cost (Streif 2009). Unfortunately, many projects, including stream restoration do not address protection and improvements for these species. Minimizing impacts to lampreys and mussels at the project site begins at the planning phase by:

1) identifying existing habitats where lampreys and mussels may be encountered via pre-project monitoring;

2) determining timing of lamprey spawning and migration periods, to avoid in-water work;
3) modifying the project in terms of timing, location and restoration design, based on information collected in 1) and 2) above.

Each of these topics is discussed in the following sections. If impacts to lampreys and mussels are unavoidable, salvage should be done (Section 5.0).

Pre-Project Planning and Monitoring

Initial pre-project restoration planning and monitoring should include specific habitat reconnaissance for potential lamprey use, and a review of available basin migration and spawning information for lampreys. Next, identify key areas for collection of lampreys and develop a general salvage plan, including an estimate of the magnitude of the salvage effort, and necessary equipment and personnel. Because native freshwater mussels are also in decline and often found in habitats that support lampreys, efforts to address this species should also be incorporated (please consult Blevins et al. 2017 & 2019 for comprehensive information).

- Obtain necessary permits for pre-monitoring, salvage and in-water work as appropriate with sufficient lead time for timely implementation of all needed activities and affected species.
- Use appropriate protocols to disinfect all field gear to prevent the spread of aquatic invasive species and disease (example protocol and other information provided in Appendix B).
- Coordinate with local biologists regarding existing lamprey and mussel distribution data, data needs, and release locations.
    - For available information on line for lamprey distribution, see www.databasin.org.
    - Coordinate with the Lamprey Regional Management Unit Team in your area (open for all to participate; email: info@pacificlamprey.org for more information to ask for technical advice from the Lamprey Technical Workgroup).
    - Mussel distribution: Contact Xerces Society at mussels@xerces.org.
- Examine areas for spawning fishes or recent redds (lampreys or salmonids) and avoid disturbance, if possible.
- Gauge location and rough area of native mussel beds and density of mussels. Avoid disturbance, or salvage if avoidance not possible (Blevins et al. 2017, 2019).
- Gauge rough densities of larval lampreys (e.g. low vs high numbers) burrowed in the Type I habitats using lamprey-specific electrofishing gear and settings (Appendix C).
- Gauge rough densities of other fishes (e.g. salmon, sculpin) via snorkeling or electrofishing (see NMFS 2000 for electrofishing guidelines). Sample for other fishes after larval lampreys to minimize lamprey injury while using salmon-specific electrofisher settings.

In-Water Work Location

Identify where in-water work and potential restoration actions have the greatest impacts (both positive and negative) to lampreys at the project site:

- Identify locations of suitable and occupied lamprey habitats (existing and planned) by life stage (Section 2.0 subheading: "Habitats").
- Identify locations of existing mussel beds.

Areas of high densities of larval lampreys and mussel beds should be identified in all locations before in-water work. In-water work in such areas should be avoided and remain watered during in-water work to avoid impacts to these species. For restoration actions, we recommend incorporating such areas into the restoration design if possible, as these areas are already providing high quality habitats.

Larval lampreys and mussels are burrowed in the sediments year-round. Determining their pre-project use at the project site during restoration planning is essential to their conservation. A single dewatering event, physical disturbance, or contamination event may impact multiple year-classes of local populations, because these organisms cannot quickly move out of danger. Larvae are often found in depositional areas along the stream margins, which often dry up first during a "work area isolation" event. Thus, larvae can desiccate unobserved while salvage operations focus on the deeper pools and primary instream areas. If impacts cannot be avoided, efforts to salvage larvae and mussels are needed (Section 5.0).

In-Water Work Timing

Use available and site-specific information to determine the best project timing to avoid impacts to the migration and spawning of lampreys (Figures 1 & 2), and modify the timing of your project if possible. Note that in-water work windows were developed to avoid impacts to salmon life histories and do not account for lampreys. Specific efforts to determine potential lamprey habitat use and timing should be made during planning.

In-water work should avoid disturbing spawning, incubation and post-hatch emergence periods of lampreys. Ideally, larval lampreys should also not be disturbed; however, this life stage is more amenable to salvage than the other life stages. For Pacific Lamprey in the Columbia River Basin, generally avoid working in streams during these periods of spawning[1]:

- March 1 – July 1 in lower elevation coastal basins with rainwater fed streams.
- April 1 – August 1 in higher elevation interior basins with snowmelt fed streams.

Lamprey redd surveys are recommended prior to instream actions in potential lamprey spawning areas. If redds, or potential redds, are observed (see Figure 4, and Section 2.0), actions should be delayed an additional 2 – 4 weeks to accommodate egg maturation and larval dispersal, if possible. For Pacific Lamprey, general life history timing in the Columbia River Basin is summarized in the following bullets:

[1] *Deviations from this pattern can occur among Pacific Lamprey within the Columbia River Basin and for other lampreys and other locations. Monitoring for redds at your site is recommended.*

- Larval lampreys of all age classes and species, and resident adult lampreys, can be present year-round; there is no in-water work window that can avoid impacts to them.
- Spawning typically starts when water temperature approaches 10 – 14˚C with a peak near 13 – 15˚C, but can continue up to about 20˚C.
- Adults and redds may be present in spawning areas from March – August (Figure 4). Young-of-the-year larvae emerge and settle into suitable habitat April – September.

Embryos hatch in about 1 – 3 weeks. Larvae drift downstream and settle into the substrate in low velocity, depositional areas approximately 1 – 3 weeks after hatching.

Modifying Projects to Benefit Lampreys

Habitat restoration projects that benefit salmonids *generally* benefit lampreys (Streif 2009). Projects designed to allow for a fully functioning stream and floodplain, including depositional areas, will provide suitable habitats for lampreys and mussels. Site assessments should examine any potential barriers (temporary or long-term) to lamprey up- and downstream passage and adjust to provide passage (see Case Study# 5 for a restoration site evaluation; Appendix D for passage information). Modifications to avoid impacts include:

- Adjust project implementation methods, timing, and location to protect spawning and migrating lampreys.
- Avoid disturbing or modifying occupied larvae habitats and mussel beds; if densely occupied, these are already functioning habitats and are best to be left "as is" and not impacted by in-water work or modified for restoration.
- Ensure unimpeded passage for up- and downstream lamprey migrations is provided, with suitable screening to reduce entrainment and prevent entry into unsafe areas, especially if dewatering a stream reach or using pumps for dewatering (Appendix D).

Most instream habitat restoration projects can benefit lampreys, even if they are not the target species. Incorporating the following recommendations into a restoration project can benefit lampreys:

- Modify restoration project plans early in the design phase to incorporate preferred lamprey habitats, and avoid modification of existing, high functioning habitats (e.g., occupied depositional areas, mussel beds).
- Incorporate the creation and enhancement of fine sediment depositional areas into restoration designs for larval lamprey and mussel habitats.
- Enhance off-channel habitat by enhancing lateral, perennial floodplain connectivity, and ensure such projects do not create ephemeral conditions that may strand lampreys and native mussels.
- Enhance and protect adult overwintering habitat by incorporating habitats that create crevices with large wood and coarse substrate, where adult lampreys can hold.
- Enhance and protect adult spawning habitat (e.g. pool tail-outs and deeper riffles).
- Large wood and pools can benefit larval lampreys (Roni 2003, Gonzalez et al. 2017).

- Process-based restoration is advisable, particularly in areas that typically have not been the focus of restoration, including medium to large streams and rivers (Homel et al. 2019).
- Modify passage project designs early on to incorporate lamprey passage and screening needs to ensure safe and timely passage (Appendix D).

4. Dewatering

Several techniques can be used to encourage escapement of lampreys during dewatering. Dewatering procedures (described below) are helpful to reduce salvage efforts and to minimize stranding of lampreys when extensive salvage is not feasible (e.g., drawdown of a large reservoir). However, many situations will require a combination of promoting escapement and salvaging (Case Studies 1, 2, 3, and 6 in Appendix E). If dewatering and salvage occurs over multiple days, re-watering the sediments during the evening hours can help larvae remaining in drying sediments to survive for salvage the following day, or provide additional escapement opportunities.

Lamprey habitats should be dewatered as slowly as possible, particularly as receding water levels begin to expose Type I habitats. Based on field observations in the Yakima Basin, up to 60% of the observed larvae in irrigation diversions were stranded on dry and drying banks when dewatering rates were high (>20 cm/h) (Lampman and Beals 2019). In a laboratory setting larval lampreys did not respond to changing head pressure and emerged only after burrowing habitat was exposed (Liedtke et al. 2015, Liedtke et al. 2020). Current recommended dewatering rates are ≤ 2.5 – 5 cm/h to allow as many larvae to emerge and escape into watered habitats (Liedtke et al. 2015; Skalicky et al. 2019; Liedtke et al. 2020).

If recommended rates are not feasible, alternative dewatering approaches are recommended to slowly expose larvae habitats over a period of several days to allow larval lampreys to escape into watered habitats. For example, reducing the water volume by 50% for the first 24 h, and then down to 25% of the original volume over the next two days, followed by 10 – 20% for a few days may work well in situations where larval lamprey habitat is concentrated in the lower 50% of the water volume. Similar methods could be employed using water surface elevations. The intent is to apply slower dewatering rates as Type I and II habitats begin to become exposed. Channel bank slope should also be considered: on steep (> 25%) banks with fairly uniform slopes, larval lampreys are more likely to move down the banks to find the new water line. However, on shallow slopes (< 10%) and uneven terrain with depressions and holes or debris, larvae are more likely to be stranded (Lampman and Beals 2019). Banks with shallow slopes will expose habitats at a faster rate.

Behavioral responses to dewatering varies widely and can depend on the time of day, substrate composition and larvae size. When salvaging lampreys, dewatering during the daylight hours is best to observe larvae. In addition, the presence of humans can deter predators from consuming exposed larvae. Dewatering during the nighttime may yield some benefits such as reduced predation from birds and potential increased activity from lampreys (Liedtke et al. 2020); however, additional studies are needed to determine benefits.

Larval lampreys can tolerate short periods of dewatering when conditions allow sediments to retain moisture (Liedtke et al. 2015). However, when sediment moisture decreases, substantial mortalities can occur within a few hours (Lampman and Beals 2019). Thus, dewatering during cool and moist periods of the day, set of days, or seasons and limiting the amount of time the sediment is dewatered to 12 – 24 h (ideally as short as possible) are potential approaches to increase lamprey survival when active salvage is not feasible.

Irrigation Diversions

Depositional areas in diversion canals may be occupied by all sizes of larvae and juveniles, because larvae are often entrained through the screens and rear in the canal (Lampman and Beals 2019). It is advised to dewater these areas as slowly as possible (see previous section). The goal should be to keep a continuously wetted channel as water levels drop to facilitate larvae egress out of the project area and into safe habitats (Case Studies 1, 2 and 3 in Appendix E).

Coordinate the initiation of dewatering to ensure the highest number of lampreys and mussels can be effectively salvaged during the work window (e.g., scheduling the dewatering early in the morning to ensure conditions are conducive for salvage by the time staff arrives). Ensure salvage staffing levels are adequate to cover the entire dewatered area in a timely matter. If salvage needs to take place over multiple days, raise the water level in the canal during the evening hours if possible to reduce predation risk and minimize stress on larvae in sediments.

Providing Refuge

Refuge holes, sprinklers, or both may prolong survival of larvae during dewatering. A sprinkler system set up in high-density larval emergence areas can prevent desiccation and likely increase survival (Lampman and Beals 2019; Beals et al. 2020a; see Case Study 2 in Appendix E). Under some circumstances, refuge holes can concentrate larvae for salvage, or function as temporary refuge if the holes remain wetted and can support lamprey survival through the dewatering event. Locate refuge holes in areas adjacent to larval habitat where lampreys are likely to emerge and concentrate. Dig holes (e.g., few scoops with a backhoe) where water will be retained, providing refuge as dewatering occurs. If no salvage efforts are planned, cover refuge holes and sprinkler areas with fine mesh (3 – 10 mm opening) or debris (sticks, grass, hay) to protect larvae from drying out or being eaten by predators.

5. Salvage

Salvage for lampreys and native mussels should be conducted when:

- sediments will be removed or disturbed; or
- habitats will be dewatered for extended time (e.g. > 24 h, or less time in dry, hot weather) and lampreys or mussels in the sediments are unlikely to survive. If keeping the site wet with

some flow during instream work, leaving organisms in otherwise undisturbed sediments may be the least harmful.

Prior to salvage, determine appropriate release sites for mussels, lampreys, and other fishes. Based on site-specific information collected during pre-project monitoring (Section 3.0), determine appropriate number of people and equipment needed for the numbers and species to be salvaged at a future date. If possible, plan and conduct dewatering and salvage early in the day when it is cooler, on cooler or overcast days, or during cooler seasons.

Develop a plan to efficiently return all species to preferred habitats, outside of potential disturbance zones from the project actions. Ideally (and often required by permits), release sites should be within the same stream.

Salvage all life stages of lampreys and mussels if dewatering or disturbing occupied habitats.

- Larval lampreys often remain in Type I and II habitats as waters recede (Table 2, Figure 3).
- Juvenile lampreys are found in Type II and III habitats.
- Adult lampreys are often under cobbles, in crevices or under structures, such as culverts.
- Mussels are often in stable, lower velocity habitats, and typically are not able to move away from dewatered habitats.

Salvage can occur prior to drawdown, during dewatering, and after dewatering using electrofishing (Appendix C); however, salvage in watered conditions may leave a substantial portion of the larvae in the sediments. Electrofishing can also be quite effective in some of the dewatered sediment, which encourage lampreys to emerge ("dry-shocking"; Appendix C). Even dry river beds can contain larval lampreys in subsurface watered areas, and consideration should be given to how to salvage these lampreys through excavation and backpack electrofishing (Rodríguez-Lozano et al. 2019). Salvage requires periodic monitoring of the dewatered areas to salvage emerging larvae and mussels, as larvae and mussels may exit the substrate immediately or take several days to emerge after an area has been dewatered (Lampman and Beals 2019; Case Study 2 and 3 in Appendix E).

Dredged or Removed Sediments

Salvage lampreys using hands, nets, and electrofishing methods (see Appendix C). If possible, remove and place sediments into fast currents to dissipate the sediments and allow most lampreys within those sediments to drift downstream. Alternatively, the top 300 mm layer of the sediment (along with lampreys) could be physically transported and released downstream in areas with few predatory fishes. If this is not possible, salvage lampreys under watered conditions prior to dredging to reduce stress and improve survival. Alternatively, remove and place the top layer of sediments in an upland area to salvage lampreys by hand (Case Study 1 in Appendix E). However, this is very labor-intensive and causes stress to lampreys from handling required. In addition, many lampreys will be overlooked due to their small size and others may be bruised or crushed by the weight of the sediments. For mussels, salvage and relocate prior to removing any sediments.

General Sequencing of Salvage – A Multi-Species Scenario

The following suggested order is conceptual and should be adjusted for site-specific conditions, species present and approximate numbers of individuals per species. For example, if a small number of mussels exist or larval lamprey habitat is minimal, it may be most efficient to salvage only during and after dewatering. If dewatering occurs during cool, wet weather, and the area will be rewatered within 12 – 24 h, mussels and larval lampreys may survive in the sediments and not require salvage. Using sprinklers to keep the sediment moist will likely increase survival. However, lampreys and mussels can die within a few hours if sediments dry quickly. In addition, larval lampreys are extremely vulnerable to predation during drawdown operations. Depending on site circumstances and whether or not ESA-listed species are present, other adjustments to the general approach below may be necessary.

Prior to dewatering

- Mussel salvage: Locate mussels by snorkeling or wading with an underwater viewing scope and then salvage them by hand. Relocation can be time-consuming. Please see guidance provided by Xerces Society: Mussel-Friendly Restoration Guide (Blevins et al. 2019).
- Watered salvage of larval lampreys: Salvage using lamprey electrofishing settings (Appendix C, Table C1), which will generally not affect other fishes.
- Salvage other fishes (e.g. salmon, sculpin) after lampreys with nets or by electrofishing with appropriate settings. See "Guidelines for Electrofishing Waters Containing Salmonids Listed under the Endangered Species Act" (NMFS 2000).

Dewatering: as water levels recede

- Salvage larval lampreys and mussels by hand and nets. Lampreys and mussels may continue to emerge from substrate minutes or days after dewatering, so re-survey frequently to minimize time out of water.
- Salvage larval lampreys in shallow water or on dewatered substrate using "dry-shocking" with lamprey-specific electrofisher settings (Table C1). Type I habitat is their preferred habitat, but many seek refuge in other habitat (Type II and III) as water levels recede.
- Some people can be hand-picking lampreys from exposed sediments, while others are electrofishing or salvaging remaining species.

After dewatering is complete

- Continue salvaging larval lampreys and mussels; re-survey and salvage as needed.

- To encourage larval lamprey emergence, "dry shock" in Type I habitat. Often lampreys will get trapped in isolated pools, so check areas around habitat structure where they may try to burrow.
- Hold all fishes in buckets, fine mesh baskets or tanks in small groups to minimize crowding, with good water quality conditions (temperature and dissolved oxygen) until release (see Table 3).
- Mussels: For short time periods, mussels can be held in buckets of water, provided water temperatures are kept cool and stable. For longer periods, hold mussels wrapped in mesh bags between wet towels in coolers with no water until release.

Release

Release all fishes throughout the salvage process as quickly as possible to minimize stress and predation risk. Salvaged lampreys should be released in or near preferred habitats, away from in-water work and other human disturbances. Larval lampreys will quickly burrow into fine sediments in low velocity areas; juvenile and adult Pacific Lamprey seek cover in coarse substrate or in crevices under large rocks or other structures. Care should be taken to release lampreys into habitats where there is a low risk to predation (Lampman and Beals 2019).

Mussels: For short transports, mussels can be transported in buckets of water to release site, provided water temperatures are kept cool and stable. For longer transports, transport mussels wrapped in mesh bags between wet towels in coolers with no water and relocate them in a pre-selected, appropriate habitat. Place native freshwater mussels in preferred habitats (stable substrate with refuge from high or low flows), safe from in-water work and other immediate disturbances. Place individuals flat on the streambed, which allows mussels to select where they burrow into the substrate.

6. Handling and Holding Lampreys

Some salvage efforts require the handling and temporary holding of lampreys. Guidelines to reduce stress, injuries, and mortalities to lampreys while handling and holding are described below. These guidelines are based on successful use with Pacific Lamprey in the Columbia River Basin. Whether and how these same methods may be employed with the same level of success on Pacific Lamprey in other areas or on other lamprey species in any location is not known. For guidance on native, freshwater mussels, see "Mussel-Friendly Restoration" (Blevins et al. 2019).

Holding and Transport for Lampreys

- Maintain the holding and transport container water temperature within ±2˚C of the release location water temperature to prevent temperature shock to the lampreys. Slow acclimation is recommended (<±3˚C per hour) to minimize stress and maximize survival.
- Keep water temperatures cool (< 18˚C). Use ice made from source river water or frozen sealed containers of ice, if necessary. Do not use store-bought ice that is not in sealed

containers, as it may contain fluoride or chlorine. Natural pure salt (3 – 5 ppt) may also be used to reduce stress for longer transports (> 1 h).

- Monitor water temperature and dissolved oxygen regularly and make changes as needed to ensure water quality parameters are adequate. Dissolved oxygen levels can be maintained using air stones with battery-powered aerators or from oxygen cylinders and a regulator.
- Hold lampreys in flow-through water as much as possible.
- Lampreys prefer dark environments — cover to darken containers.
- Do not exceed the maximum recommended density in transport containers (Table 3).

<u>Guidelines Specific to Adult Pacific Lamprey</u>

- Equip holding and transport containers with aerators to ensure dissolved oxygen levels are near saturation.
- Provide smooth surfaces for lamprey attachment with their sucker mouths. Avoid placement in containers with only mesh or perforated metal screen surface.
- Ensure there are no gaps larger than 13 cm at the top of the transport containers to avoid escapement – lamprey can easily climb up the container walls.

<u>Guidelines Specific to Larval and Juvenile Pacific Lamprey</u>

- Aerators are recommended for long-duration holding or transport of larval and juvenile lampreys, but not necessary for short duration as long as density guidelines are met (Table 3) and dissolved oxygen levels do not drop below ~90% saturation.
- Maintain > 10 cm gap between water surface and top of containers or use other types of barrier – juvenile lampreys can climb and escape similar to adult lamprey.
- Use fine mesh nets and scoops (< 750 micron preferably) to minimize loss of young-of-year and small larvae.
- Laundry mesh baskets with fine mesh opening (< 750 micron) work well for holding all sizes of larvae in flow-through water during salvage and can fit inside garbage bins for transfer and quick transfer to release site.
- For short-term holding (< 8 h), a non-abrasive cover (such as cotton string mop head or dense conifer branch) should be placed in holding containers, where possible, to give exposed larvae cover and reduce stress.
- For longer-term holding (e.g., > 8 h), sediment (fine sediment for larvae and coarse sediment for transformers) should be added to holding containers to provide the best holding habitat; however, utmost care is needed to ensure lampreys are not harmed in the process of adding, transferring, or removing the sediment. If adding fine sediment to holding containers, an effort should be made to sift sediment to < 750 microns to reduce potential damage to < 50 mm larvae; a 500 – 750 micron net or laundry mesh baskets can be used for this process.
- In general, consider the logistical pros and cons and health of salvaged lampreys during holding and transport. As stated above, sediment should be provided for refuge. However, providing sediment is not practicable or advisable in all situations, particularly those in which there is the potential to handle many thousand larvae and juveniles, and in which transfer with sediment can lead to pinching, abrasion, and mortality of the lampreys.

Table 3. Maximum recommended lamprey density in transport containers of standing water. Recommendations are for 80% full containers, based on experience from Pacific Lamprey in th Columbia River Basin.

Life Stage	Body Length (mm)	Weight (g)	Maximum # per 4 L	Maximum # in 19 L Bucket	Maximum # per 120 L Bin
Adult[1]*	660	460	1	4	25
Juvenile[2]*	140	4.0	10	40	250
Medium Larvae[3]	100	1.5	25	100	650
Small Larvae[3]	40	0.15	250	1,000	6,500

[1]Based on adult translocation programs from Lower Columbia River hydro dams to holding facilities.
[2]Based on juvenile salmonid criteria of 10 g/L (Liedtke et al. 2012) and juvenile holding for acoustic telemetry research (Beals and Lampman 2019).
[3]Based on juvenile salmonid criteria of 10 g/L (Liedtke et al. 2012) and larval lamprey salvage from irrigation diversions.
*Adult and juvenile Pacific Lamprey are more sensitive to low oxygen than larvae, so use aerators and maintain the numbers at or below the maximum values whenever possible.

Anesthetics

Lampreys of all life stages do not need to be anesthetized for transport or measurements. However, their use may help reduce stress associated with these activities. For identification and length measurements, use plexiglass viewing containers (see right) that limit movement of larval lampreys to identify species and measure lengths. Plastic, translucent bags with a ruler inside can also be used for coarse length estimates. However, when more data need to be collected (such as fin clips for genetics), use anesthesia as needed.

These suggested dosages and exposure times should be adjusted to account for specimen size, water temperature, and water chemistry. It is best to start at the lower concentrations, and then gradually increase concentration until effective at the lowest possible concentration. Use caution: higher concentrations may delay or impede recovery. Ideally, maintain concentration so that sedation is achieved in 3 – 5 minutes, and recovery in < 5 minutes. Allow lampreys to fully recover prior to release.

Adult Lampreys

MS-222 (70 – 100 mg/L) buffered with equal dosage of sodium bicarbonate (baking soda with no additives;[2] Moser et al. 2002) can be used, but requires a 21-day holding period to prevent lamprey from potential harvest and human consumption. Alternatively, AQUI-S 20E (50 – 100 mg/L) can be used to sedate adult Pacific Lamprey (Moser et al. 2007; Christiansen et al. 2013). For adults of smaller species, juvenile recommendations should be followed (see following section); gradually increase concentration if lower doses do not work.

Larval and Juvenile Lampreys and Adults of Smaller Lamprey Species

MS-222 (70 – 100 mg/L) buffered with the same amount of sodium bicarbonate (Schultz et al. 2014; Liedtke et al. 2019b; Mueller et al. 2019), or BENZOAK (50 mg/L; Moser et al. 2007; Christiansen et al. 2013) is often recommended for larval and juvenile life stages. When anesthetics were compared, MS-222 performed the best in terms of sedation and recovery time, and BENZOAK performed slightly better in terms of reducing fungus growth (Christiansen et al. 2013). AQUI-S (50 – 100 mg/L) can also be used for larval / juvenile lampreys, but time-to-sedation can be less predictable, and lampreys display some irritation (active swimming) when exposed to the solution. If fungus is an issue for juvenile lampreys and a safe field remedy is needed, a 1-h treatment using 3% natural salt was found to be very effective in removing and eliminating fungus compared to formalin and hydrogen peroxide treatments (Beals et al. 2020b).

7. Sampling and Recording Species Data

- Lampreys and mussels should be sampled and released as soon as possible after capture to minimize stress.
- Large predatory fishes should be kept separate from smaller lampreys to avoid predation. Use of artificial or natural cover (mesh box, plants, cotton string mop head, rocks, etc.) in the holding container may also limit predation.
- Lampreys and mussels should be observed for general condition and injuries (e.g., long recovery time, bruising, and/or injuries). Each lamprey should be revived completely before release.
- Pertinent water quality (e.g., conductivity and temperature) and sampling notes (e.g., shocker settings, fish condition, mortalities) should be recorded in a logbook to improve technique and help train new operators. Observe and record stress behavior (gasping, side-rolling, etc.), injuries, and mortalities throughout the entire sampling process, including fish capture, measurements, and release.
- Mussels can be identified to genus-level (*Margaritifera, Anodonta,* or *Gonidea*), or photographed for later identification (See Appendix A for mussel identification resources).

[2] The buffer will ensure that the MS-222 will not acidify waters that do not have sufficient buffering capacity, which could irritate the gills of the lampreys.

Time is often limited when salvaging lampreys. However, recording a few measurements on a subsample of lampreys can be very useful (e.g. 30 lampreys). The following information is the minimum recommended for data collection:

- Total length (mm)
- Life stage [larvae (no eye), juvenile (eyed), adult]
- Species identification
- Photos (use white background for tails, clear glass/plastic plate for mouth; Figure 5)
    - Tail close-up for larvae/juveniles (photo a)
    - Mouth dentition for juveniles/adults (photo b)
    - Overall body for all life stages (photo c), e.g. when taking genetic samples or identification is questionable.

Please coordinate with local biologists and members of your Lamprey Regional Management Unit Group and the Lamprey Technical Workgroup (email info@pacificlamprey.org) that may be seeking more detailed information, which will vary on a case-by-case basis.

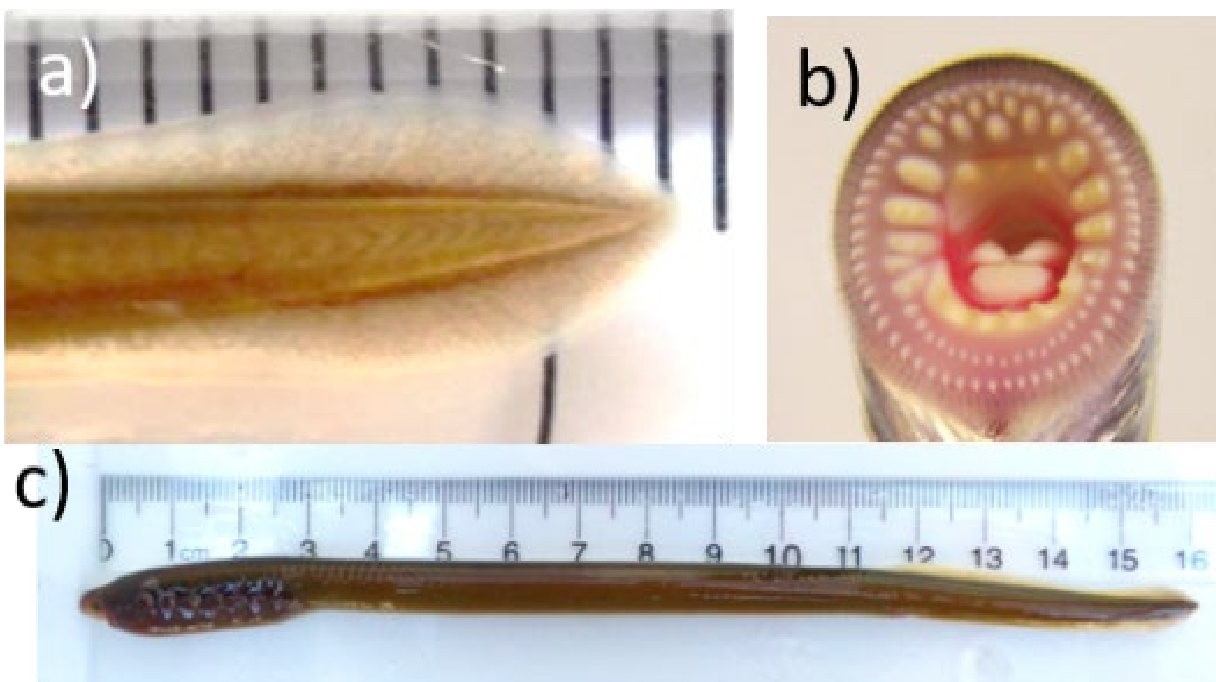

Figure 5. Examples of photographs to assist in species identification.

8. Post-Implementation Monitoring

To understand whether and how in-water work may have affected lampreys, monitor lamprey occurrence, numbers, and distribution after project implementation. Develop clearly defined goals and objectives prior to monitoring to ensure the best possible results and conclusions. We recommend sharing this information to help address information gaps and update the guidelines in this living document where needed (see Case Studies 4 and 5 in Appendix E). Documentation and data sharing opportunities are listed below:

For all fishes

Report species and numbers of all fishes as required by your permits.

For lamprey distribution

Share information with local biologists, and the local Lamprey Regional Management Unit Group or the Lamprey Technical Workgroup (email: info@pacificlamprey.org) to increase our collective knowledge and understanding. Report species locations online at Databasin.org to update publicly available distribution maps.

For freshwater mussel distribution and relocation

Report distribution and relocation information to the Xerces Society (email: mussels@xerces.org).

NOTES:

9. Glossary

Adult: "Life stage in which the lamprey are in various states of sexual maturation (including immature through spawning). Unlike juveniles, sexually immature adults are no longer feeding and are actively migrating upstream to spawning grounds…." (Clemens 2019).

Dry shocking: Method in which the cathode and anode of the electroshocker are placed onto dewatered substrate and the "tickle" setting is used to stimulate larvae to exit from the substrate for sampling (Lampman and Beals 2019).

Electronarcosis: The inadvertent, prolonged stunning (immobilization) of larvae and juveniles from repeated shocking prior to their exiting the substrate. Electronarcosis can result in an undersampling of lampreys and can also potentially injure or kill them.

Juvenile: "Life stage existing only in parasitic lampreys. Resident lampreys that do not feed during their adult stage [after transformation] (i.e., brook lampreys) do not exhibit a juvenile life stage…This is the preferred term for parasitic lampreys that have transformed from larvae into eyed, small versions of the adults…. That is, in addition to eyes, this life stage bears sharp teeth and an oral sucker. Juveniles are sexually immature…." (Clemens 2019).

Larva: "Eyeless, filter-feeding life stage that usually resides in the substrate (soft silt and sand substrates with organic material is usually preferred)" (Clemens 2019).

Stun: Backpack electrofisher setting with a different waveform and pulse frequency than "tickle" that temporarily immobilizes larval and juvenile lampreys so that they can be netted.

Tickle: Backpack electrofisher setting with a different waveform and pulse frequency than the "stun" setting. This setting is used prior to the stun setting with the primary objective of stimulating larval and juvenile lampreys to exit the substrate of the stream and enter into the water column.

Transformer: "In some situations, this term is appropriate because it can be carefully used to describe the stage between larva and juvenile (in the case of parasitic lampreys) or between larva and adult (in the case of brook lampreys), if the transformation is incomplete" (Clemens 2019).

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APPENDIX A. Available Resources – Lampreys and Freshwater Mussels

(Hyperlinks embedded)

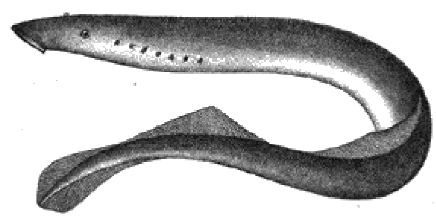
Lamprey Summary Documents

- **Conservation challenges and research needs for Pacific Lamprey in the Columbia River Basin** (Clemens et al. 2017). Broad overview paper.
- **Pacific Lamprey Habitat Restoration Guide** (Crandall and Wittenbach 2015). Description of the biology, ecology, and cultural significance of lamprey, threats and best management practices to protect and restore populations.
- **Climate Change Vulnerability Assessment for Pacific Lamprey in Rivers of the Western U.S.** (Wang et al. 2020).

Lamprey Distribution Maps: **Databasin.org** (online, interactive GIS map – search "lamprey")

Lamprey Passage Guidance

- **Practical Guidelines for Incorporating Adult Pacific Lamprey Passage at Fishways** (Lamprey Technical Workgroup 2017). Guidance on providing upstream passage within existing fishways and in new fishway designs, discussion of lamprey passage structures.
- **Design Guidelines for Pacific Lamprey Passage Structures** (Zobott et al. 2015). Guidance for designing and installing lamprey ramps for upstream passage.



- **CA Fish Passage Forum:**
    - **Lamprey Passage Recommendations**
    - **Culvert passage assessment**
- **FishXing Software** assists practitioners in the evaluation and design of culverts for fish passage, including ecological considerations and stream simulation design.

Fish Screens

- **Fish Screen Oversight Committee** (FSOC) provides technical information necessary to facilitate effective planning and implementation of fish screening projects.
- **Fish Passage Solutions on the West Coast: Culverts, Tidegates, and Fish Screens** (NOAA Fisheries website)
- **Anadromous Salmonid Passage Facility Design** (NMFS 2011) includes screening criteria for salmonids
- **Effectiveness of common fish screen materials for protecting lamprey ammocoetes – Influence of sweeping velocities and decreasing flows**. (Mesa et al. 2017).
- **Effectiveness of fish screens in protecting lamprey ammocoetes – Pilot testing of variable screen angle** (Liedtke et al. 2019a).

Lamprey Regional Plans and General Information:

- **Columbia River Inter-Tribal Fish Commission**
- **Pacific Lamprey Conservation Initiative**
- **2018 Pacific Lamprey Assessment**
- **Pacific Lamprey Regional Implementation Plans** (18 different regions!)
- **Tribal Plan Pacific Lamprey Restoration Plan for the Columbia River —Columbia River Inter-Tribal Fish Commission (2011)**
- **USACE Pacific Lamprey Improvements Implementation Plan 2008-2018**

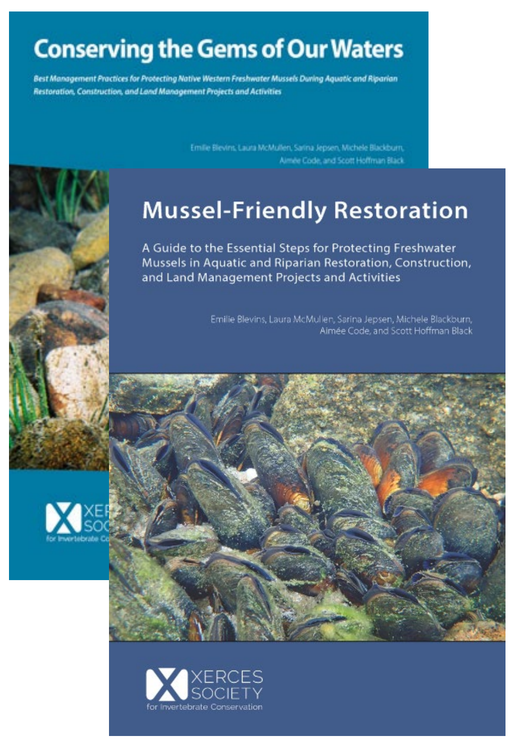
Lamprey Education/Outreach:

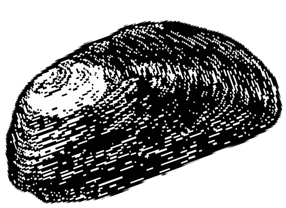
- **Educational Resources**
- **Fourth – Sixth Grade curriculum**
- **Pacific Lamprey Story Map**
- **The Lost Fish** (a short film)
- **The Plight and Curious Life of Asum (Pacific Lamprey)** (short video)

Native Freshwater Mussel Resources

Conserving the Gems of Our Waters: Best Management Practices for Protecting Native Western Freshwater Mussels and its shorter, companion user's guide ***Mussel-Friendly Restoration*** include information on determining if native mussels are present at your site, identification, project development and review, and salvage and relocation.

- **Mussel Identification** (CTUIR 2016)
- **Extinction risk of Western North American freshwater mussels** (Blevins et al. 2017). Conservation overview paper.
- **Pacific Northwest Native Freshwater Mussel Workgroup**
- **Western Freshwater Mussel Database** (Xerces Society/Confederated Tribes of the Umatilla Indian Reservation). Geospatial data for freshwater mussel occurrence in the western U.S. Available upon request (mussels@xerces.org)





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Date: 4/02/20

EXAMPLE
Field Technical Operating Procedure

Aquatic invasive species cleaning and disinfection procedures for boats and field equipment

Scope:

The Columbia River Fish and Wildlife Conservation Office performs work within multiple aquatic systems across a wide geographic range. It is our responsibility to be conscious of where high-risk invasive species occur and take proper precautions to minimize the risk of transporting or spreading aquatic invasive species (AIS) through our work.

Policy:

- Executive order 13112 (USOFR 1999) prohibits federal agencies (except under certain conditions) from carrying out actions "likely to cause or promote the spread of invasive species" and directs agencies to implement programs with the goal of preventing the introduction and spread of invasive species in their work.
- The U.S. Fish and Wildlife Service Pacific Region Policy on Minimizing the Introduction of Invasive Species by Service Activities aims to increase employee awareness of invasive species and calls for Region 1 Programs to develop and implement invasive species prevention guidelines for their field activities.

Resource Threat:

- The introduction and establishment of invasive species is considered one of the greatest threats to global biodiversity, second only to habitat destruction.
- Invasive species have been identified as the cause in decline of at least 30% of species currently protected under the Endangered Species Act.
- Invasive species are a leading factor in freshwater fish extinctions and endangerments.
- The Department of Interior spends hundreds of millions of dollars annually on AIS control and management.
- Aquatic invasive species reduce the diversity and abundance of native species, degrade aquatic habitats, threaten water quality and availability, alter important ecological processes and pose a general threat to commercial, agricultural and recreational industries.

Pre-Survey Planning:

Before heading into the field, be aware of the invasive species you may encounter. Information on current AIS distribution can be found in the websites below.

- The USGS Nonindigenous Aquatic Species (**NAS**) website (http://nas.er.usgs.gov/) is an excellent resource to obtain current, spatially referenced AIS distribution information in your work area.
    - Click on the '*Database & Queries*' dropdown, highlight '*NAS database*', then select your query type: AIS by state, county, hydrologic unit code (2, 6, or 8), or specific geographic area (spatial query).
- The University of Georgia's Early Detection & Distribution Mapping System, or **EDDMapS**, is a web-based Early Detection Rapid Response (EDRR) tool that includes state and county distribution maps, Google Maps interface for point distribution, and online invasive species reporting capabilities.
    - https://www.eddmaps.org/distribution/

Avoidance of Unnecessary Exposure:

Care should be taken to minimize contact with AIS at field sites. If contact cannot be avoided, take the appropriate measures to thoroughly clean and/or disinfect gear following exposure. Consider using dedicated field equipment if regularly working in an area with invasive species.

Cleaning and Disinfection:

The following are recommended procedures for cleaning and disinfecting field equipment and gear to prevent the introduction and spread of AIS.

Boat/boat trailer

If no AIS present in waterbody

1. **Clean:** remove all visible plants, mud and debris from boat, prop, anchor and trailer. Discard debris in garbage can away from water.
2. **Drain:** all standing water from boat (e.g., bilge, live wells) and run motor 5-10 seconds to blow out excess water and vegetation from internal drive before leaving waterbody.
3. **Rinse:** boat and equipment with hot tap water (at least 40˚C or 104˚F) or spray with high-pressure water.
4. **Dry:** all surfaces completely with a towel or allow to dry naturally (i.e., 5-7 days in hot dry conditions or up to 30 days in cool damp conditions).

If AIS are known or suspected to be in waterbody

1. **Clean:** remove all visible plants, mud and debris from boat, prop, anchor and trailer. Discard debris in garbage can away from water.
2. **Drain:** all standing water from boat (e.g., bilge, live wells) and run motor 5-10 seconds to blow out excess water and vegetation from internal drive before leaving waterbody.

3. **Disinfect:** motor and non-porous surfaces (e.g., hull, trailer, anchor, paddle) with steam or hot water pressure washing equipment (≥140˚F at point of contact) for no less than 10 seconds. Porous items (e.g., ropes) should be exposed to hot water (≥140˚F) a minimum of 10 minutes, and internal compartments (e.g., bilge, live well, ballast tank) should be exposed to hot water (≥120˚F) for a minimum of 2 minutes. **NOTE** – cooler water temperatures may be used, but longer exposure times are required (e.g. 110°F for 20-30 minutes).
4. **Dry:** boat and equipment completely (i.e., 5-7 days in hot dry conditions or up to 30 days in cool damp conditions).

<u>Field gear (e.g., nets, buckets, waders and boots)</u>

If no AIS present in waterbody

1. **Clean:** remove all visible plants, mud and debris from equipment using a stiff bristle brush. Discard debris in garbage can away from water.
2. **Drain:** all standing water from equipment before leaving waterbody.
3. **Rinse:** or wash equipment with potable freshwater.
4. **Dry:** all surfaces completely with a towel or allow to dry naturally (i.e., 5-7 days in dry warm conditions or up to 30 days in cool wet conditions).

If AIS are known or suspected to be in waterbody

NOTE – Consider using dedicated field equipment if regularly working in an area with invasive species.

1. **Clean:** remove all visible plants, mud and debris from equipment using a stiff bristle brush. Discard debris in garbage can away from water.
2. **Drain:** all standing water from equipment before leaving waterbody.
3. **Disinfect:** four methods may be used depending on gear type.

- <u>*Method 1*</u> – Drying. Allow equipment to dry completely (i.e., a minimum of 5 days or more depending on weather conditions). This method is recommended for large nets (e.g., fyke nets, seines) or non-porous equipment.
  NOTE – this method is <u>NOT</u> suitable for felt soled boots.

- <u>*Method 2*</u> – Heat. Steam or hot water pressure wash (≥140˚F). Expose non-porous surfaces for minimum of 10 seconds. Porous materials and gear should be submerged in water kept above 140°F for 10 minutes.
  NOTE – this method is not recommended for Gore-Tex waders.

- <u>*Method 3*</u> – Freezing. Freeze equipment at 14˚F (-10˚C) for a minimum of 8 hours, or at 15˚F to 32˚F (-9˚C to 0˚C) for a minimum of 24 hours. This method is suitable for waders and boots.
  NOTE – this method should be used in tandem with chemical treatment (see *Method 4*) as some fish pathogens may survive freezing temperatures.

- <u>*Method 4*</u> – Chemical. Soak equipment in a 1% Virkon Aquatic solution for a minimum of 10 minutes, or a 2% solution for a minimum of 20 minutes if New

Zealand mudsnail are present. ***NOTE*** – chemical disinfection should never occur near a waterbody and solution should be disposed of on dry land or down a sewage drain.

4. **Dry:** equipment completely (i.e., 5-7 days in dry warm conditions or up to 30 days in cool wet conditions).

Chemical Disinfection Procedure:

NOTE – Mix Virkon solution in a well-ventilated area, use protective gloves and safety glasses when handling both powder and liquid solution, and wash hands thoroughly after use. See the product label and Material Safety Data Sheet for additional information.

- Ensure equipment/gear is completely free of organic material before soaking in disinfectant. This will prolong the effectiveness of the Virkon solution.
- Prepare Virkon solution as follows:
  - Use 1 level scoop of Virkon powder per gallon of water for a 1% solution.
  - Carefully place dry powder in disinfection tub or portable hand sprayer (avoid inhaling dust).
  - Fill container to desired depth with clean tap water.
  - Stir the solution to fully dissolve the Virkon powder.
- Soak or liberally spray gear and allow to sit for a minimum of 10 minutes.
- Rinse gear with clean water (optional but will prolong the life of your gear).
- Virkon solution is stable for 7-14 days. Use Virkon test strips to test the efficacy of the solution.
- Old solution may be safely disposed of by pouring outdoors onto dry land, or down a sewage drain. Dilute the solution with a 5-gallon bucket of water to minimize the environmental impact.

How to Report Invasive Species:

If you observe undocumented AIS in the field, collect the following information and report to the appropriate invasive species alert system below.

- Name, email, and telephone number of observer
- Type of Species (e.g., amphibian, fish, mollusk, plant, reptile, etc.)
- Species common name, genus and species (if known)
- Date of observation
- State and County observation was made
- GPS Coordinates (or detailed description of location)
- Photo of organism

(continued on the next page)

USGS Nonindigenous Aquatic Species (**NAS**) Database (any state)

- https://nas.er.usgs.gov/SightingReport.aspx

State of Idaho

- Idaho Invasive Species Hotline: 1-877-336-8676

State of Oregon

- Oregon Invasive Species Hotline: 1-866-468-2337
- Online Reporting Form: https://oregoninvasiveshotline.org/reports/create

State of Washington

- Washington Invasive Species Hotline: 1-877-946-3378
- WA Online Reporting Form & links to **WA Invasives** reporting app: https://invasivespecies.wa.gov/report-a-sighting/

References:

USOFR (United States Office of the Federal Register). 1999. Executive order 13112-invasive species, Federal Register 64: 25 (3 February 1999):6183-6186.

APPENDIX C. Electrofishing for Lamprey

These guidelines assume familiarity with general best practices for electrofishing and handling fish. For more information, see NMFS (2000).

Electrofishing Guidelines for Lampreys[3]

Electrofishing surveys for lampreys are typically done using backpack electrofishers in small streams (< 1.0 m in depth). Three types of electrofishers have the specific sampling settings for larval lampreys:

- ABP-2 "Wisconsin" electrofisher (ETS Electrofishing, Verona, WI)[4];
- Smith-Root LR-24 model electrofisher[5]; and
- Smith Root Apex Backpack electrofisher[11].

Other electrofishers can be adjusted to some extent and used for larval lampreys, but it is more difficult and effectiveness of those electrofishers is less certain.[6]

- Electrofishers used for sampling larval lampreys have two wave forms, a lower frequency "tickle" wave form to coax larval lampreys out of the substrate and a higher frequency "stun" wave form to immobilize emergent larval lampreys for netting (Table C1). Capture efficiencies vary according to site characteristics, visibility, electrofishing gear, electrofishing techniques, net mesh size, the number of netters, and the experience, reaction time, and visual acuities of samplers, among other factors. Initial voltage settings should start low, and if ineffective, gradually increased to the lowest effective setting. *First stage:* Begin at a low setting — use 125 V direct current with a 25% duty cycle applied at a slow rate of 3 pulses/s, to induce larvae to emerge from the substrate. At low water temperatures (≤ 10˚C) or low water conductivity, the voltage may need to be increased (150 – 200 V).
- Using a pattern of 3 slow pulses followed by a skipped pulse (3:1 burst pulse) helps entice larval lampreys to emerge.
- *Second stage:* immediately after larval lampreys emerge, use a fast pulse setting of 30 pulses/s to immobilize and net them. For experienced shockers/netters, it is not always necessary to stun lampreys for netting.

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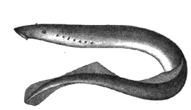
[3] *Modified from Appendix A of USFWS and USFS (2010).*

[4] *Set up information for ETS at http://etselectrofishing.com/brochures/ets_backpack.pdf or http://etselectrofishing.com/products/backpack-electrofishing-systems/*

[5] *Set up information for Smith-Root at https://www.smith-root.com/support/kb/setting-up-a-backpack-electrofisher-to-capture-larval-lamprey/*

[6] *Conventional electrofishing gear set for salmonid capture uses higher voltage and frequencies, which potentially causes electronarcosis of larval lampreys, resulting in failure to emerge and a recording of false absence.*



Electrofishing should be conducted in an upstream direction to maintain visibility, avoiding turbid conditions downstream (in backwater conditions, direction should be reversed). Electrofishing should sample at about 60 seconds per meter, with more effort directed at Type I habitat (Table 2). Conduct multiple passes to increase salvaged numbers[7]. Note that exposure to extended periods of electrofishing has been associated with electronarcosis, which immobilizes larvae and prevents emergence from the substrate. A 15 minute break between each pass will reduce the likelihood of electronarcosis.

One or more netters should be present while electrofishing, especially in high density areas. In most conditions, it is best to minimize disturbing the stream bottom to maintain water clarity to maintain visibility. Regardless of visibility, "blind netting" [using fine mesh nets (500 – 750 micron) to sweep the water] immediately after the slow pulse is applied can increase collection efficiency, especially for very small larvae (Lampman and Beals 2019).

Post-Drawdown: Lamprey "Dry-Shocking" Guidelines

In dewatered conditions, a "dry-shocking" technique on moist sediments using the regular lamprey frequency settings (Table C1) will encourage larvae to exit the sediments. Dry shock Type I habitat for larval lampreys, focusing on concave areas and dips in topography, where larval lampreys are more likely to be stranded. Juveniles and adults may be found buried in rockier areas.

Dry-shock 1 – 2 m^2 at a time. Place the anodes about 0.5 m apart and tickle-pulse at ~60 seconds per m^2. Move to next 1 - 2 m^2 and continue. As above, adjust for local conditions – in some instances, 30 seconds of shocking will be sufficient; in other areas > 60 seconds may be needed. Splashing or pouring water over the exposed areas can sometimes increase efficiency.

Table C1: Electrofishing Guidelines for Larval Lampreys (either watered or dry-shocking).

	**"Tickle" Burst Slow Pulse Primary Way Form**	**"Stun" Standard Fast Pulse Secondary Wave Form**
Starting Voltage	125 v	125 v
Pulse Frequency	3 Hz	30 Hz
Duty Cycle	25%	25%
Burst Pulse Train	3:1	N/A
Pace	60 – 90 s / m^2	N/A

[7] *Some research has indicated an average of 20% of lampreys emerge per pass (e.g. Steeves et al. 2003).*

APPENDIX D. Fish Passage and Screening Guidelines

Safe passage upstream and downstream can be a significant limiting factor for lampreys of all life stages. Water developments (hydroelectric, irrigation, industrial and municipal), road crossings, tide gates, and traditional fishways designed for salmon can impede or prevent passage (LTW 2017).

Upstream passage for Adult Pacific Lamprey

Pacific Lamprey face many challenges with respect to man-made barriers. This species has slower swimming speeds (less than half) of adult anadromous salmon species. However, Pacific Lamprey are able to use "burst and attach" locomotion in areas of high velocities (0.6 – 2.4 m/s; LTW 2017), provided a smooth, continuous surface exists to enable attachment with their mouths. Structural features at road crossings/culverts and within traditional fishways can be problematic to Pacific Lamprey upstream migrations; these features include[8]:

- Near-bottom velocities > 1 m/s
- Acute edges or sharp angles, especially in areas where velocities are > 1 m/s
- Porous surface (grates), gaps or holes, or seams/cracks/gaps that break suction on otherwise smooth surfaces, thus preventing or breaking attachment by mouth
- Heavy moss/algae that prevents attachment by mouth
- Confusing turbulence (non-laminar flow)
- Screens, mesh, or holes with > 2.5 cm openings that can lead lamprey back downstream or areas with no upstream egress;
- Perched orifices/entrances (fishway or culvert)
- Baffles, weirs, sills or other structures in a culvert or fishway,
- Repeated challenges (e.g., weirs) that exhaust available energy reserves
- Seasonally dewatered streams and seasonal loss of connectivity.

The **Practical Guidelines for Incorporating Adult Pacific Lamprey Passage at Fishways** (LTW 2017) offers more details for designing and implementing passage for lampreys at dams. Zobott et al. (2015) provide design guidelines for **Pacific Lamprey Passage Structures** (LPS, or ramps). The **California Fish Passage Forum** provides behavioral and design considerations for lampreys in fishways.

For road crossings, the best design for passage of all lamprey species and life stage is to create a natural stream channel or mimic a natural stream channel through "stream simulation design" that allows free passage upstream and downstream. The **Lamprey Technical Workgroup** is working on a separate guidelines document to address passage needs for Pacific Lamprey at road crossings that will be complete in June 2020 (a Bonneville Power Administration funded project: #2017-005-00). The document will include detailed information on passage assessment at culverts, problems, solutions, and case studies.

[8] Modified from the California Fish Passage Forum: Culvert passage assessment ("**First Pass Data Sheet**")

Fish Screens

Water developments can harm fishes through entrainment, impingement, migration delays, predation, injury and desiccation. Protecting diverse species and life stages with fish screens in these facilities is challenging. No one screen design, placement, material or operation will work at all sites to protect all species.

In West Coast streams of the United States with ESA-listed anadromous salmonids, the National Marine Fisheries Service (NMFS) developed design and operation criteria for fish screens (NMFS 2011). Screens designed and operated to standard criteria (NMFS 2011) to protect juvenile salmonids are generally protective of lampreys > 65 mm total length (Rose and Mesa 2012). However, larger gaps often exist at facilities that allow larger larvae to be entrained (e.g., loose or damaged rubber gaskets or seals).

A variety of fish screen materials are used in irrigation diversions, including woven wire, perforated plate, profile bar, and Intralox materials. Based on lab and field studies (Rose and Mesa 2012, Lampman and Beals 2019, Liedtke et al. 2017), we recommend, when possible, the following when considering fish screen types for lampreys:

- Use the smallest mesh opening possible to minimize entrainment of smaller larvae; however, watch for impingement of larvae.
- Use perforated plate, Intralox, or profile bar screen materials rather than woven wire screen material.
- Minimize the approach velocity while maximizing the sweeping velocity.
- Design fish screens and headgates with the shallowest angle practical (i.e. angle should be as close as possible to parallel to the direction of the flow, not perpendicular; Liedtke et al. 2019a).

Due to the unique nature of most screen sites, it is strongly encouraged to contact local screening and passage experts to help plan and implement the project. The **Fish Screen Oversight Committee** members are experts at fish screening, specifically to NMFS criteria, and several guidance documents can be found on their webpage.

When pumps are used to dewater a project area prior to construction, at a minimum follow NMFS criteria for end of pipe fish screens (NMFS 2011). Where possible, use smaller mesh openings (e.g., 1 mm; e.g. https://zinvent.com/products) to prevent entrainment of or injuries to smaller larvae (Lampman and Beals 2019; see Case Study #3 in Appendix E). Regularly clean the screens to minimize impingement and turbulent velocities around the screen.

!!See Appendix A for a list of links and documents referred to above!!

APPENDIX E. Case Studies

Table E1. List of Case Studies. More will be added as they become available.
Last update: May 4, 2020.

Site **River** **State**	**Brief Description**
Dryden Diversion Irrigation Diversion Yakima River Washington	#1- Salvage of lampreys from dredged materials.
Sunnyside Irrigation Diversion Yakima River Washington	#2- Salvage of lampreys from a large river diversion.
Bachelor Hatton Irrigation Diversion Ahtanum Creek, Yakima River Washington	#3- Salvage of lampreys from a small river diversion
Multiple sites Mid- Upper Columbia Subbasins Eastern Washington	#4- Larval lamprey electrofishing surveys.
Habitat restoration sites Methow River Washington	#5- Larval lamprey use of salmonid restoration projects.
Salvage Techniques Evaluation Leaburg Lake, McKenzie River Oregon	#6 – Evaluation of salvage techniques – slow drawdown.
Stage 0 Restoration South Fork McKenzie River Willamette Basin Oregon	#7 – Valley-scale Restoration Improves Habitat for Pacific Lamprey

#1- Salvage of Lampreys from Dredged Materials Dryden Diversion Dam, Wenatchee River, Washington

Public Utility District No. 1 of Chelan County (CCPUD) operates the Dryden diversion dam along the Wenatchee River (Fig. 1). The headworks structure seasonally diverts water from the river into the Highline Canal for irrigation. As part of routine maintenance operations, CCPUD dredges accumulated sediments from upstream of the diversion structure and dewaters the canal.

The slow water and fine sediment in the canal forebay provides refuge to thousands of larval and juvenile Pacific Lamprey. The Yakama Nation Fisheries and other partners aided CCPUD in lamprey salvage operations in the canal. Based on this collaborative effort and experience, simple, adaptive, and efficient methods to rescue and salvage entrapped lamprey from dredged materials were developed to improve salvage efficiency and minimize mortality.

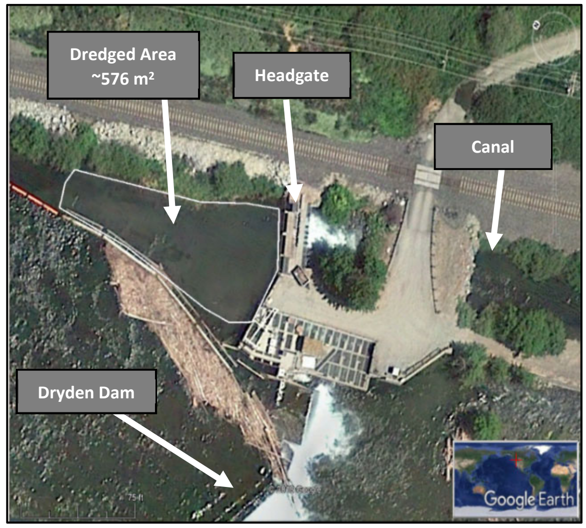


Figure 1. Dredged forebay of Dryden Diversion on the Wenatchee River (RKM 27.8, Dryden, WA).

Salvage Operation

The forebay area was dredged on March 4, 2016, using a 150-ft tall crane and a grab dredge (Fig. 2). The grab dredge placed 6-8 cubic yards of dredged material at a time into a modified dump truck (Wilsonville Concrete Products, Wilsonville, OR; Fig. 3). The truck's water-tight design significantly limited loss of lamprey during transfer. Each truck load was transferred to a nearby dirt lot and spread out using hand rakes and a backhoe. Larvae were primarily gathered by hand from the sediment surface (Fig. 4). Periodically, water was sprayed over sediment using a pump and fire hose (pin stream spray) to spread out sediment and uncover burrowed larvae. ETS ABP-2 backpack electro-fishers were used to recover lamprey from areas of pooled water. A total of 3,614 larvae and 5 eyed juvenile lamprey (tallied using mechanical counters; Fig. 5) were salvaged from four truckloads of sediment by a dozen persons. About 1.5 - 3 hrs were spent on each truckload for lamprey salvage. Salvaged lamprey were released a few km downstream of the diversion into the Wenatchee River (river km 24.1) with 50-60 m^2 of larval lamprey habitat (Type I/II) (Fig. 5). In 7 days, 18,746 larvae and 21 eyed juvenile lamprey were salvaged from ~244.5 cubic yards of sediment (~30 truckloads). As a result, the density upstream of the headworks was estimated to be 33 lamprey m^{-2}. Initially, it was requested to dredge the upper sediment layer (~1 ft) first so that salvage efforts could be focused on the sediment depth where the most lamprey would be encountered. However, moving the large crane around twice was too time consuming for existing tight contractual deadlines. Thus, sediment from all depths was transferred and examined for lamprey. Although some differences in densities were noted per each truckload, none of the loads had zero or near zero lamprey.

Figure 2. The 150-ft tall crane's grab dredge used for sediment removal.

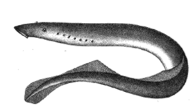


Figure 3. Custom-made waterproof dump truck owned by Wilsonville Concrete Products (Wilsonville, OR). Overview (left photo) and the inside (right photo).

Figure 4. Efforts to salvage larval lamprey from discarded material included searching the sediment surface by hand (left photo), and use of a fire hose to disturb and spread sediment to expose burrowed lampreys (right photo).

Figure 5. Multiple mechanical counters were used to tally the thousands of lamprey encountered during the dredging operation (left photo). All lamprey salvaged were released downstream in slow water larval lamprey habitat (right photo).

Recommendations

- Place a large tarp / pond liner (preferably non-black or brown color for best visibility) under the dredged sediment to prevent lamprey from burrowing into the dirt (when spraying water, this tends to occur).
- Place the tarp on a slant, with the dredged sediment at a slightly higher elevation to allow water and lamprey to flow downhill for easier collection (see Fig. 6).
- Use electrofishers with lamprey settings (e.g., ETS ABP-2 Backpack) in wetted areas to improve capture efficiency in isolated pools (e.g., 500-700 lamprey were salvaged in one isolated pool). Repeated passes may be necessary (and are encouraged).
- Many lamprey (especially YOY) are small and easily overlooked within the fine sediment. It is important to spend ample time to search and scan through the sediment.
- Regularly monitor temperature in all static water buckets/holding containers and use aerators whenever possible. Maintain containers at least half full with water to minimize temperature fluctuations and maintain adequate dissolved oxygen levels.
- Add fresh water periodically and keep within 2-3°C of the river temperature. If needed, temper holding water slowly prior to release (goal of <1.5°C change per 30 min) to match release temperature; start this process prior to traveling to the release site if possible.
- Release larvae at dispersed locations across entire release area, releasing more upstream to allow them to drift downstream and spread out. Monitor lamprey recovery at site before and after release and note any injuries (e.g., bruising) and mortalities. Watch for predation of released lamprey by (document predating fish species if possible). Frequent predation might warrant the release at an alternate site.
- Additional lamprey sifter designs that could potentially improve the efficiency of the salvage operations are shown below (Fig. 6).

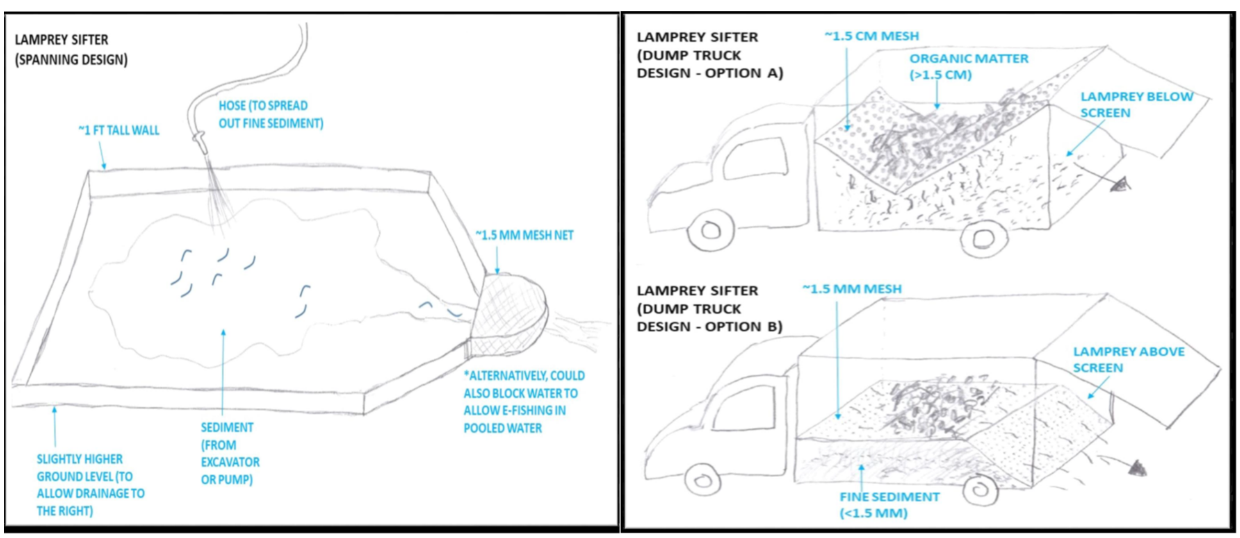


Figure 6. Potential designs that could improve lamprey salvage efficiency, including a lamprey sifter (spanning design) that can be placed on the ground (left photo) and a specially designed dump truck with a sifter (right photo).

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#2- Salvage of Lampreys from a Large River Diversion Sunnyside Diversion, Yakima River, Washington

Background and Issue

Figure 1. Overview of Sunnyside Diversion located at RKM 171.1 of the Yakima River (Yakima, WA). The white polygon highlights the area where the majority of the entrained lampreys and fine sediment are found.

Sunnyside Diversion (Fig. 1) is a large irrigation diversion (maximum flow = 1,300 cfs) that entrains many thousands of larval and juvenile lampreys each year (Pacific and Western Brook species). The irrigation season generally lasts from mid-March through late-October. There are 15 rotating drums (4.6 m diameter) with woven wire mesh fish screens (3.4 mm openings). Screens do not meet current NOAA screening criteria for new construction (≤2.4 mm). Once the headgate is closed, the Bureau of Reclamation operates two large industrial pumps (20.3 and 30.5 cm) to dewater the screen area for annual maintenance. The majority of larval lampreys Yakama Nation Fisheries salvage are found in low velocity areas with fine sediment deposits immediately downstream of the fish screens. Annual maintenance operations must occur soon after the headgate is closed, generally leaving 1-2 weeks for lamprey salvage. To maximize salvage efficiency, lamprey salvage techniques and protocols must continually evolve and adapt to new situations. The following case study aims to 1) summarize strategies and results from lamprey salvage efforts in 2018 and 2) provide general recommendations to salvage lampreys entrained in large river irrigation diversions.

Salvage Operation

At Sunnyside Diversion, coordination between diversion operators and salvage crews is crucial to limit lamprey mortality. In 2017, there was a miscommunication and the water level dropped rapidly (56 cm hr^{-1}), exposing sediments late in the day on a Friday (~7 pm), where thousands of larvae resided. In an emergency measure, the salvage crew began work early the next morning, but many lampreys (>3,700) were already dead on the dry sediment. Only 875 lampreys (~19%) were alive. In 2018, a new dewatering plan was developed to ensure 1) dewatering started earlier in the week (avoiding especially Fridays), 2) dewatering would stop at or before the end of the day so sediment would not dewater overnight, and 3) the Yakama Nation Fisheries salvage crew were allowed to turn on/off the pumps to slow the dewatering rate when needed. This resulted in a much slower dewatering rate (20.8 cm hr^{-1}) once water levels began to expose sediments, and most lampreys were picked up as they emerged, resulting in a much higher survival rate (~93%) for the 1,231 lampreys collected from dry banks.

Overall lamprey salvage operations took place for five days between November 6 and 13, 2018. Using ETS ABP-2 Backpack electrofishers, a total of 2,237 additional lampreys were salvaged from the wetted habitat (60 upstream and 2,177 downstream of the fish screens). Electrofishing efforts initially focused on isolated pools of water that formed as the water level receded (Fig. 2). A total of 268 lampreys were removed from isolated pools, with an average density of 44.7 lampreys m^{-2}. The dry shocking technique also proved successful in removing live lampreys concealed under visibly dry sediment. After the water level stabilized, electrofishing efforts focused on the fine sediment along the water's edge where larval lamprey densities tended to be high, likely from larvae following the receding water levels.

Figure 2. Example of a visibly dry areas where larval lampreys could still be concealed under the surface of the sediment where dry shocking can be effective (pouring water on the bumpy surface or over the cracked sediment at the bottom of the hill).

In 2018, we developed an experimental sprinkler system to provide water to larval lampreys stranded on and within dewatered banks. The sprinkler system was constructed with various sizes of PVC pipes (ranging from 12.5-50.8 cm diameter) and deployed on dewatered banks in larval lamprey habitats for 3 to 4 days during the initial dewatering. The system was relatively inexpensive (<$1,600), flexible, portable, and easy to operate. The system consisted of five sprinkler heads, each with a spray diameter of ~8 m. The sprinkler system was turned off when staff was available to salvage lampreys, and turned on at the end of day to minimize the desiccation and stranding of lampreys overnight. The sprinkler system appeared to keep exposed lampreys moist overnight, but also provided water to isolated pools that would otherwise have dried up.

Figure 3. Overview of the sprinkler system operation downstream of the fish screens at Sunnyside Diversion immediately after dewatering of the key larval lamprey habitat occurred. Part of the sprinkler system was able to cover the high density isolated pools.

In addition to lampreys, each year 200~300 live/dead Western Pearlshell Mussels (*Margaritifera falcata*) are collected from the canal (primarily downstream of the fish screens ;Fig. 4). The mussels downstream of fish screens were likely entrained during the juvenile/glochidia stages and managed to survive and overwinter multiple years in the dewatered canal with only subsurface flow. Each year a large portion of mussels within the diversion are susceptible to desiccation, and once they are downstream of the fish screens no path back to the river is available.

Figure 4. Western Pearlshell mussels collected from the canal downstream of the fish screens at Sunnyside Diversion in 2017. The left photo shows many live and dead mussels collected (up to 15 cm long) and the right photo shows the general area of the canal where they were collected.

Recommendations and Take Home Ideas

Dewatering Rate

We recommend a dewatering rate of < 10 cm hr^{-1} once sediment deposits begin to expose (Fig. 5). With a salvage crew on site to salvage lampreys as they emerge, mortality can be minimized even with faster dewatering rates (e.g., ~20 cm hr^{-1}). However, if no salvage crew is available (e.g., night time or weekends), slower dewatering rates (<5 cm hr^{-1}) are recommended to maximize the lampreys' ability to "self-rescue."

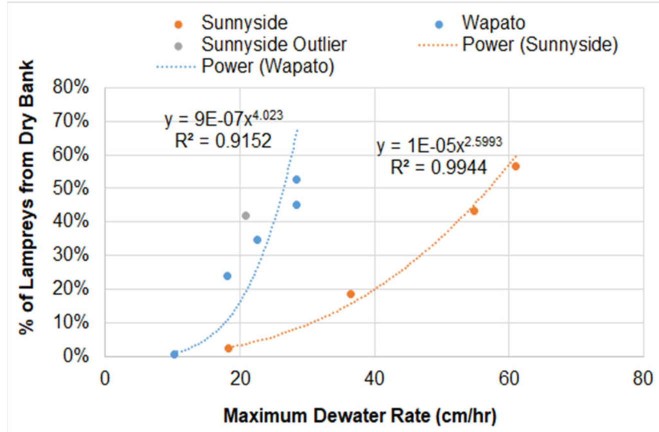

Figure 5. Scatter plot of maximum dewatering rates and percent of lampreys captured from dry banks annually between 2014 and 2018 at Sunnyside and Wapato diversions. The trend line (power function), associated equation, and r-square values are also shown. Wapato Diversion is another large scale irrigation diversion on the Yakima River close to Sunnyside Diversion.

Salvage crews should begin work as soon as possible as lamprey habitats begin to dewater. Larval lampreys can become stranded on dried sediment immediately after dewatering. Lampreys may also perish in standing water pools if left for prolonged periods at high densities.

Dry Banks

- As water levels recede, lampreys should be removed from dry banks. Dry banks should be searched multiple times throughout the dewatered period (even over several days). Lampreys do not emerge all at once and may take several hours to several days to emerge to the surface.
- Using a sprinkler system to maintain wetted habitats during dewatering events can be effective to prolong the life of exposed lampreys or those still trapped within the sediment. The system is inexpensive, simple and adaptable to most diversion areas. The sprinkler system should be deployed as soon as sediments become exposed and left in operation for several days or until the majority of larvae are salvaged.
- Dry shocking (see Appendix B) can be used on exposed bank areas, especially in areas with high densities of lampreys. Pouring water over the area can sometimes increase its efficiency.
- Fish friendly screens should be placed on pumps used to dewater areas or run sprinkler systems. We recommend screening material of $\leq$2.4 mm. The outlet hose from the pumps should be placed back into the stream or into the fish bypass system, so that any lampreys entrained into the pump will have a chance to return to the river.
- Based on average larval lamprey length to width ratio, lampreys <90 mm can pass through 3.4 mm wire mesh and <55 mm can pass through 2.4 mm perforated plate. Unseen gaps between or under fish screens can also pass larger lampreys.

Electrofishing (See Appendix B for more information)

- Electrofishing efforts should first focus on Type I and II areas with limited water availability (i.e. sediment that is in the process of becoming dewatered or limited water within isolated pools).
- All areas in the canal (further upstream and downstream of the screens) should also be surveyed and salvaged if needed.

- It is important to survey Type II habitat with coarse substrates, which can occasionally hold many lampreys, especially larger larvae and eyed juveniles. Also, lampreys in the fine sediment can move into Type II habitat as the water level recedes.

Other Recommendations

- Other species should be considered during lamprey salvage operations (e.g., freshwater mussels - see ***Mussel-Friendly Restoration*** *(Blevins et al 2019)*). While conducting lamprey salvage operations, it is recommended that staff keep an eye out for freshwater mussels in all project areas, especially in areas with rocky/sandy bottoms where density seems to be higher, to help restore this important group of filter feeders. We recommend this search to occur in the early part of the dewatering operation while survival rates tend to be higher.
- Mussels can be salvaged by removing from sediment, placing in a bucket or cooler, and translocating to an existing population or to a site with suitable habitat (stable substrate, adequate flow year-round). Transport mussels with water if air temperature is cool enough to avoid rapid warming during transit. If water or air temperature are warm, or if transportation will be lengthy (> 1 hr), transport mussels in mesh bags, in a cooler or bucket, between layers of cool, damp towels.
- Close coordination with all appropriate agencies is important for a successful lamprey salvage. In the case of Sunnyside Diversion, close coordination with the Bureau of Reclamation led to enhanced lamprey survival during project operations, due to slower dewatering rates and seamless pump operation scheduling.

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#3- Salvage of Lamprey from a Small River Diversion Bachelor-Hatton Diversion, Ahtanum Creek, Washington

Background and Issue

Irrigation diversions pose risks for larval lampreys throughout their range. Larval lampreys are attracted to the slow water and fine sediments that typically collect near the fish screens. When these systems are shut down after the irrigation season, entrapped lampreys are vulnerable to injury and mortality during dewatering and annual maintenance operations. Bachelor-Hatton Diversion (Fig. 1) is located on Ahtanum Creek (river km 31.8), a tributary to the Lower Yakima River. Each year, thousands of lampreys are encountered at this diversion, despite its small size (maximum flow of 58 cfs) and short irrigation season (mid-April to early July). In 2015, over 10,000 larval lampreys were salvaged from this small diversion, primarily using electrofishing. The following case study aims to 1) summarize our salvage efforts and observations during the lamprey salvage efforts in 2015 and 2) provide recommendations to salvage lampreys trapped within small stream irrigation diversions.

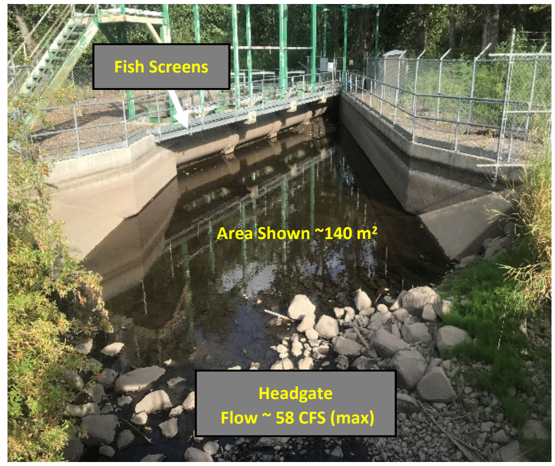

Figure 1. Upstream of the fish screens at Bachelor-Hatton Diversion after irrigation shutdown, RKM 31.8 on Ahtanum Creek (Yakima, WA).

Salvage Operation

The headgate and downstream canal gates were closed on July 10, 2015, with small leakage of water still seeping in. Lamprey salvage efforts began on July 14, 2015, and continued until January 28, 2016 (seven survey dates). Dredging operations occurred on October 16 and 17, 2015. An ETS ABP-2 Backpack Electrofisher was used to remove larval lampreys concealed in wetted fine sediment. In total, 10,698 larval lampreys (10,343 upstream and 355 downstream of the fish screens) were salvaged and returned to Ahtanum Creek, downstream of the headgate.

Figure 2. The 50 gallon min^{-1} pump used to lower the water (left photo) and the lamprey mortalities found within the pump (right photo).

During the survey period, a total of 1,518 dead (or nearly dead) lampreys were found on dewatered banks (n=8; all from downstream of the fish screens), on top of wetted habitat (n=810; all from upstream of the fish screens), and on dredged material (n=700). During the dredging operation, two pumps (50 gallon min^{-1} and 300 gallon min^{-1}) were placed immediately upstream of the fish screens and used to draw down the water level (Fig. 2). Using hand nets at the hose outlet of each pump (subsampling), we estimated that approximately 1,188 larval lampreys passed through these pumps during approximately 500 minutes (8.3 hrs) of total running time (average of 142 lamprey/hour). We estimated between 16% and 25%

mortality from the 50 gallon min^{-1} pump and 56% mortality from the 300 gallon min^{-1} pump, resulting in an estimated 321 lamprey mortalities. We received permission from the Yakama Nation and the Ahtanum Irrigation District to allow a small amount of flow (~150 gallon min^{-1}) through the headgate to return directly through the bypass channel post irrigation season. This operation helped provide fresh water to the entrained lampreys and likely prolonged lamprey survival both upstream and downstream of the fish screens. The downstream canal gates were closed, so none of this water flowed downstream into the irrigation canal.

Figure 2. The post irrigation water (~150 gallons min^{-1}) entering the area upstream of the headgate (left photo) and the overall wetted area upstream of the fish screens receiving this water (right photo).

Recommendations and Take Home Ideas

- Even the smallest diversions pose a risk to larval and juvenile lampreys. Irrigation diversions that are within lamprey distribution and collect fine sediment should be checked for larval lampreys regardless of the diversions' size.
- Salvage crews should begin work as soon as possible as lamprey habitats begin to dewater. Larval lampreys can become stranded on dried sediment immediately after dewatering. Lampreys may also perish in standing water pools if left for prolonged periods at high densities.
- All areas in the canal (further upstream and downstream of the screens) should also be surveyed and salvaged if needed
- Maintaining some flow into the canal to exit through the bypass after the irrigation season could be an alternative to prolong the life of entrained lampreys, extending the time available for salvage. Small irrigation diversions can easily become turbid during salvage: a small amount of flow entering the diversion can increase water clarity and salvage efficiency.
- Fish friendly screens should be placed on pumps used to drop water levels. We recommend a screening material of $\leq$ 2.4 mm. The outlet hose from the pumps should be placed back into the stream so that pumped lampreys will have a chance to return.
- Fish screens are not effective to prevent entrainment of all larval lamprey, especially those less than 60-90 mm. Unseen gaps between or under screens can also pass larger lampreys.
- Discarded material from the dredging process should either be 1) placed back into free-flowing water and allowed to drift downstream, or 2) if placed on dry lands, searched for larval lampreys. If placed on dry lands, spread the dredged material on a flat surface to allow ample opportunities to find concealed lampreys. A sprinkler system, using a small pump and canal or river water, can be used to keep sediment wet and prolong lamprey survival during salvage efforts.

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#4- Larval Lamprey Electrofishing Surveys
Yakima Nation Ceded Lands (Mid/Upper Columbia Subbasins)

Background and Issue

Since 2008, Yakama Nation (YN) Fisheries has been conducting larval lamprey electrofishing surveys to document the status of Pacific Lamprey and effects of adult translocation within the Yakama Nation Ceded Lands in arid Eastern Washington (Yakima, Wenatchee, Entiat, Methow, Klickitat, White Salmon subbasins and other Mid/Upper Columbia tributaries; Fig. 1). We conduct "full surveys" on established index sites every 1-2 years to assess habitat availability, relative abundance by species and size groups, and other habitat parameters. We also conduct "short surveys" that focus on presence/absence and changes in distribution. Surveys are conducted annually between July and mid-October.

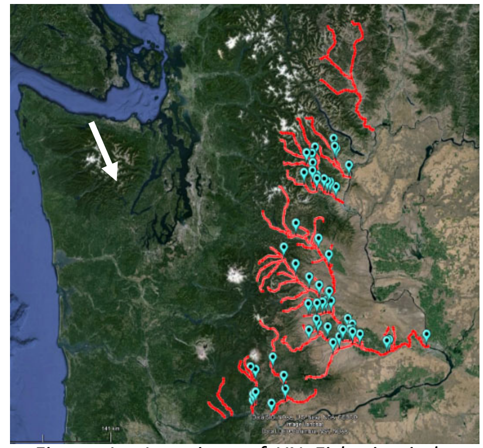

Figure 1. Locations of YN Fisheries index sites located within the Yakama Nation Ceded Lands in Washington.

Study Design

YN Fisheries target watersheds that are typically 200 km^2 with river sizes of 20 km or larger (Note: in humid regions, Pacific Lamprey can be found in much smaller systems; e.g., 50 km^2 and 10 km rivers). Designated index sites are spaced every 15-25 km. In the Yakima River, these sites are every ~50 km due to its large size. We use aerial images from Google Earth to focus our surveys in prime larval lamprey habitat within the reach. Type I habitat is preferred larval lamprey habitat consisting of fine sediment and organic matter; Type II habitat is acceptable habitat consisting of shifting sand or a mix of coarse and fine substrate (Fig. 2). Type III habitat consisting of only coarse substrate or hard pan clay and is not suitable. Current and historical aerial images and on-the-ground conditions are reviewed to identify the best longstanding accessible larval lamprey habitat for index monitoring. Land access permission is obtained prior to the surveys. Our 14 step-by-step protocols at pre-identified index sites are the following:

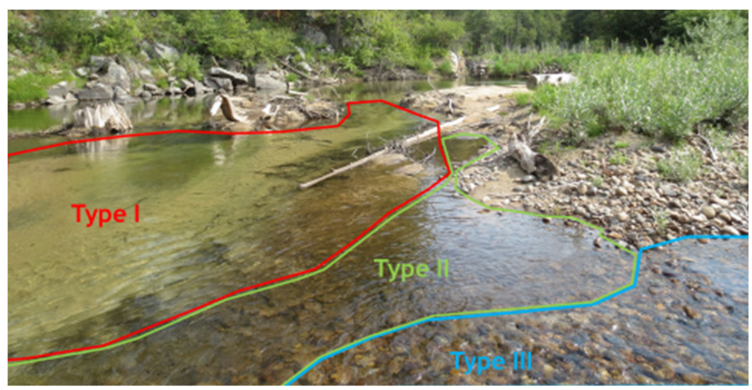

Figure 2. Examples of Type I, II and III habitats.

1. Mark off a 50-m reach that contains the largest amount of larval lamprey habitat.
2. Estimate the overall amount of Type I and II habitat within the 50 m reach (in 1 m^2 increments).
3. Using an ETS ABP-2 Backpack Electrofisher in shallow (< 1 m) water, subsample 10 m^2 or more of the overall Type I habitat available within the reach. When overall Type I habitat is limited (< 10 m^2 or < 10% of overall larval lamprey habitat), 10 m^2 or more of Type II habitat is also subsampled. A 3-5 m long cable/rope (with each meter clearly marked) is useful for area estimate. We use a single pass survey that includes missed lampreys (i.e. observed but not captured) to measure relative density and abundance.
4. Record the amount of time electrofished (slow pulse time, which is typically 33% of the overall time) as a measure for Capture Per Unit Effort (CPUE). 60 sec per m^2 is our target pace.

5. Separately tally the number of Young of the Year (YOY 0+ age) and 1+ age lampreys that were missed while surveying each habitat type. YOY lampreys are counted separately due to the difficulty in capturing this age class efficiently, the highly variable densities, and very patchy distribution. YOY lengths are typically < 25 mm by September and < 35 mm by December.
6. Assess the survey visibility (% of water visible in 10% increments). Think about the percent of water volume not visible (due to wind, depth, turbidity, aquatic vegetation, etc.) and subtract this value from 100%. Missed lamprey numbers are divided by this percent to improve the estimate for the "true" number of missed lampreys.
7. Measure other habitat features, including water depth, temperature (surface vs. subsurface), conductivity, voltage needed to reach 1.0 amperage, and sediment type / depth at the best plot.
8. Sort and count the number of lampreys captured by four groups [Pacific Lamprey ≥ 50 mm (PA), *Lampetra* lamprey ≥ 50 mm (WB), unknown larvae ≤ 50 mm (UN), and YOY]. If total # of 1+ age is substantially larger than 100 (e.g., > 120), stop at 100.
9. Weigh the total weight of each of the PA, WB, and UN groups using a ziplock bag (0.5-1 gallon) with a small amount of water (tared). YOY weight is typically negligent, but if YOY number is > 10, could also weigh the YOY with a 0.01 g scale (typically individual weight of YOY is 0.01-0.10 g). Provide a wind break for scale. These values will be used for mass estimation.
10. Using a photarium (no anesthetic necessary), measure the length of 50 representative lampreys from the sorted lampreys based on the proportion of the 1+ age groupings [e.g., if the sorted sample is PA=25, WB=43, UN=32 (100 total), measure PA=23, WB=21, UN=16 (50 total)]. Measure the largest and smallest from each group to capture max and min values.
11. Weigh three individual larvae weights for each of the 1+ age groups (aim for a large, medium, and small size samples, where possible) to gain a representative condition factor.
12. If there are additional eyed lampreys (juvenile PA, adult WB) that were not measured in the 40 samples, count the total number of those additional ones (if time allows, measure and weigh all separately from the 40 samples).
13. Measure five YOY lengths and reassess max size threshold (aim for largest, smallest, and three representative samples to get the range as well as average values).
14. Once all biological and habitat survey data are taken, release larvae back to the surveyed habitat.

Summary

The combination of data above will provide representative biological measurement data (N=40) as well as the estimation of habitat availability (Type I/II area within 50 m), relative density (# and mass density and CPUE) and relative abundance (estimated # and total mass within the 50-m reach) for each of the four groups (PA, WB, UN, YOY) and typically takes 2 hrs per site (1.5-3 hrs).

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#5- Larval Lamprey Use of Salmonid Restoration Projects Methow River, Washington

Background and Issue

There is an extensive and resource-intensive effort underway to improve stream habitat conditions in the Columbia River Basin, primarily to assist with recovery of ESA-listed salmonids. A portion of these projects have the potential to also improve habitat conditions for lamprey, but to achieve this, the unique life-history traits and habitat needs of lamprey must be considered throughout the life of the project from planning through implementation. By integrating the needs of lamprey into salmonid-based restoration efforts, project sponsors and managers can increase the overall ecological value of their project with potentially minimal additional cost.

Figure 1. Fine sediment accumulation downstream of an engineered wood structure installed to benefit salmonid recovery, Methow River, Washington.

Study Design

Several salmonid-based habitat restoration projects in the Methow River watershed that included large wood installations as a treatment component have been monitored since 2011 for: 1) accumulations of fine sediment that could serve as larval lamprey rearing habitat and 2) use of the fine sediment accumulations by larval lamprey. Larval sampling occurs annually during periods of low water when the fine sediment accumulations are most accessible. Larval lamprey presence sampling is completed by either electrofishing or hand sifting of sediment. Restoration sites are visited annually post-high water to examine development of fine sediment accumulations, but no detailed habitat data collection is undertaken.

Figure 2. Numerous larval lamprey have been observed within this patch of fine sediment that has accumulated downstream of an engineered wood structure (visible in the upper portion of the image) installed to benefit salmonid recovery, Methow River, WA. The wood structure was

Results and Discussion

Figure 3. Several distinct bands of fine sediment accumulation can be seen downstream of this engineered wood structure in the Methow River, WA. These accumulations include sand (outer band) and finer sediment/detritus (inner band). Larval Pacific lamprey have been observed inhabiting both of these micro-habitats.

We found extensive development of larval lamprey rearing habitat in close proximity to five engineered wood structures installed along the streambank. Prior to restoration, fine sediment was not present at any of these locations. After restoration, accumulations of fine sediment most commonly developed downstream of the structures. Sediment accumulations began to form the year after installation following the spring runoff. Size and configuration of the sediment patch varied from location to location based on stream channel and water flow patterns. Larval lamprey presence and abundance also varied among locations and ranged from just a single larva to >5/m^2. We found that fine sediment accumulations can persist relatively unchanged at some locations for many years, but also shift in both size and shape over the course of just one flow event. During our study, an extensive adult lamprey translocation effort was undertaken in the basin; we attribute the significant increases in larval abundance observed at many sites to this effort rather than the actual quality of habitat occupied, but note that projects increased habitat availability simply through the fine sediment accumulations.

Summary and Take Home Ideas

We have documented numerous locations in the Methow River watershed where fine sediment suitable for larval lamprey rearing has accumulated around (especially downstream of) engineered wood structures. While these structures were installed to benefit recovery of ESA-listed fish species, they are providing habitat for other aquatic species, including imperiled lamprey. Our efforts are just a starting point from which more detailed studies could be conducted that investigate the relationships between salmonid-based large wood installation projects, as well as other types of restoration techniques (e.g. beaver dam analogue structures), and their use by lamprey. Specifically, certain log configurations may be able to develop more sediment depending on stream channel characteristics and water flow patterns. A particular wood structure design could leverage these characteristics to maximize accumulations of fine sediment. Detailed habitat monitoring of the sediment accumulations will aid in this analysis.

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#6- Evaluation of Salvage Techniques - Slow Drawdown Leaburg Dam, McKenzie River, Oregon

Background and Issue

Larval lamprey naturally reside and burrow in fluvial sediments and are especially vulnerable to stranding and mortality during dam operations or other in-water work that dewater nursery habitats. To evaluate the effects of drawdown in the Leaburg Reservoir (Figure 1), a study was conducted during a slow, 92 cm, drawdown, at 4.6 cm/hour, to 1) examine changes in larvae distribution, abundance, and density before and after drawdown; 2) evaluate several techniques for larvae salvage during drawdown; and 3) examine larvae emergence from burrows during dewatering.

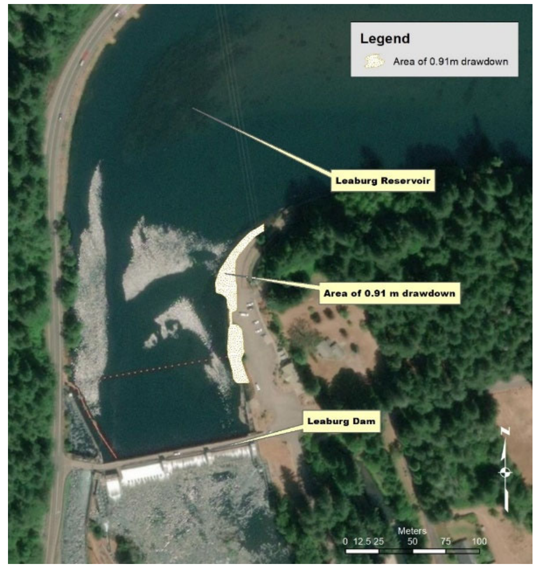

Figure 1. Study site depicting Leaburg Reservoir and the area of impacted by drawdown at RKM 62.4 of the McKenzie River.

Study Design

The complete write-up of this study is available at https://www.fws.gov/CRFWCO/CRFPO_pubs.cfm

During the drawdown, four techniques to salvage and quantify larvae were evaluated in eight plots: 1) excavation, 2) electrofishing the dewatered sediments or "dry shocking," 3) liquefaction, and 4) observation (Figure 2). For excavation, sediments were removed down to 15 cm depth and larvae were sieved from the sediment. Dry shocking used lamprey specific electrofishing techniques to encourage larvae from the sediment, so that larvae can be salvaged by hand. Liquefaction, a technique used on coastal beaches in Washington to enumerate razor clams, was intended to create a slurry of water and sediments from which larvae could be salvaged by hand. Observation (watching numbers of lamprey emerging over time) provided information on the number and time for larvae to emerge from dewatering sediments at this slow drawdown rate (4.6 cm/hour). In addition, larval distribution, abundance, and density were evaluated before and after the drawdown using a deepwater electrofishing boat set up especially for larval lamprey (Figure 2).

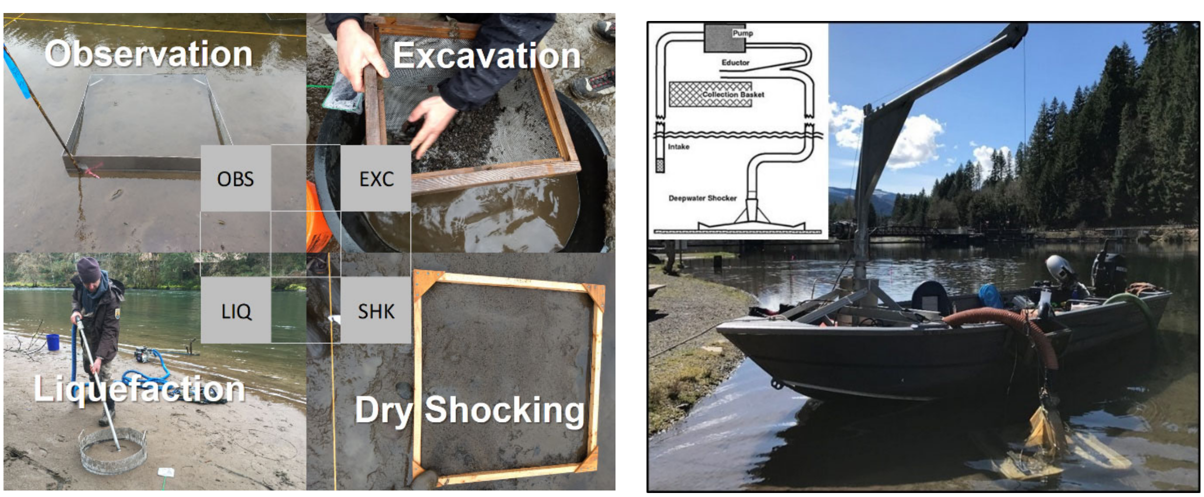

Figure 2. Example plot (3x3 m) and techniques evaluated during drawdown (right). Deepwater electrofishing boat designed for larval lamprey detection (left). Electrofisher schematic (left inset): Figure 1b in Bergstedt, R. A., and J. H. Genovese. 1994. New technique for sampling sea lamprey larvae in deepwater habitats. N. American Journal of Fisheries Management 14(2): 449-452.

Quantitative results are available within the complete report. Generally, of the four techniques evaluated for salvage during drawdown, **dry shocking** the dewatered sediments was the most effective for salvage in these circumstances: it encouraged larvae to emerge so they could be salvaged by hand, and has been successfully used in other salvage efforts (Beals and Lampman 2018). However, long-term effects of dry shocking are not understood, and if long-term survival rates were found to be low, the costs might outweigh the benefits. In some conditions when the dewatering period is short (<24 hrs), it may be more beneficial to allow lamprey to stay in the sediments, as larvae are tolerant of low oxygen levels provided the area remains sufficiently moist. **Excavation** was useful for research and likely provided the best abundance estimate, but was too time-consuming and disruptive to sediment for most salvage efforts. **Liquefaction** was not successful due to the high flow level of the available pump, but may prove useful if adjustments are made to the flow rate, which would require further refinement and testing to determine efficacy. **Observation** gave insight into the behavior of lamprey that emerge and their ability to move back into receding waters. The larger larvae that emerged were more able to keep up with a slowly receding water level than smaller lamprey, but all emerged lamprey were exposed to increased predation and less suitable weather conditions, and movement across the sediment appeared difficult (see Photo to right). Further, based on analysis further described in the report, only about 50% of the larvae emerge at all.

Estimates pre- and post-drawdown made using a **deepwater electrofisher** indicated that the drawdown reduced average density of larval lamprey in the de-watered area. Average densities declined from 10.7 larvae/m^2 (95%: 9.5 – 12.3) pre-drawdown to 2.3/m^2 (95%: 1.9 – 2.8) after re-watering. Although we know that many larvae emerged, we do not know what proportion of these individuals moved and re-burrowed outside the study area, re-burrowed within the study area after re-watering, or perished due to exposure to desiccation or predation by terrestrial predators.

Summary and Take Home Ideas

Substantial numbers of lamprey live in sediment deposits, and can be affected by dewatering activities, even when areas are dewatered very slowly. Half of the larvae in the sediments did not emerge after water receded. Larger lamprey were generally more able to keep up with receding waters, while smaller lamprey could often not. Dry shocking was the most practicable salvage technique, and encouraged lamprey to emerge from the sediments, when using lamprey specific shocking techniques. However, the areas to be dewatered, especially in reservoirs, may be too expansive to effectively salvage by any means, and a slow draw-down will allow more lamprey to successfully self-rescue. In all situations, site-specific conditions should be considered: if habitats will be dewatered for long periods, it may be best to dewater slowly and promote self-rescue, and salvage high-density areas to the extent possible. If a short drawdown (<24-48 hrs), quickly dewatering and rewatering during cool, wet periods may allow lamprey to survive in the sediments. Deepwater electrofishing was an effective means to sample for pre- and post-drawdown, but more research is needed to understand the ultimate fate of lamprey in the drawdown area.

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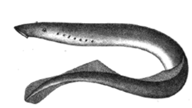


Valley-scale Restoration Immediately Improves Habitat for Lampreys

Background

In 2018 and 2019, 2 phases of a large-scale river restoration project (650 acres total) were completed on the lower 1.25 miles and 200 acres of the South Fork McKenzie River (Figure 1). The project design follows a 'Stage 0' approach in order to maximize hydrologic connectivity and ecological benefits across the valley bottom (Cluer and Thorne, 2013; Powers et. al., 2018). Prior to the construction of Cougar Dam and extensive levees and berms and a long history of logging and stream cleaning, the lower South Fork was a complex, anastomosing system in a broad alluvial valley, unique within the McKenzie Sub-basin. The South Fork was once a biological hotspot that provided exceptional habitat for Pacific lamprey, spring Chinook salmon, bull trout, and other native fishes. Anthropocene impacts had transformed the South Fork into a primarily single-thread, incised transport channel that flushed out wood, fine sediment and gravels, nutrients, and organic matter, resulting in a relatively unproductive valley (Figures 1 and 3).

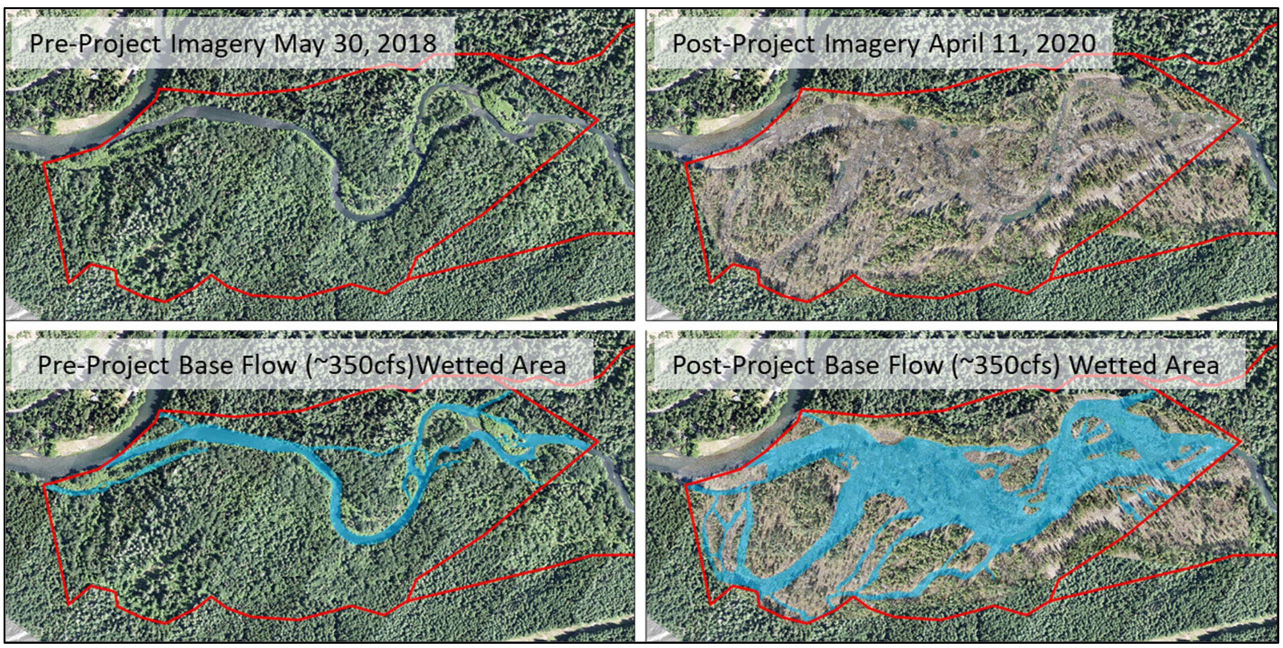
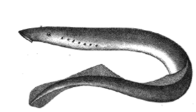


Figure 1. Pre- vs. post-project imagery and wetted area (shown in blue) following implementation of Phases 1 and 2 in 2018 and 2019, respectively. South Fork McKenzie River, Willamette River Basin, Oregon.

Project Goals

The goals of the project are to:

- Restore the physical, chemical, and biological processes that maintain a healthy, diverse, and resilient ecosystem;
- Re-establish depositional environments to maximize longitudinal, lateral, and vertical connectivity at base flows, resulting in self-formed and self-sustaining dynamic wetland-stream complexes over time;
- Increase habitat availability, diversity, and quality for ESA-Threatened spring Chinook salmon and bull trout, Pacific lamprey, and other native aquatic and riparian species.



Project Design and Implementation

The design followed Stage 0 principles and used tools developed specifically for Stage 0 projects (Geomorphic Grade Line Relative Elevation Models; Powers et. al., 2018). Artificial features (e.g. berms, levees, drainage ditches, riprap, fill) were identified and removed and that sediment (115,000 cubic yards) was used to fill and lift incised channels up to an elevation that would reactivate historic flow paths and reconnect the valley (Figure 2). High densities of large woody material (>4,200 pieces total; >24 pieces/acre) were then added throughout the valley bottom. No channels were constructed.

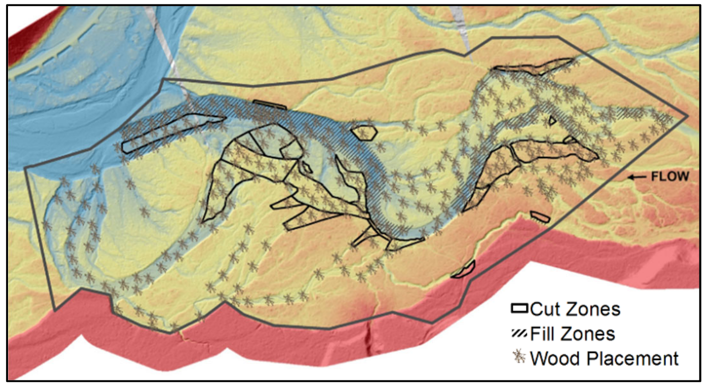


Figure 2. Simplified design map for Phases 1 and 2.

Fish Salvage Efforts

Prior to filling of any channels, water was temporarily diverted around project areas and extensive fish salvage efforts occurred in all former channels using techniques such as seining, electrofishing, and hand netting in coordination with ODFW. A total of about 500 larval lampreys and 1 adult were collected and moved to either above or below the project area. About 7,600 other critters (salmonids, sculpin, dace, amphibians, crayfish) were collected and relocated, including 14 mussels.

Total Project Costs

The cost for both phases combined was $2.9 million sourced from several entities. USFWS contributed $142,000 in Bull Trout Recovery funding and $150,000 was provided by Bonneville Power Administration/ Pacific States Marine Fisheries Commission through the Pacific Lamprey Conservation Initiative.

Figure 3. Pre-project conditions (left) as a single-thread transport channel and one year post-project conditions (right) with maximum valley connectivity and complexity.

Preliminary Monitoring Results

Our robust effectiveness monitoring program includes a suite of process-based metrics that will track changes in fluvial processes, habitat characteristics, and the biological community. The short-term monitoring data shows encouraging results: an immediate transformation of geomorphology, water table, and stream energy; dramatic increases in habitat diversity; and rapid biological recolonization. Metrics directly related to Pacific lamprey habitat have all increased significantly within a year of implementation

(Table 1). We now run our hands through sandy patches throughout the project area and larval lampreys pop out in high densities (Figure 4). An on-going, separate study found 5 tagged adult lamprey entered the South Fork, presumably to spawn.

The increase in gravels and suitable spawning habitat coincided with a large return year of spring Chinook salmon adults and 241 redds were documented in the project area in Fall 2019 – a 6-fold increase in redd density from the next best year in the last decade (Figures 5 and 6).

Table 1. Preliminary monitoring results for Phases 1 and 2.

MONITORING METRIC	PRE-PROJECT	POST-PROJECT	% / AREA CHANGE
Base Flow Wetted Area	20.5 acres	76.2 acres	272% 55.7 acre ⬆
Area of Low Velocity (<1fps) Rearing Habitat*	~11 acres	~65 acres	491% 54 acres ⬆
Area of Fine Sediment/Potential Lamprey Rearing Habitat*	~4 acres	~34 acres	750% 30 acres ⬆
Area of Gravels/Potential Lamprey Spawning Habitat*	~3 acres	~29 acres	867% 26 acres ⬆

** Extrapolated from monitoring transect data to wetted area.*

Figure 4. Larval lampreys are now frequently found in the abundant fine sediment patches throughout the project area.

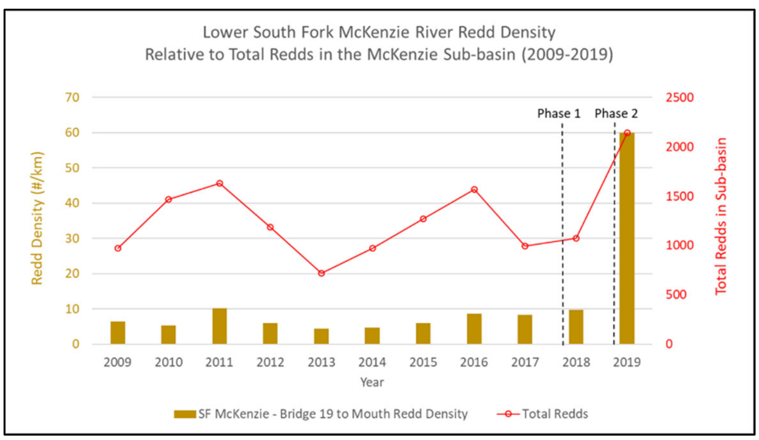


Figure 5. Redd density in the project area over the last decade.

Figure 6. A pair of spawning Chinook in the Phase 2 project area a couple weeks after implementation.

References:

Cluer, B., & Thorne, C. (2013). A stream evolution model integrating habitat and ecosystem benefits. River Research and Applications, 30, 135–154.

Powers PD, Helstab M, Niezgoda SL. A process-based approach to restoring depositional river valleys to Stage 0, an anastomosing channel network. River Res Applications 2018:1–11.

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