

*Best Management Guidelines for Native Lampreys
During In-water Work*



*Living Document, Original Version 1.0 - May 4, 2020
Lamprey Technical Workgroup*

Recommended Citation:

Lamprey Technical Workgroup. 2020. Best management guidelines for native lampreys during in-water work. Original Version 1.0, May 4, 2020. 26 pp. + Appendices. Available: <https://www.pacificlamprey.org/ltwg/>.

NOTE: Hyperlinks were updated on June 1, 2022. No other changes were made.

Acknowledgements:

This document was drafted by a subgroup of the Lamprey Technical Workgroup (in alphabetical order): Jody Brostrom (USFWS), Ben Clemens (ODFW), Ann Gray (USFWS), Ralph Lampman (Yakama Nation Fisheries), Theresa “Marty” Liedtke (USGS), Zoltan Matica (California Department of Water Resources), and Joe Skalicky (USFWS)), and critically reviewed by multiple members of the Lamprey Technical Workgroup.

Questions? Email info@pacificlamprey.org

TABLE OF CONTENTS

Goals	1
1. Introduction.....	1
2. Lamprey Biology and Habitat Use	2
Habitats.....	5
3. Planning for In-water Work.....	7
Pre-Project Planning and Monitoring.....	8
In-Water Work Location	8
In-Water Work Timing.....	9
Modifying Projects to Benefit Lampreys	10
4. Dewatering.....	11
Irrigation Diversions	12
Providing Refuge.....	12
5. Salvage.....	12
Dredged or Removed Sediments.....	13
General Sequencing of Salvage – A Multi-Species Scenario	14
6. Handling and Holding Lampreys.....	15
Holding and Transport for Lampreys.....	15
Anesthetics	17
7. Sampling and Recording Species Data	18
8. Post-Implementation Monitoring.....	20
9. Glossary	21
10. References.....	22

APPENDICES

- Appendix A. Available Resources – Lampreys and Freshwater Mussels
- Appendix B. Disinfecting Protocol Example – Aquatic Invasive Species
- Appendix C. Lamprey Electrofishing Guidelines
- Appendix D. Lamprey Fish Screen and Passage Guidelines
- Appendix E. Case Studies

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

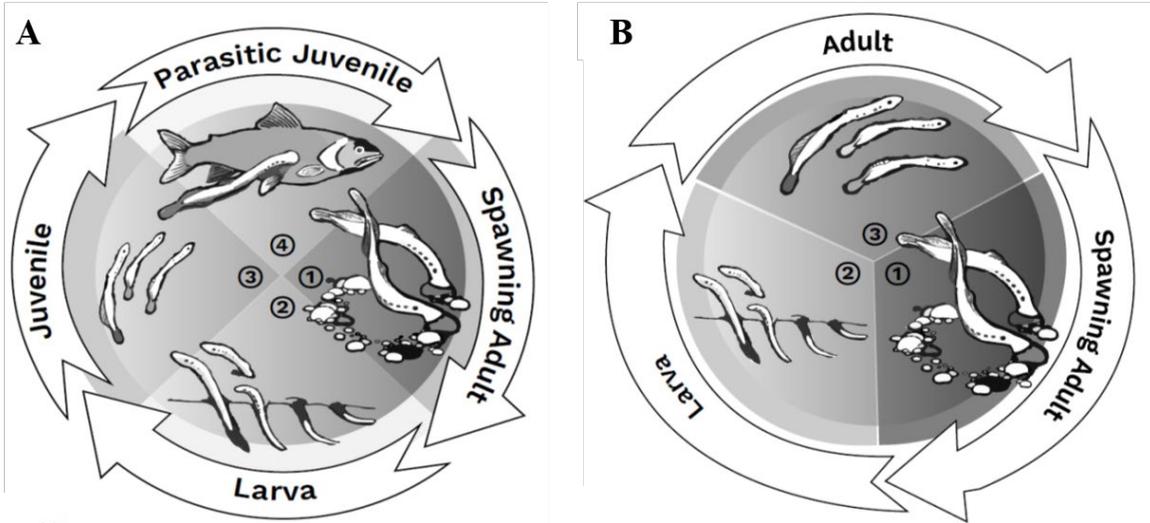


Figure 1. Lamprey life cycles for parasitic lampreys (A) and resident lampreys (B). The numbers “1” and “2” refer to spawning adult and larval rearing life stages, respectively, for both A and B. For A, “3” or “juvenile” represents the outmigrant life stage, and “4” represents the parasitic life stage.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

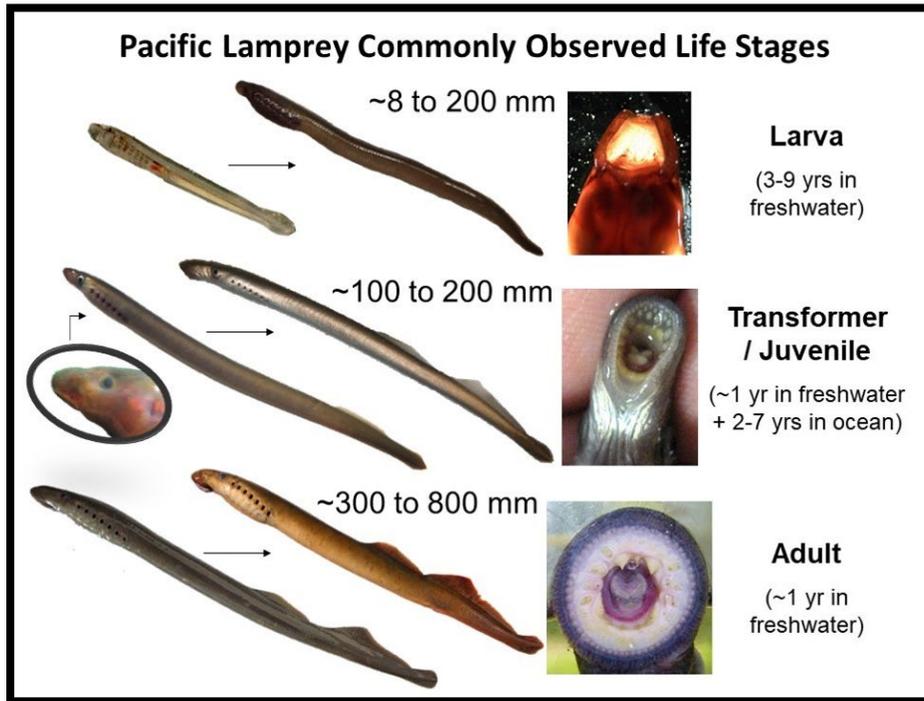


Figure 2. Pacific Lamprey life stages. From top to bottom, larva (first feeding to larger size), transformer (with two stages of emerging eye), juvenile (fully transformed silver body), and adult (migrant recently re-entering freshwater to sexually mature). Credit: R. Lampman.

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

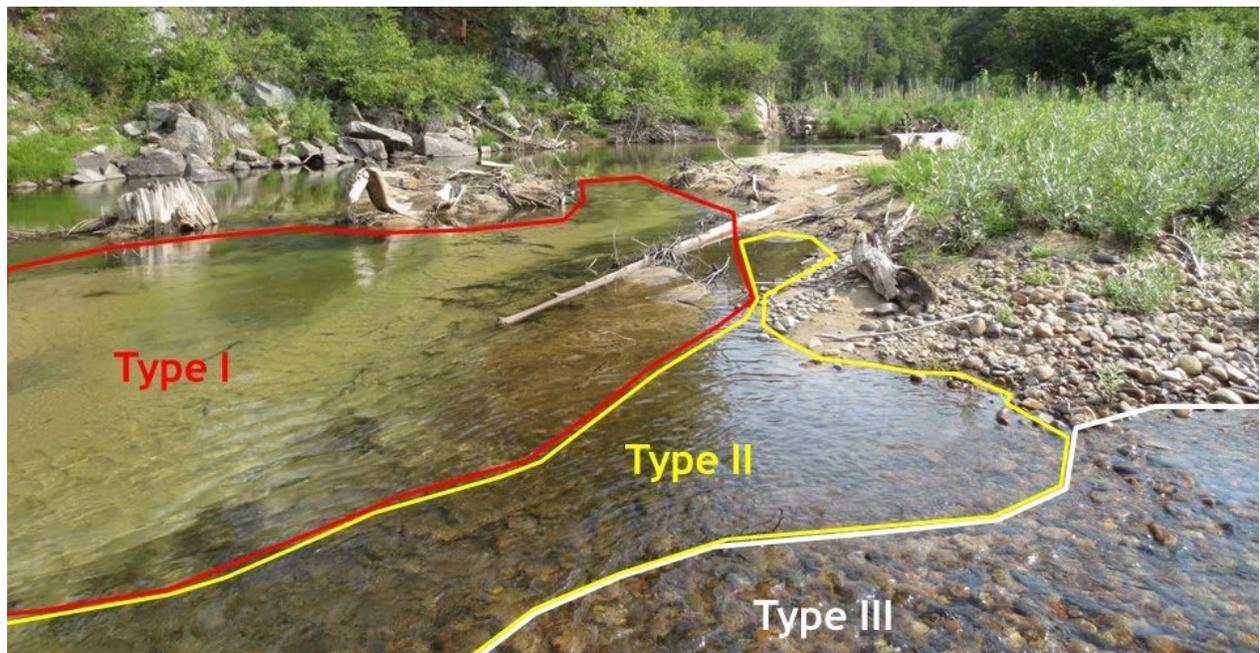


Figure 3. Example of Type I, II and III habitats used by lampreys. Credit: R. Lampman.

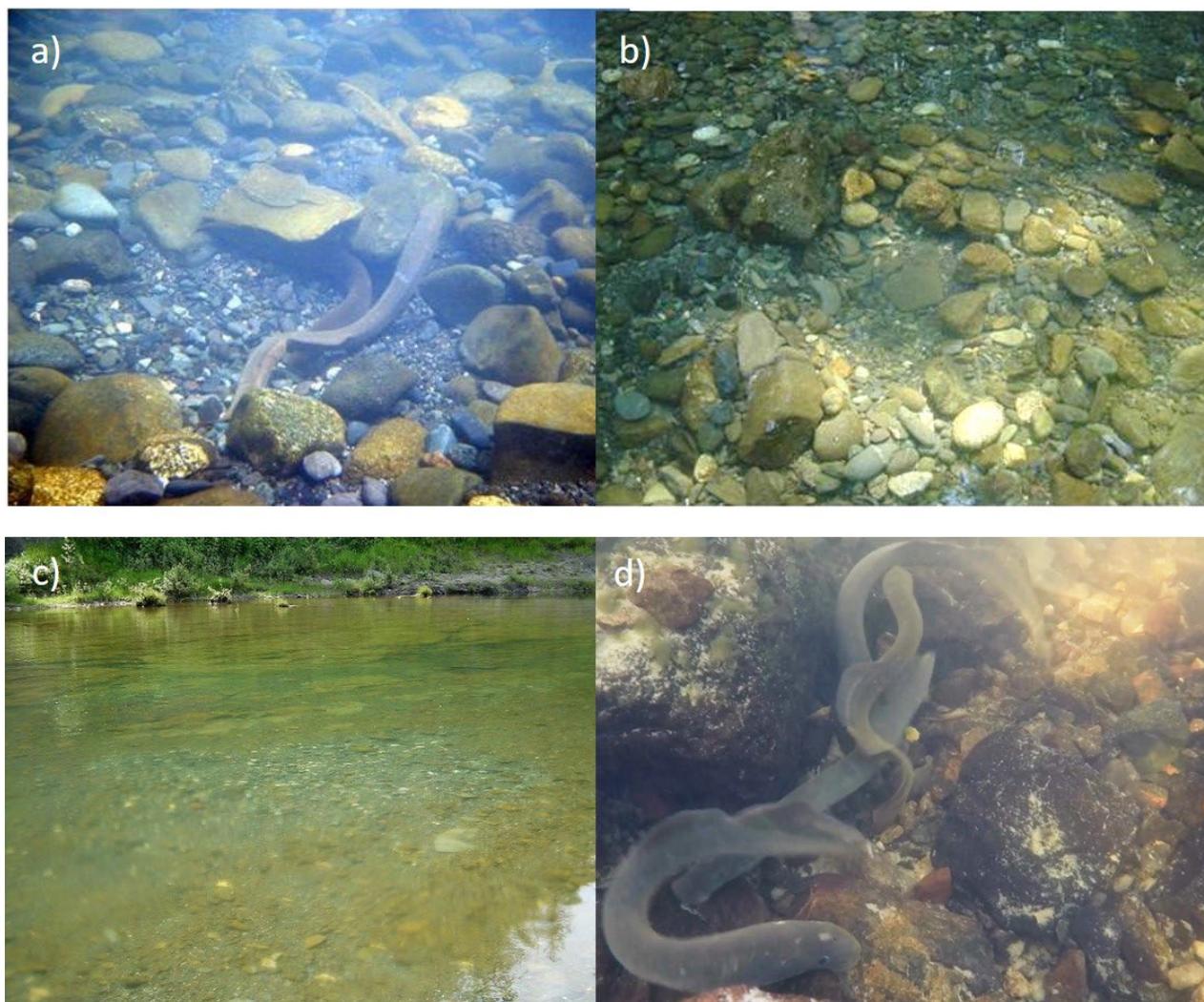


Figure 4. Examples of Pacific Lamprey redds. Photos a) and b) represent typical Pacific lamprey redds. Photos c) and d) are examples of atypical or less easily detected redds. Photo credit: A. Brumo (a –c); R. Litts (d).

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 spawning¹:

- 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 $\leq 2.5 - 5$ 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 $\pm 2^{\circ}\text{C}$ of the release location water temperature to prevent temperature shock to the lampreys. Slow acclimation is recommended ($< \pm 3^{\circ}\text{C}$ per hour) to minimize stress and maximize survival.
- Keep water temperatures cool ($< 18^{\circ}\text{C}$). 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).

Guidelines Specific to Adult Pacific Lamprey

- 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.

Guidelines Specific to Larval and Juvenile Pacific Lamprey

- 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 the 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

¹Based on adult translocation programs from Lower Columbia River hydro dams to holding facilities.
²Based on juvenile salmonid criteria of 10 g/L (Liedtke et al. 2012) and juvenile holding for acoustic telemetry research (Beals and Lampman 2019).
³Based 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.

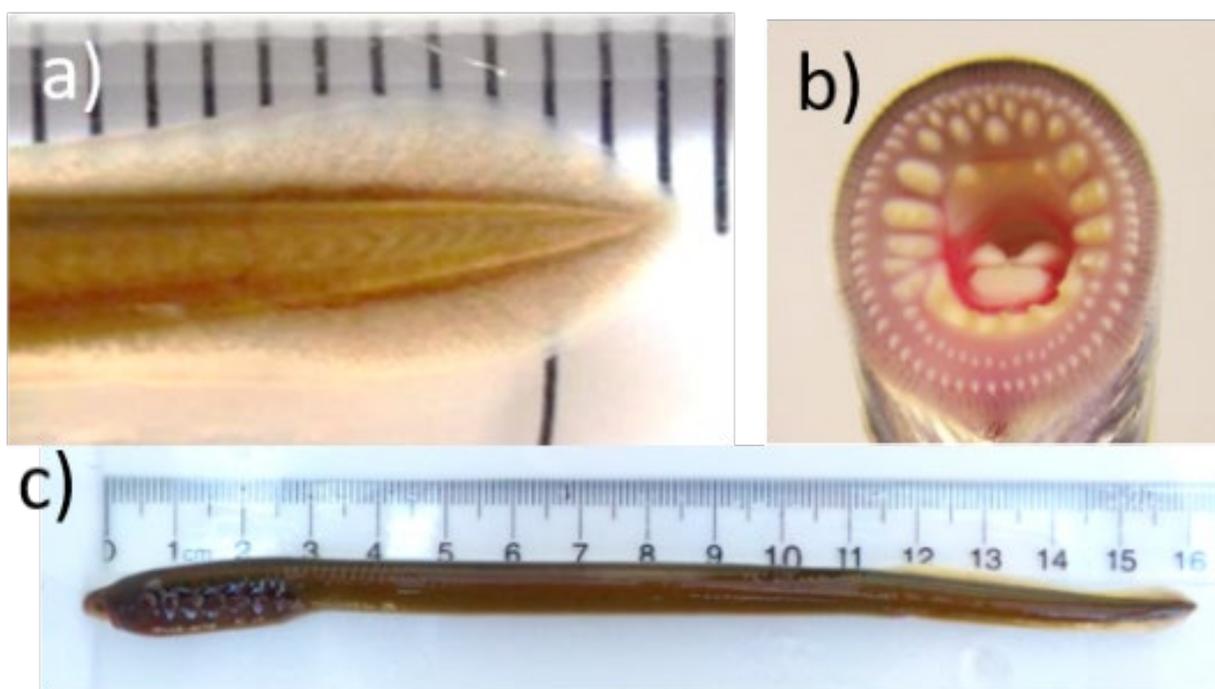


Figure 5. Examples of photographs to assist in species identification.

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 \(email: musseles@xerces.org\)](mailto: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).

10. References

- Beals, T., and R. Lampman. 2019. Survival assessment of juvenile Pacific Lamprey implanted with a dummy acoustic tag for a Yakima Basin acoustic telemetry study. Appendixes 3.3 and H1 of Yakama Nation Pacific Lamprey Project 2018 Annual Progress Report. Prepared for the Bureau of Reclamation (Cooperative Agreement No. R15AC00044), Boise, Idaho, and U.S. Department of Energy, Bonneville Power Administration (Project No. 2008-470-00), Portland, Oregon. 21 pp.
- Beals, T., D. Lumley, and R. Lampman. 2020a. Summary assessment of larval/juvenile lamprey entrainment in irrigation diversions within the Yakima Subbasin, 2019. Appendixes 3.1 and D1 of Yakama Nation Pacific Lamprey Project 2018 Annual Progress Report. Prepared for the Bureau of Reclamation (Cooperative Agreement No. R15AC00060), Boise, Idaho, and U.S. Department of Energy, Bonneville Power Administration (Project No. 2008-470-00), Portland, Oregon. 14 pp.
- Beals, T., D. Lumley, and R. Lampman. 2020b. The effectiveness and safety of three treatment methods for juvenile Pacific Lamprey (*Entosphenus tridentatus*) fungal infection control: Hydrogen peroxide, formalin, and salt. Appendixes 3.4 and H2 of Yakama Nation Pacific Lamprey Project 2018 Annual Progress Report. Prepared for the Bureau of Reclamation (Cooperative Agreement No. R15AC00060), Boise, Idaho, and U.S. Department of Energy, Bonneville Power Administration (Project No. 2008-470-00), Portland, Oregon. 10 pp.
- Blevins, E., L. McMullen, S. Jepson, M. Backblurn, A. Code, and S.H. Black. 2017. Conserving the Gems of Our Waters. The Xerces Society for Invertebrate Conservation. Portland, Oregon. 108 pp. Available: <https://xerces.org/publications/guidelines/conserving-gems-of-our-waters>.
- Blevins, E., L. McMullen, S. Jepson, M. Blackburn, A. Code, and S.H. Black. 2019. Mussel Friendly Restoration. The Xerces Society for Invertebrate Conservation. Portland, Oregon. 32 pp. Available: <https://xerces.org/publications/guidelines/mussel-friendly-restoration>.
- Brumo, A.F., L. Grandmontagne, S.N. Namitz, and D.F. Markle. 2009. Approaches for monitoring Pacific Lamprey spawning populations in a Coastal Oregon stream. Pages 203 – 222 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, and P.B. Moyle (editors), Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72. Bethesda, Maryland.
- Christiansen, H.E., L.P. Gee, and M.G. Mesa. 2013. Anesthesia of juvenile Pacific Lampreys with MS-222, BENZOAK, AQUI-S 20E, and Aquacalm. North American Journal of Fisheries Management 33: 269 – 276.
- Clemens, B.J. 2019. A call for standard terminology for lamprey life stages. Fisheries. 44: 243 – 245.
- Clemens, B.J., L. Weitkamp, K. Siwicke, J. Wade, J. Harris, J. Hess, L. Porter, K. Parker, T. Sutton, and A.M. Orlov. 2019. Marine biology of the Pacific Lamprey *Entosphenus tridentatus*. Reviews in Fish Biology and Fisheries. Available: <https://doi.org/10.1007/s11160-019-09578-8>

- Clemens, B.J., R.J. Beamish, C.C. Kelly, M.F. Docker, J.B. Dunham, A.E. Gray, J.E. Hess, J.C. Jolley, R.T. Lampman, B.J. McIlraith, M.L. Moser, M.G. Murauskas, D.L.G. Noakes, H.A. Schaller, C.B. Schreck, S.J. Starcevich, B. Streif, S.J. van de Wetering, J. Wade, L.A. Weitkamp, and L.A. Wyss. 2017. Conservation challenges and research needs for Pacific Lamprey in the Columbia River Basin. *Fisheries*. 42: 268 – 280.
- Clemens, B.J., T.R. Binder, M.F. Docker, M.L. Moser, and S.A. Sower. 2010. Similarities, differences, and unknowns in biology and management of three parasitic lampreys of North America. *Fisheries*. 35: 580 – 594.
- Crandall, J.D., and E. Wittenbach. 2015. Pacific Lamprey habitat restoration guide. First edition. Methow Salmon Recovery Foundation. Twisp, Washington. 54 pp. Available: http://www.methowsalmon.org/Documents/PacificLampreyRestorationGuide_web.pdf
- CRITFC (Columbia River Inter-Tribal Fish Commission). 2011. Tribal Pacific Lamprey restoration plan for the Columbia River Basin. Portland, Oregon. Available: www.critfc.org/wp-content/uploads/2012/12/lamprey_plan.pdf.
- CTUIR (Confederated Tribes of the Umatilla Indian Reservation). 2016. Quick Reference Guide to Western Freshwater Mussels. 2 pp. Available: https://pnwmussels.org/wp-content/uploads/2016/07/QuickMusselGuide_CTUIR.pdf
- Dawson, H.A., B.R. Quintella, P.R. Almeida, A.J. Treble, and J.C. Jolley. 2015. The ecology of larval and metamorphosing lampreys. Pages 75 – 137 *In* M.F. Docker (editor). *Lampreys: biology, conservation and control*, volume 1. Springer, Fish and Fisheries Monograph Series, New York.
- Gonzalez, R., J. Dunham, S. Lightcap, and J. McEnroe. 2017. Large wood and instream habitat for juvenile Coho Salmon and larval lampreys in a Pacific Northwest stream. *North American Journal of Fisheries Management*. 37: 683 – 699.
- Gunckel S.L., K.K. Jones, and S.E. Jacobs. 2009. Spawning distribution and habitat use of adult Pacific and Western brook lampreys in Smith River, Oregon. Pages 173 – 190 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, and P.B. Moyle (editors). *Biology, management, and conservation of lampreys in North America*. American Fisheries Society, Symposium 72, Bethesda, Maryland.
- Hansen, M.J., C.P. Madenjian, J.W. Slade, T.B. Steeves, P.R. Almeida, and B.R. Quintella. 2016. Population ecology of the sea lamprey (*Petromyzon marinus*) as an invasive species in the Laurentian Great Lakes and an imperiled species in Europe. *Reviews in Fish Biology and Fisheries*. 26: 509 – 535.
- Homel, K.M., C.M. Lorion, and B.J. Clemens. 2019. Challenges and opportunities to apply process-based restoration at scales appropriate to anadromous fishes. *American Fisheries Society Symposium* 91. Pages 479 – 514 *In* D. Dauwalter, T. Birdsong, and G. Garrett (editors). *Multispecies and watershed approaches to freshwater fish conservation*. Bethesda, Maryland.
- Johnson, N.S., T.J. Buchinger, and W. Li. 2015. Reproductive ecology of lampreys. Pages 265 – 303 *In* M.F. Docker (editor). *Lampreys: biology, conservation and control*, Volume 1. Springer, Fish and Fisheries Monograph Series, New York.

- Lampman, R. and T. Beals. 2019. Exploring techniques to reduce lamprey and salmonid entrainment into canals. Yakama Nation Pacific Lamprey Project Final Progress Report (Project ID No. 2621). Prepared for the U.S. Department of Interior, Bureau of Reclamation, Boise, Idaho. 151 pp.
- Lampman, R., M. Moser, A. Jackson, R. Rose, A. Gannam, and J. Barron. 2016. Developing techniques for artificial propagation and early rearing of Pacific Lamprey *Entosphenus tridentatus* for species recovery and restoration. Pages 160 – 195 In A.M. Orlov, and R.J. Beamish (editors). Jawless fishes of the world, Volume 2. Cambridge Scholars Publishing, New Castle upon Tyne, UK.
- LTW (Lamprey Technical Workgroup). 2017. Practical guidelines for incorporating adult Pacific Lamprey passage at fishways, Living Document. June 2017. White Paper. 47 pp + Appendix. Available: <https://www.pacificlamprey.org/ltwg/>
- Liedtke, T.L., J.W. Beeman, and L.P. Glee. 2012. A standard operating procedure for the surgical implantation of transmitters in juvenile salmonids. U.S. Geological Survey Open-File Report 2012 – 1267. 50 pp. Available: <https://pubs.usgs.gov/of/2012/1267/pdf/ofr20121267.pdf>.
- Liedtke, T.L., L.W. Weiland, and M.G. Mesa. 2015. Vulnerability of larval lamprey to Columbia River hydropower operations – effects of dewatering on larval lamprey movements and survival. U. S. Geological Survey Open-File Report 2015 – 1157. 28 pp. Available: <http://dx.doi.org/10.3133/ofr20151157>.
- Liedtke, T.L., D.J. Didricksen, L.K. Weiland, J.A. Rogala, and R. Lampman. 2019a. Effectiveness of fish screens in protecting lamprey (*Entosphenus* and *Lampetra* spp.) ammocoetes – Pilot testing of variable screen angle: U.S. Geological Survey Open-File Report 2019 – 1044. 21 pp. Available: <https://doi.org/10.3133/ofr20191044>
- Liedtke, T.L., R.T. Lampman, D.Z. Deng, T.E. Beals, M.S. Porter, A.C. Hansen, T.J. Kock, R.G. Tomka, and P. Monk. 2019b. Movements of juvenile Pacific Lamprey (*Entosphenus tridentatus*) in the Yakima and Columbia Rivers, Washington, 2018 – A pilot study using acoustic telemetry. U.S. Geological Survey Open-File Report 2019 – 1058. 29 pp. Available: <https://doi.org/10.3133/ofr20191058>.
- Liedtke, T.L., L.K. Weiland, J.J. Skalicky, and A.E. Gray. 2020. Evaluating dewatering approaches to protect larval Pacific Lamprey. U. S. Geological Survey Open-File Report 2020 – 1026. 32 pp. Available: <https://doi.org/10.3133/ofr20201026>
- Manzon, R.G., J.H. Youson, and J.A. Holmes. 2015. Lamprey metamorphosis. Pages 139 – 214 In M.F. Docker (editor). Lampreys: biology, conservation and control, Volume 1. Springer, Fish and Fisheries Monograph Series, New York.
- McGree, M, T.A. Whitesel, and J. Stone. 2008. Larval metamorphosis of individual Pacific Lamprey reared in captivity. Transactions of American Fisheries Society. 137:1866-1878.
- Mesa, M.G., T.L. Liedtke, L.K. Weiland, and H.E. Christiansen. 2017. Effectiveness of common fish screen materials for protecting lamprey ammocoetes – Influence of sweeping velocities and decreasing flows. U.S. Geological Survey Open-File Report 2017 – 1163. 19 pp. Available: <https://doi.org/10.3133/ofr20171163>.

- Moser, M.L., A.L. Matter, L.C. Stuehrenberg, and T.C Bjornn. 2002. Use of an extensive radio receiver network to document Pacific Lamprey (*Lampetra tridentata*) entrance efficiency at fishways in the Lower Columbia River, U.S.A. *Hydrobiologia* 483: 45 – 53.
- Moser, M.L., J.M Butzerin, and D.B. Dey. 2007. Capture and collection of lampreys: the state of the science. *Reviews in Fish Biology and Fisheries* 17(1): 45 – 56. doi:10.1007/s11160-006-9037-3.
- Moser, M.L., A.D. Jackson, M.C. Lucas, and R.P. Mueller. 2015a. Behavior and potential threats to survival of migrating lamprey ammocoetes and macrophthalmia. *Reviews in Fish Biology and Fisheries*. 25: 103 – 116.
- Moser, M.L., P.R. Almeida, P.S. Kemp, and P. Sorensen. 2015b. Lamprey spawning migration. Pages 215 – 263 *In* M.F. Docker (editor). *Lampreys: biology, conservation and control*, Volume 1. Springer, Fish and Fisheries Monograph Series, New York.
- Mueller, R., S. Liss, Z.D. Deng. 2019. Implantation of A New Micro Acoustic Tag in juvenile Pacific Lamprey and American Eel. *Journal of Visualized Experiments*. Available: <https://www.jove.com/video/59274> and DOI: doi:10.3791/59274
- NMFS (National Marine Fisheries Service). 2000. Guidelines for Electrofishing Waters Containing Salmonids Listed under the Endangered Species Act. June 2000. 5 pp. Available: https://archive.fisheries.noaa.gov/wcr/publications/reference_documents/esa_refs/section_4d/electro2000.pdf.
- NMFS (National Marine Fisheries Service). 2011. Anadromous Salmonid Passage Facility Design. July 2011. NMFS, Northwest Region, Portland, Oregon. 140 pp. Available: https://www.dfw.state.or.us/fish/passage/docs/fish_passage_design_criteria.pdf.
- Potter, I.C., H.S. Gill, C.B. Renaud, and D. Haoucher. 2015. The taxonomy, phylogeny, and distribution of lampreys. Pages 35 – 74 *In* M.F. Docker (editor). *Lampreys: biology, conservation and control*, Volume 1. Springer, Fish and Fisheries Monograph Series, New York.
- Renaud, C.B. 2011. Lampreys of the world: An annotated and illustrated catalogue of lamprey species known to date. Food and Agriculture Organization of the United Nations, Rome. Species Catalogue for Fishery Purposes No. 5. 109 pp.
- Rodríguez-Lozano, P., R.A. Leidy, and S.M. Carlson. 2019. Brook lamprey survival in the dry riverbed of an intermittent stream. *Journal of Arid Environments*. 166: 83 – 85. Available: <https://doi.org/10.1016/j.jaridenv.2019.04.016>
- Roni, P. 2003. Responses of benthic fishes and giant salamanders to placement of large woody debris in small Pacific Northwest streams. *North American Journal of Fisheries Management*. 23: 1087 – 1097.
- Rose, B.P and M.G. Mesa. 2012. Effectiveness of common fish screen materials to protect lamprey ammocoetes. *North American Journal of Fisheries Management*. 32: 597 – 603.
- Schultz, L.D., M.P. Mayfield, G.T. Sheoships, L.A. Wyss, B.J. Clemens, S. Whitlock, and C.B. Schreck. 2014. Role of large- and fine-scale variables in predicting catch rates of larval

- Pacific Lamprey in the Willamette Basin, Oregon. *Ecology of Freshwater Fishes*. 25: 261 – 271.
- Skalicky, J.J., J.E. Harris, J.M. Barkstedt, A.E. Gray, and B.J. Clemens. 2019. Evaluation of changes in abundance and methods for salvage of larval lamprey during a “slow” water drawdown and dewatering in Leaburg Reservoir, Oregon. Final Report. U.S. Fish and Wildlife Service, Columbia River Fish and Wildlife Conservation Office, Vancouver, Washington. 30 pp. www.fws.gov/columbiariver/publications.html
- Slade, J. W., J.V. Adams, G.C. Christie, D.W. Cuddy, M.F. Fodale, J.W. Heinrich, H.R. Quinlan, J.G. Weise, J.W. Weisser, and R.J. Young. 2003. Techniques and methods for estimating abundance of larvae and metamorphosed sea lampreys in Great Lakes tributaries, 1995 to 2001. *Journal of Great Lakes Research*. 29 (Supplement 1): 137 – 151.
- Steeves, T.B., J.W. Slade, M.F. Fondale, D.W. Cuddy and M.L. Jones. 2003. Effectiveness of using backpack electrofishing gear for collecting sea lamprey (*Petromyzon marinus*) larvae in great lakes tributaries. *Journal of Great Lakes Research*. 29: 161 – 173.
- Stone, J. 2006. Observations on nest characteristics, spawning habitat, and spawning behavior of Pacific and western brook lamprey in a Washington stream. *Northwest Naturalist*. 87: 225 – 232.
- Streif, B. 2009. Considering Pacific Lampreys when implementing instream activities. Pages 255 – 268 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, and P.B. Moyle (editors). *Biology, management, and conservation of lampreys in North America*. American Fisheries Society, Symposium 72, Bethesda, Maryland.
- USFWS (U.S. Fish and Wildlife Service). 2019. Pacific Lamprey (*Entosphenus tridentatus*) Assessment. 283 pp. Available: <https://www.pacificlamprey.org/assessment/>
- USFWS and USFS (U.S. Fish and Wildlife Service and U. S. Forest Service). 2010. Best management practices to minimize adverse effects to Pacific Lamprey (*Entosphenus tridentatus*). 25 pp.
- Wang, C.J., H.A. Schaller, K.C.Coates, M.C. Hayes, and R.K. Rose. 2020. Climate change vulnerability assessment for Pacific Lamprey in rivers of the Western United States. *Journal of Freshwater Ecology*: 35:1, 29 – 55. Available: <https://doi.org/10.1080/02705060.2019.1706652>.
- Zobott, H., C.C. Caudill, M.L. Keefer, R. Budwig, K. Frick, M. Moser, and S. Corbett. 2015. Design guidelines for Pacific Lamprey passage structures. Technical Report 2015-5 of Center for Ecohydraulics Research and Department of Fish and Wildlife Sciences to the U.S. Army Corps of Engineers, Portland District. Available: <https://www.uidaho.edu/~media/UIdaho-Responsive/Files/cnr/FERL/technical-reports/2015/2015-5-LPS-Design.ashx>

APPENDIX A. Available Resources – Lampreys and Freshwater Mussels

(Hyperlinks embedded)

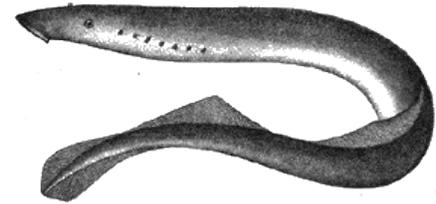
Lamprey Summary Documents

- [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**

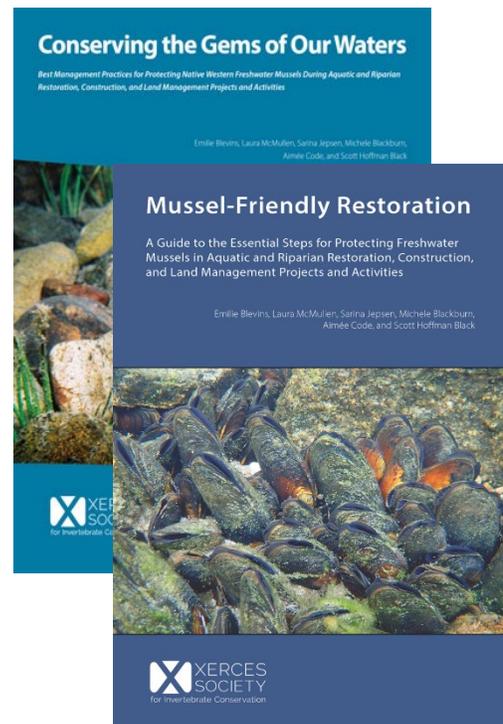
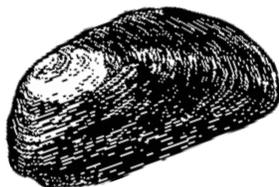
Lamprey Education/Outreach:

- **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)



Columbia River Fish and Wildlife Conservation Office
1211 SE Cardinal Ct, Suite 100
Vancouver WA, 98683
1-360-604-2500

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 ($\geq 140^{\circ}\text{F}$ at point of contact) for no less than 10 seconds. Porous items (e.g., ropes) should be exposed to hot water ($\geq 140^{\circ}\text{F}$) a minimum of 10 minutes, and internal compartments (e.g., bilge, live well, ballast tank) should be exposed to hot water ($\geq 120^{\circ}\text{F}$) 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).

Field gear (e.g., nets, buckets, waders and boots)

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.
 - **Method 1** – 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 **NOT** suitable for felt soled boots.
 - **Method 2** – Heat. Steam or hot water pressure wash ($\geq 140^{\circ}\text{F}$). 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.
 - **Method 3** – 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.
 - **Method 4** – 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 Lampreys³

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 electrofisher⁵; and
- Smith Root Apex Backpack electrofisher¹¹.

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 ($\leq 10^{\circ}\text{C}$) 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.

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 numbers⁷. 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 m² at a time. Place the anodes about 0.5 m apart and tickle-pulse at ~60 seconds per m². Move to next 1 - 2 m² 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 Wave 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 include⁸:

- 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 (page)
Dryden Diversion Irrigation Diversion Yakima River Washington	#1- Salvage of lampreys from dredged materials. (E-1)
Sunnyside Irrigation Diversion Yakima River Washington	#2- Salvage of lampreys from a large river diversion. (E-4)
Bachelor Hatton Irrigation Diversion Ahtanum Creek, Yakima River Washington	#3- Salvage of lampreys from a small river diversion (E-8)
Multiple sites Mid- Upper Columbia Subbasins Eastern Washington	#4- Larval lamprey electrofishing surveys. (E-10)
Habitat restoration sites Methow River Washington	#5- Larval lamprey use of salmonid restoration projects. (E-12)
Salvage Techniques Evaluation Leaburg Lake, McKenzie River Oregon	#6 – Evaluation of salvage techniques – slow drawdown. (E-14)
Stage 0 Restoration South Fork McKenzie River Willamette Basin Oregon	#7 – Valley-scale Restoration Improves Habitat for Pacific Lamprey (E-16)

