Monitoring and Minimizing Effects of Dredging on Lampreys

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PACIFIC LAMPREY CONSERVATION INITIATIVE

Lamprey Technical Workgroup

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Introduction

The Lamprey Technical Workgroup (LTWG) is a technical advisory committee of the Conservation Agreement for Pacific Lamprey in the States of Alaska, Washington, Oregon, Idaho, and California. The LTWG provides technical support and acts as an advisory group within the Conservation Agreement. The LTWG consists of several subgroups that provide technical information for dissemination to various audiences. This paper was developed by the Juvenile Entrainment and Dredging Investigations Subgroup of the LTWG.

Complex life cycles contribute to the susceptibility of Pacific Lamprey (*Entosphenus tridentatus*) and other lamprey species (herein, "lampreys") to environmental and anthropogenic change (Musick et al. 2000; Maitland et al. 2015; Clemens et al. 2020). Pacific Lamprey move over extensive spatial and temporal scales to successfully complete their life cycles (Clemens et al. 2010, 2020; Dawson et al. 2015). Anadromous lampreys use freshwater benthic habitats as larvae, a diversity of habitat in streams and rivers as juveniles, the ocean as parasitic juveniles, and then freshwater again as adults during their upstream migration and subsequent spawning (Clemens et al. 2010; McIlraith et al. 2015; Clemens 2019). Human impacts on habitats and ecological communities potentially affect lampreys at each life history stage.

Because larvae spend several years rearing in freshwater substrates (primarily fine sediment and organic matter), they are vulnerable to human-caused substrate disturbances (HCSD), including dredging. Unlike most anadromous juvenile salmonids (*Oncorhynchus* species), lampreys of various age classes are present in fresh water year-round; therefore in-water work windows that avoid all life stages of lampreys do not exist. Dredging is considered a threat and one reason for the decline of Pacific Lamprey (Luzier et al. 2011; Maitland et al. 2015; Clemens et al. 2020). Dredged substrates (spoils) removed from the water and disposed on land have the potential to contain larval and juvenile lampreys (Lampman and Beals 2019). Excavation of substrates by heavy equipment can remove high numbers and multiple age classes of larval lampreys because lamprey at this stage generally prefer similar habitat and do not segregate by age class (King et al. 2008; Beals and Lampman 2016).

The objectives of this paper include:

- Summarize knowns and uncertainties regarding the effects of HCSD on larval and juvenile lampreys.
- Summarize additional information needed about the effects of HCSD on lampreys to further their conservation.
- Provide best management guidelines (BMGs) for known HCSD to protect lampreys to the extent possible, including release protocols for salvaged lampreys.
- Provide a list of key research and data needs.
- Provide case studies of efforts to protect lampreys from disturbances or where information useful to the protection of lampreys was collected.

A document summarizing BMGs for native lampreys during in-water work was developed in May 2020 (LTWG 2020). It provides guidelines to minimize impacts to lampreys during in-water work, including HCSD. This paper is intended to provide more details specific to HCSD, and to provide more specific case studies. This paper is intended to be a “living document”, to be refined and revised as more is learned and additional case studies become available. This document does not cover small scale mining operations because insufficient information exists on this topic.

Relevant Life History Information

Pacific Lamprey are anadromous, spawning in freshwater where eggs incubate and larvae rear for several years. A detailed description of their life history is provided elsewhere (see Close et al. 2002; Clemens et al. 2010; Dawson et al. 2015). Fourteen different species of lampreys are known to occur along the west coast of North America, and these species exhibit different anadromous and resident life histories (Renaud 2011; Potter at al. 2015). For purposes of this paper, it is important to note that larvae burrow into soft stream bottoms where they feed on organic matter for four or more years until the onset of metamorphosis into juveniles (for anadromous lampreys) or adults (for resident lampreys; Clemens 2019). The relative importance of habitat variables can change with the body size of larvae. Habitat must provide adequate substrate for burrowing, generally to a depth of 15 cm (Applegate 1950; Liedtke et al. 2015), and a regular supply of the suspended and/or benthic organic matter upon which larval lampreys feed. Generally, larvae burrow into depositional areas with soft substrate near stream margins associated with pools, alcoves, side channels, and glides (Graham and Brun 2007; Dawson et al. 2015). As lampreys grow and transform, they gradually shift from fine sediments in slow water habitats to coarser substrates in fast water habitats (Dawson et al. 2015).

Adults returning to freshwater from the ocean hold for an extensive period (typically just over a year, but sometimes 2-3 years) prior to spawning. Holding habitat varies, but adults are often found in deep, swift water seeking refuge within coarse substrate or bedrock crevices (Lampman 2011).

Dredging Purposes and Methods

Dredging includes a wide variety of activities that disturb the substrates of estuaries, rivers, streams, and lakes. Purposes of dredging may include:

- Deepening and maintaining shipping or navigation channels
- Deepening and maintaining ports for marinas, docks, houseboats, etc.
- In-water mining such as suction dredge mining and gravel mining
- Facility maintenance and management (irrigation, intakes, road crossings, etc.)
- Other in-water construction activities

A wide variety of earth-moving methods can be used to dredge in large systems, including hopper dredges, clamshell (bucket) dredges, and cutterhead dredges (Figure 1). Other methods such as venturi dredge pumps have been used for relatively small dredging operations (see LTWG 2020). Dredged material may be directly transported to disposal areas or transported indirectly by ship or barge. Dredged material may be disposed on land, in-channel as artificial islands, in other areas of the water body or in the ocean.

Hopper dredges are self-propelled vessels with an internal sediment storage basin called a hopper, and a hydraulic pumping system used to fill the hopper. Most hopper dredges use doors or valves in the bottom of the hull to remove the dredged material after transport to a disposal area. A clamshell or bucket dredge picks up material mechanically with a clamshell bucket that usually hangs from an onboard crane or a crane barge. Dredged material is often placed on a barge for transport to disposal areas. A cutterhead dredge uses a cutting mechanism to loosen material and transport it to a suction device. Dredged material is typically discharged either through a pipe directly to a disposal area or to a barge for transport.

Potential Effects of Dredging

Because larval lampreys generally burrow no deeper than about 15 cm (Applegate 1950; Liedtke et al. 2015), HCSD may directly affect burrowed lamprey through physical injury or mortality caused by dredging activities or by moving the dredged material (including burrowed lamprey) to upland or other disposal areas that are not suitable for lamprey survival. Burrowed lamprey present at disposal areas may also be adversely impacted by the deposition of dredged materials. Placement of large amounts of dredged material onto burrowed lamprey can obstruct their access to the water column, resulting in their entombment and death.

Historically, data acquired about the entrainment of lampreys from dredging operations was obtained from investigations designed to detect impacts to other species such as salmon, Green Sturgeon (*Acipenser medirostris*), and Dungeness crab (*Metacarcinus magister*). We are unaware of any studies that have been specifically conducted to address entrainment of lampreys during dredging; however, some entrainment studies conducted in the Fraser and Columbia Rivers and Grays Harbor, Washington did document entrainment of lampreys (Braun 1974; Dutta and Sookachoff 1975a and 1975b; Tutty 1976; Stevens 1981; Armstrong et al. 1982; Dinnel et al. 1986a and 1986b; Dumbauld et al. 1988; McGraw et al. 1988; Larson and Moehl 1990; McGraw and Armonstrong 1990). More recent monitoring documented substantial entrainment of lampreys during dredging operations in the Sacramento-San Joaquin River Delta in California (MEC and NAS 2018; see Appendix A).

This paper is focused on the potential effects of HCSD on larval lamprey burrowed into the sediment. However, HCSD may also affect migrating or holding juveniles and adults. It is possible for juveniles and adults to be entrained by dredging operations, but an additional and perhaps more likely effect may result from the increased turbidity and potential release of contaminants associated with substrate disturbance. Little is known about these potential effects on juvenile and adult lamprey.

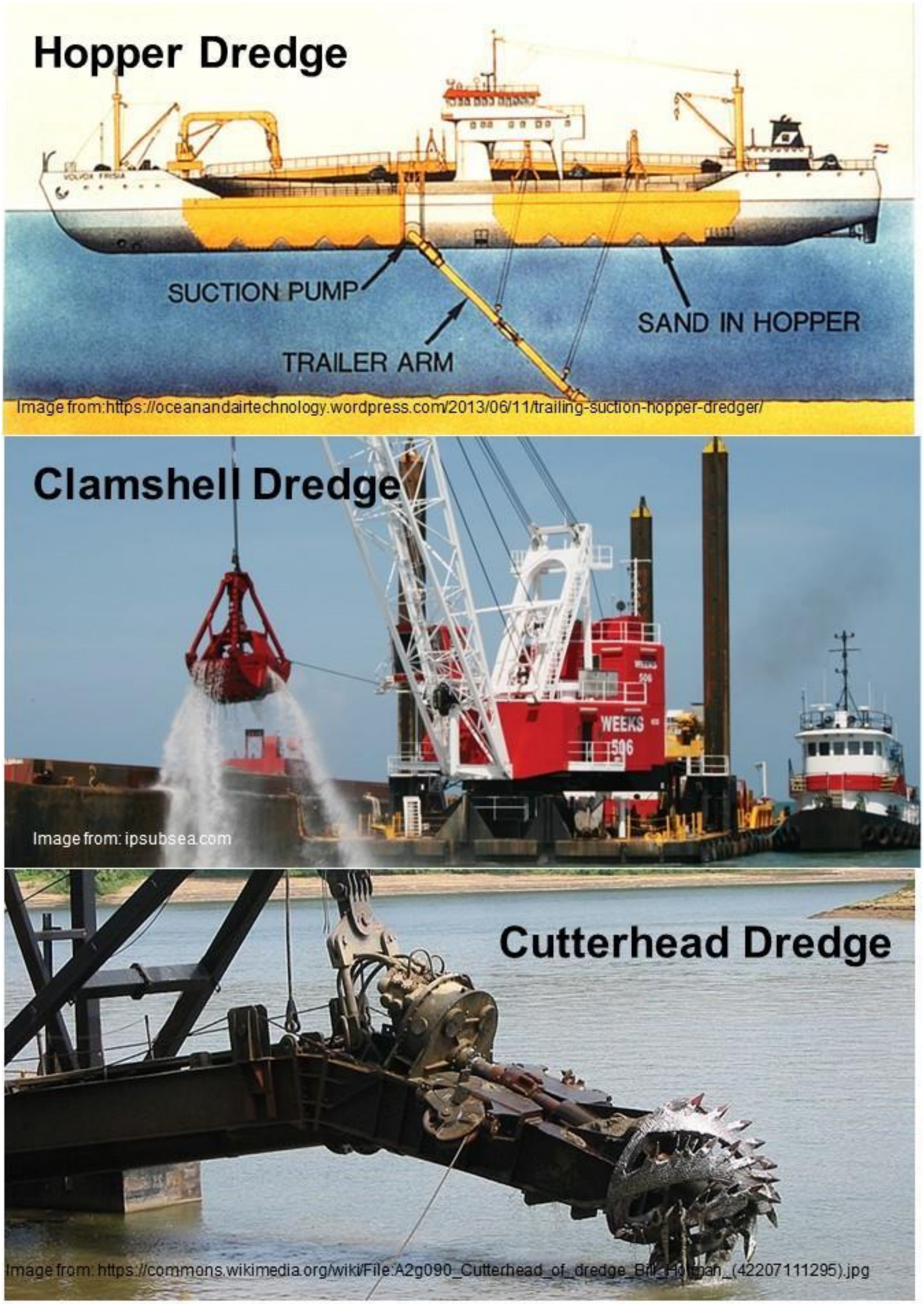

Figure 1. Examples of hopper, clamshell (bucket), and cutterhead dredges.

Recommended Best Management Guidelines

LTWG (2020) recommends placing dredged sediments in fast currents to dissipate sediments and allow lamprey to drift downstream, or alternatively to remove the top 30 cm of sediment and transport it (and lampreys) downstream to areas with no known concentrations of predatory fish. If this is not possible, then lampreys should be salvaged prior to or during dredging. Here we provide more detail regarding LTWG (2020) recommendations regarding dredging and additional steps/procedures to protect lampreys from dredging operations.

The more detailed BMGs presented below focus on larval lampreys that are present in the fine sediment substrate to be dredged. Recommendations include:

- Conduct a pre-dredging assessment to determine if larval lampreys are present in the project area and to facilitate before/after comparisons of distribution and abundance.
- If spoils are to be placed in-water, conduct a pre-disposal assessment of the disposal site. If larval lamprey are present, the disposal site should be reconsidered (e.g., an alternative in-water site).
- Remove (and dispose as recommended below) the upper layer (approximately 30 cm) of the substrate first to facilitate monitoring and subsequent salvage.
- Dispose of dredge spoils in the watered areas away from redds, areas known to have high concentrations of predatory fishes, and areas known to have high densities of larval lampreys (i.e., river mouths; Harris and Jolley 2017).
    - Choice of appropriate areas will therefore depend upon knowledge of the system.
    - Choice of appropriate areas should be made in consultation with local biologists.
- If in-water disposal is not possible, then removing the upper layer first (either into fast currents to dissipate downstream or placed on land in an area for hand salvage) is paramount to minimizing adverse effects.

It will be difficult to conduct pre-salvage operations in deep water because salvage tools in these areas do not exist. Methods to assess deep-water lamprey presence, distribution and abundance are available (Bergstedt and Genovese 1994; Jolley et al. 2012; Harris and Jolley 2017; Mueller et al. 2012; Arntzen and Mueller 2017); however, these methods are based on electrofishing and have significant limitations in salinities over 1 ppt. Methods have also been developed to examine dredge spoils for fish including lampreys (MEC and NAS 2018; see Appendix A).

The LTWG also recommends release protocols for lampreys that are removed prior to dredging or salvaged during operations:

- Larval lampreys should be released into suitable habitat (fine substrate composed of sand/silt/clay and detritus/organic matter, often found in backwater areas or along channel margins).
- Lampreys (larvae, juveniles, and adults) should be released away from known predator concentrations.

- The release location should be selected to prevent entrainment or access back into the project area or other areas of potential harm.

Further Research

Knowledge of the effects of HCSD on lampreys is incomplete, and future research should address a number of inter-related questions:

- What are the effects of channel dredging on all lamprey life stages (larval, juvenile, and adult)?
    - How and when do lamprey rear, migrate, and distribute in the navigation channel, other areas subject to dredging such as ports and marinas, in-water disposal sites, river mouths, estuaries and mainstem habitats?
    - Are juvenile and adult lampreys subject to entrainment from dredging along with larvae?
    - What are the direct and indirect mortality rates on lampreys from dredging?
    - How do the different methods/types of dredging influence impacts on lamprey?
    - What occurs when dredged sediment is disposed on top of existing larval lamprey habitat?
    - How does increased sediment from HCSD such as dredging effect juvenile and adult lampreys?
- How might individual lamprey behavior minimize or exacerbate the effects of dredging on them?
    - Are there potential effective solutions that take advantage of lamprey behavior to improve rescue and overall survival rates?

With one exception (Jolley et al. 2011), habitat use and distribution within the Columbia River estuary (and other large estuaries) is still unknown, and the impacts of channel maintenance dredging on lampreys in large rivers such as the Lower Columbia River have not been adequately documented. Estimating the effects of HCSD on lampreys is correlated with understanding their habitat use. Increased knowledge of habitat use by lampreys in systems subjected to HCSD can allow a better estimate of the effects of HCSD and focus conservation measures. As previously noted, some studies reported that lampreys were found in material dredged from deep water, and more recently lampreys were detected during monitoring of deep water dredging in the Sacramento/San Joaquin River Delta (MEC and NAS 2018; Appendix A).

Monitoring of the spoils from clamshell dredging in the forebay of an irrigation diversion in the Wenatchee River Subbasin in Washington has demonstrated that a high number of larval lamprey can be captured and rescued in some tributary environments (Beals and Lampman 2016; LTWG 2020). A total of 18,740 larval lamprey and 21 juvenile lamprey were captured and rescued from 244.5 cubic feet of dredged material, which is about 77 lamprey per cubic foot (Lampman and Beals 2019). Additional research on the effects of dredging in tributary environments and the feasibility of rescuing lamprey from these dredging operations would be beneficial.

Knowledge of lamprey behavior during and immediately after habitat disturbance is important for conservation. In the short term, information is lacking about the effects of HCSD on lampreys. Whenever possible, HCSD activities should be actively monitored, and when lampreys are detected/observed, salvage should occur. Development and refinement of methods and technologies that effectively sift/sort lampreys from spoils at an adequately fast rate is needed (see Appendix A). Enhanced salvage data can considerably increase the information regarding the extent of the effects of habitat disturbances on lampreys. Finally, the impacts of in-water sediment disposal in larval rearing habitat warrants further research.

Conclusions

Although much remains to be learned regarding the ecology of lampreys in deep waters and their vulnerability to habitat disturbances, dredging and other HCSDs can adversely affect lampreys, particularly larvae burrowed in sediment. Larval lampreys usually inhabit the upper portion of the substrate and are therefore vulnerable to 1) direct mortality from HCSD, 2) mortality caused by being moved to upland or otherwise inappropriate disposal sites, and 3) mortality resulting from being entombed by disposed dredge material.

Additional information and tools are needed to improve understanding of the magnitude of the effects of HCSD on lampreys. Direct monitoring of dredged material for lampreys has been scarce, and incidental information regarding lampreys in dredged materials is considerably limited (MEC and NAS 2018). Pre-dredging evaluations for lamprey presence are challenging to conduct, and the ability to salvage larval lampreys from deep water sites is currently limited.

We have provided a detailed list of BMGs for known HCSD to protect lampreys, including release protocols for salvaged lampreys. Conducting additional research as suggested above should improve our knowledge and facilitate further refinements to BMGs. Summaries of the most recent efforts to monitor dredged material are included in this paper as case studies (Appendix A). An additional case study on a clamshell (grab) dredging project in a tributary environment is also included in LTWG (2020).

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Glossary

Anadromous: Life history strategy used by some fishes, including lampreys to feed and grow in the ocean to their maximum body size, followed by migration back into fresh water where they sexually mature and spawn.

Benthic: Bottom-dwelling mode of life in aquatic habitats.

Depositional: Aquatic habitats characterized by little to no current. Hence suspended particulates of biological and non-biological origins tend to settle out and *deposit* onto the substrate in these habitats.

Appendix A. Case Studies

Last Update: March 2021	
1.	Monitoring Cutterhead Dredging in the Sacramento/San Joaquin River Delta, California
2.	Monitoring Hopper Dredging in San Francisco Bay, California
3.	Development of New Salvage Methods: Sluice Box Lamprey Sifter Using a Venturi Dredge Pump in Naches, Washington (Wapatox Canal)
4.	A Pilot Study to Assess the Effects of Sediment Deposition on Larval and Juvenile Lampreys in Prosser, Washington (Chandler Canal)

Case Study 1 - Monitoring Cutterhead Dredging in the Sacramento/San Joaquin River Delta, California

Hydraulic cutterhead dredging is conducted to maintain the depth of the federal navigation channels in the Sacramento/San Joaquin River Delta (Delta) to the Ports of West Sacramento and Stockton (Figure A-1). Monitoring was conducted on behalf of the U.S. Army Corps of Engineers (USACE) through consultation with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service due to concern over dredging impacts to ESA-listed Green Sturgeon, Central Valley steelhead (*Oncorhynchus mykiss*), and winter-run Chinook Salmon (*O. tshawytscha*). Monitoring was conducted by screening the outfall of the dredge at the location where the dredged material is deposited. The screen is a flow-through device that allows monitoring of the entire output of the dredge (Figure A-2). The screening method employed may be used to provide estimates of the numbers of lampreys that are entrained and may also be used to salvage entrained lamprey.

From 2006 through 2017 many species of fish and invertebrates were entrained. Western River Lamprey (*Lampetra ayresii*) were the most commonly entrained native fish species, and during some years, were the most commonly entrained fish species overall (Table A-1; MEC and NAS 2018). Lampreys were found at most dredging locations and were abundant at some locations in comparison to other entrained species. Inter-annual variation in the number of lampreys entrained was likely due to annual variation in the amount of material dredged, annual changes in monitoring effort and locations, and annual changes in the abundance of lampreys at the dredged locations.

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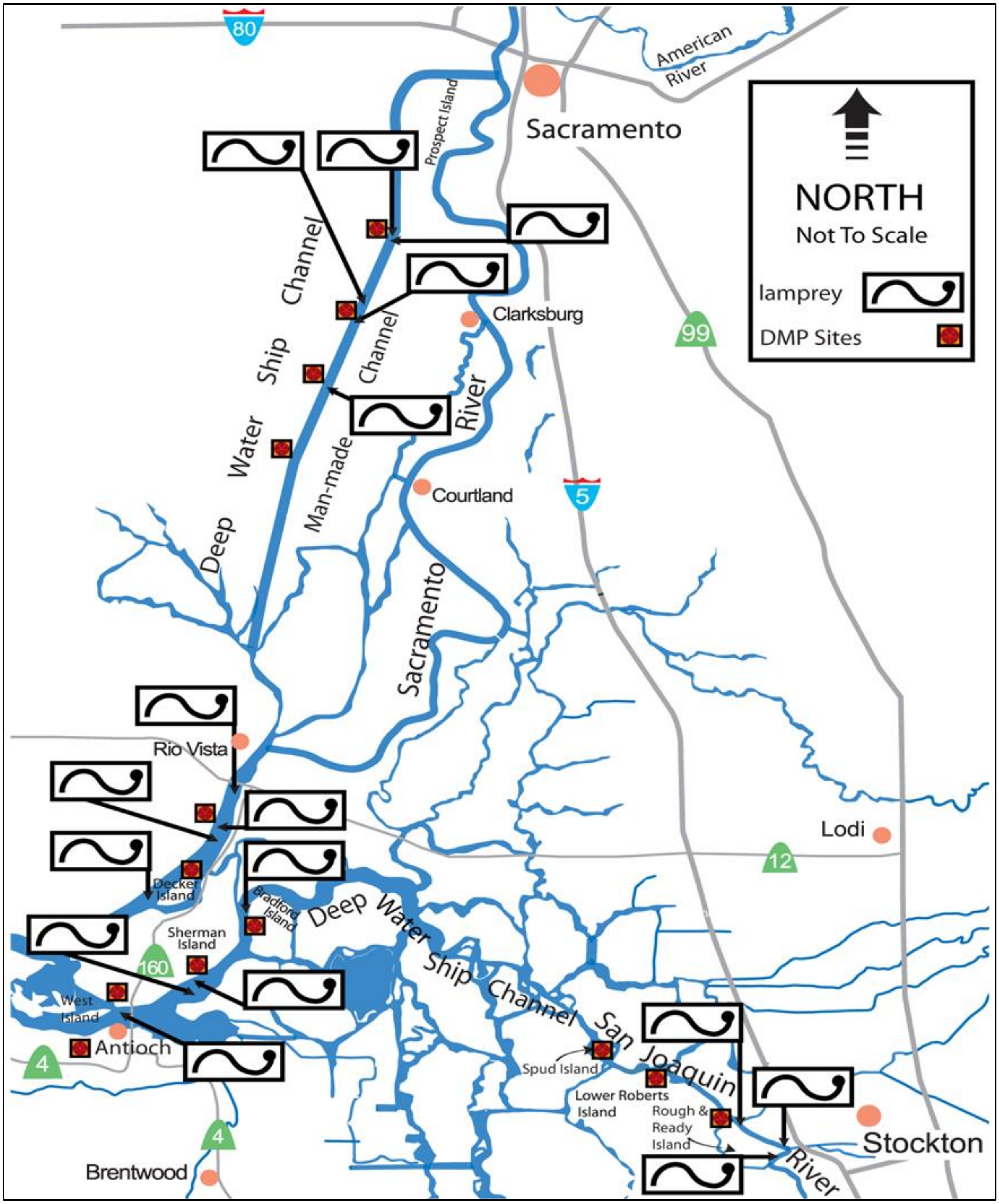

Figure A-1. Cutterhead dredging locations at which lampreys were detected from 2006 through 2017. Monitoring occurred at dredge material placement (DMP) sites near dredging locations.

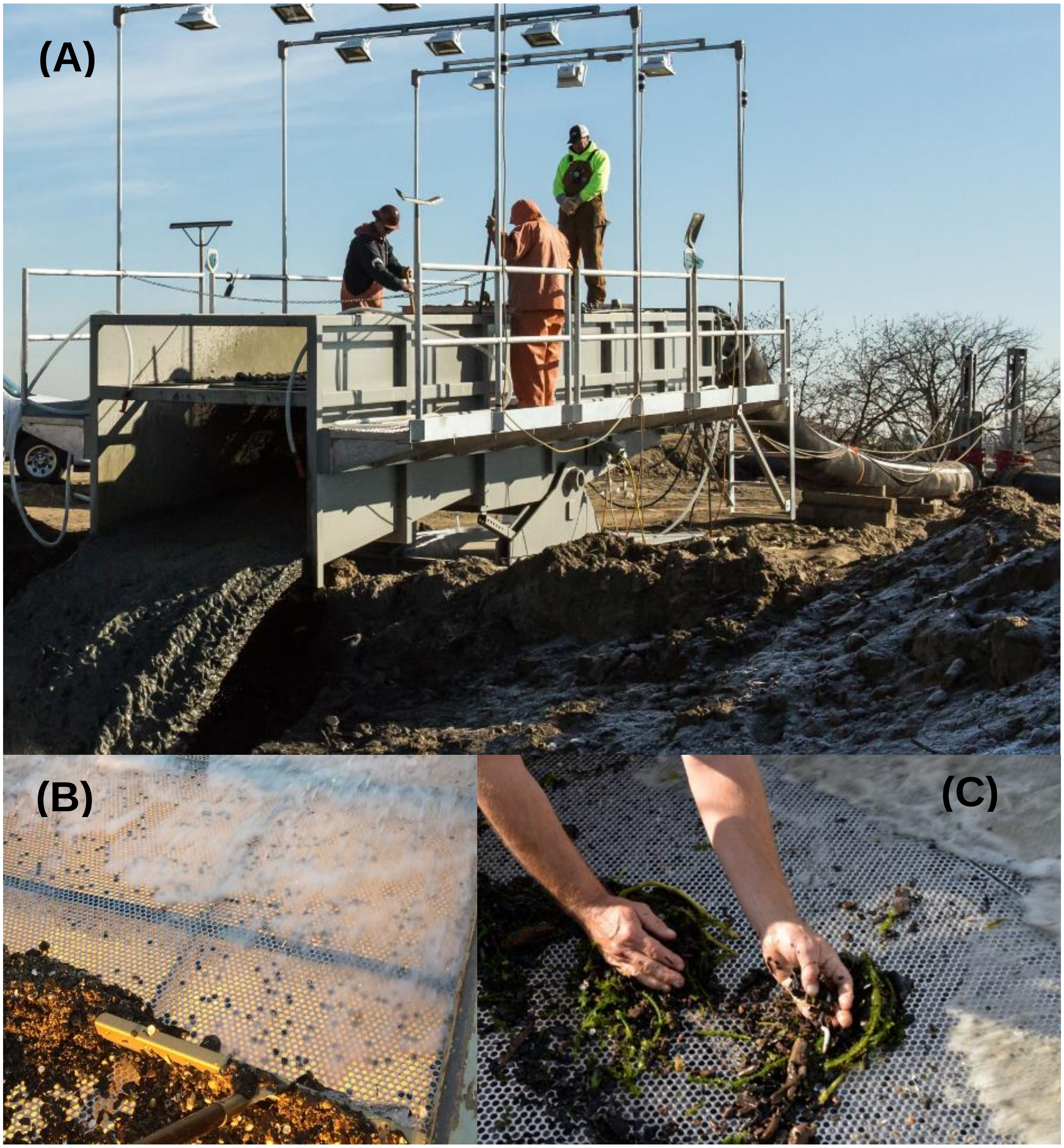

Figure A-2. A screening device used to monitor cutterhead dredge material. (A) shows the screen connected to the dredge discharge pipe with material flowing through; (B) shows water and dredged material flowing over the screen; (C) shows examination of dredged material for fish and other organisms.

Table A-1. Lamprey entrainment data from monitoring maintenance dredging of the Stockton and Sacramento deep-water channels, 2009 through 2017.

Year	Number of Lampreys Entrained		Rank of Lampreys among Species		Percent of Total Fish (individuals)	Percent of Material Monitored	Cubic Yards of Material Dredged (dry)
	Raw	Expanded[1]	Overall	Natives			
2009	20	380	4	1	4.96	5.64	391,559
2010	156	1043	2	1	29.33	7.23	248,749
2011	32	259	2	1	9.33	8.34	331,405
2012	0	0	--	--	0	8.18	111,919
2013	39	--[2]	2	1	10.74	8.06	188,024
2014	131	1,443	2	1	26.63	7.90	41,115
2015	407	2,790	1	1	65.65	16.00	154,329
2016	220	805	1	1	47.52	28.10	262,000
2017[3]	193	580	1	1	62.06	29.47	303,330
2017[4]	194	741	1	1	70.29	29.19	105,326

[1] Number of lamprey entrained was expanded to account for the percent of material monitored for each dredging reach and summed for all reaches (typically 5-10 reaches per year), rather than expanded to account for overall percent of material monitored.

[2] 2013 data was not expanded

[3] 2017 emergency season

[4] 2017 regular season

Case Study 2 - Monitoring Hopper Dredging in San Francisco Bay, California

The *Essayons* is a trailing-arm suction (hopper) dredge (see Figure 1) that is used annually in the San Francisco Estuary in several locations, starting just downstream of the location in the Delta where cutterhead dredging stops (Case Study 1), and extending into Central San Francisco Bay. Monitoring was initiated in 2010 and is conducted by screening the dredged material. Areas routinely dredged by the *Essayons* extend from the upper extent of the estuary, and therefore are barely saline, down to areas that are similar in salt content to seawater (33 ppt) during most of the year.

This monitoring, which primarily uses a basket designed to retain Dungeness crab larvae (Figure A-3), was conducted on behalf of the USACE due to concerns about impacts to Longfin Smelt (*Spirinchus thaleichthys*). The screening method employed is not capable of providing precise estimates of the numbers of organisms entrained due to the inability to assess significant portions of the dredged material, and due to the inability to determine the portion of material that is assessed. The basket is not able to be used for unlimited periods of time because it fills up and overflows. Unlike the screen used in the Delta (Case Study 1), it receives only a small fraction of the dredged material. Additionally, the mesh size of the basket is large enough for entrained lamprey to escape and drop into the hopper. It is therefore likely that the number of entrained lamprey are under-represented.

Western River Lamprey were encountered during monitoring. However, in contrast to the monitoring of cutterhead dredging in the Sacramento/San Joaquin Delta (Case Study 1), they were encountered less than other fish species. Less than 10 individuals were encountered during monitoring in 2011 and 2015 through 2017 (Jordan Gold, MEC, personal communication). All lampreys were larvae or juvenile.

It should be possible to use a screening method (aboard the *Essayons*) that is similar to the method used for the cutterhead dredge (Case Study 1) to provide estimates of the numbers of organisms entrained. The monitoring method must be able to quantitatively assess substantial amounts of the dredged material and must be able to determine the proportion of dredged material assessed. The *Essayons* operates in many other locations in the Pacific Northwest. Improved monitoring equipment could be used in locations where no investigations have yet been conducted to assess impacts to lampreys and other fishes.

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Figure A-3. Basket used to collect dredged material on the hopper dredge *Essayons*. (A) shows the basket being filled during dredging; (B) shows dredged material being washed from the basket while looking for entrained organisms.

Case Study 3 - Development of New Salvage Methods: Sluice Box Lamprey Sifter Using a Venturi Dredge Pump in Naches, Washington (Wapatox Canal)

A pilot study was conducted in 2017-2018 at Wapatox Diversion on the Naches River to explore alternatives to electrofishing and netting for salvage of larval lampreys. We worked closely with Natural Solutions, Inc. (Helena, Montana) to operate an educator pump suction dredge to remove lampreys and sediment from the canal bottom. This venturi-style pump was attached to a modified sluice box (originally designed for gold mining and other in-stream dredging operations) to sift lampreys (Figures A-4 and A-5; Table A-2). The goal of this pilot project was to provide proof of concept with the lamprey sifter design, test larval lamprey passage through the system, and identify any potential problems with its use.

The sluice box was operated on November 16 and 17, 2017. The water depth at Wapatox Diversion was approximately 24-48 inches. The depth that was dredged was approximately 12 inches. The sluice box was operated for a total of 80 minutes on day 1 and 122 lampreys were captured (CPUE of 1.5 lamprey min^{-1}). On day 2, the sluice box was operated for 60 minutes and 130 lampreys were captured (CPUE of 2.2 lampreys min^{-1}). Overall, the injury rate of captured lampreys was 4.1% and 3.1% on days 1 and 2, respectively. The injuries varied from severed heads (causing mortality) to a slight scrape on the side of the body.

A backpack electrofisher designed for the capture of larval lampreys was used on the outside edges of the dredged areas after dredging operations ended on day two. The electrofisher was run for 3.3 minutes and a total of 94 lampreys were captured (CPUE = 28.9 lampreys min^{-1}).

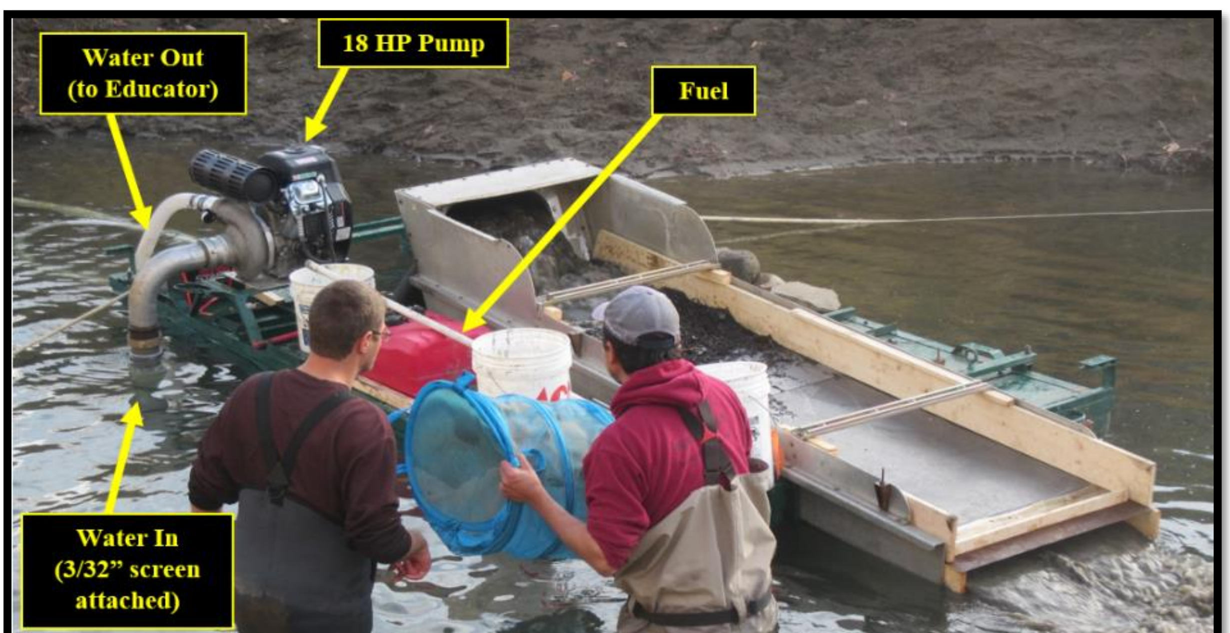

Figure A-4. Side angle view of the sluice box system with labels for major components.

Figure A-5. The sluice box in operation. "T"-handle was used to maneuver the suction hose. The weight of the pump on one side created the potential for imbalance.

Table A-2. Summary of the dimensions and operation specifics of the sluice box designed and operated by Natural Solutions, Inc. (Helena, Montana).

Component	Specification
Pump horsepower	18
Pump discharge (gpm)	100-400
Flow to educator (gpm)	50-100
Suction flow through nozzle (gpm)	300-400
Hose length – pump to educator (ft)	15
Hose diameter – pump to educator (in)	2
Hose length - nozzle to flair (ft)	30
Hose diameter – nozzle to flair (in)	4
Sediment collection rate (yds/hr)	1-4
Sluice box length (in)	112
Sluice box width (in)	29
Perforated plate mesh size (in)	3/32
Minimum water depth (in)	18

Impediments to effectiveness of the lamprey sifter included 1) coarse organic matter was mixed in with the fine sediment and lampreys, making the separation of lampreys very difficult and time consuming (Figure A-6), 2) dredging a large area of fine sediment was very time consuming; and 3) not knowing where to focus dredging effort. Organic debris does not pass through the perforated mesh plate; hence, it was very difficult to separate larval lampreys trapped in the large volumes of organic debris. In general, larval lampreys tend to congregate in areas where the organic debris is highest (their preferred habitat), so this problem is inevitable if high amounts of organic debris are present in the area of interest. It is time consuming to cover a small area with sluice box dredging, including both operation and equipment preparation. If there is a large area of potential habitat for larval lamprey it is difficult to be efficient. Focusing effort is also difficult if distribution and relative density of lamprey is not known. A number of solutions for these impediments were tested (Table A-3).

Figure A-6. Collection of lampreys from the sluice box during salvage operation. Sifting through the large amounts of organic debris to find lampreys proved to be time consuming and difficult.

Table A-3. Potential impediments to and solutions for salvaging lampreys by using a venturi dredge pump and sluice box sifter.

Impediment	Potential Solutions
Coarse organic matter	Collect all organic debris along with lampreys trapped within it and return them together to the river. This will limit the time needed to separate and sort out the lampreys, but would preclude counting, measuring, and identifying lamprey to species.
	Create a pool of water on top of the perforated plate, where organic debris can spread out, and swimming lampreys can easily be observed and captured. This could be achieved by placing stop logs with limited openings above and underneath the perforated screen plate at the outlet end of the sluice box. However, holding too much water will increase the loading, potentially impacting the buoyancy of the sluice box.
	Install two separate sifting plates (a coarse mesh that all larval/juvenile lampreys can pass and a fine mesh that larval/juvenile lampreys cannot pass) so that large debris can be first removed from the sediment mix with lampreys.
Large area to dredge	Limit the depth of the dredging effort. Larval lampreys reside primarily in the top 15 cm of habitat. Focusing on the top 15 cm allows more area to be covered, with potentially less organic debris.
	Build the sluice box large enough so that the fine sediment can be collected using heavy equipment (e.g., backhoe)
	Build the sieve into a dump truck so that the sifting can take place while the dump truck is in transport (as a result of transport vibrations). This will remove one step from the sorting of fine sediment and/or organic debris. The transported lampreys/sediment mix could then be spread out on the ground for lamprey salvage.
Unknown lamprey distribution	Electrofish the area first. Use the sluice box in areas with the highest observed density of lampreys to greatly improve efficiency.
	Combine the sluice box dredging with an electrofishing operation –the dredging can focus on the larvae that emerge from the fine sediment, greatly limiting the amount of sifting and sieving needed to capture the lampreys

For more information see:

Beals, T., and R. Lampman. 2016. Summary of a pilot project to improve lamprey salvage efficiency: Venturi pump sluice box design. In Yakama Nation Pacific Lamprey Project 2017 annual report (Appendix 3.3, Cooperative Agreement No. R15AC00044). Prepared for the U.S. Dept. of Interior, Bureau of Reclamation, Boise, ID. 20 pp.

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In addition to project contacts, Jordan Gold of Marigold Environmental Consulting is acknowledged for his input and recommendations concerning design of the sluice box sifter. Jordan donated many hours discussing the design with the project contacts.

Case Study 4 – A Pilot Study to Assess the Effects of Sediment Deposition on Larval and Juvenile Lampreys in Prosser, Washington (Chandler Canal)

A pilot study was conducted in November 2020 in a dewatered irrigation diversion along the Lower Yakima River (Chandler Canal, Prosser, WA) using 1-m^2 enclosures to assess lamprey responses to electrofishing settings related to voltage and duty cycle and to deposition of fine sediment (Figure A-7). Thirty four lampreys (small [30-60 mm] = 10, medium [60-90 mm] = 10, large [90-120 mm] = 10, juvenile Pacific Lamprey = 2, subadult Western Brook Lamprey = 2) were released into each of the three cylindrical enclosures. The two primary goals were to test the effectiveness of electrofishing settings in cold water conditions (< 10˚C) and to evaluate lamprey behavior associated with the deposition of fine sediment on top of their rearing habitat.

The conditions within the three enclosures at the start of the study were the following: water depth 6-10 cm, sediment depth 10-15 cm, water temperature 6.3-6.8 ˚C, and water conductivity 208-219 (see A in Figure A-8). Most of the released larval lampreys burrowed instantly after release and all burrowed within 15 min; over 80% of the transformed lampreys also burrowed in the fine sediment. The initial electrofishing test using various voltage settings (125-225 volts) was conducted 60 min after the burrowing of all larval lampreys were confirmed. The capture efficiency was the highest for 225 volts (100%) and was high for 175 volts (74%) and 125 volts (82%) as well (Figure A-8). However, these lampreys received very little acclimation time after release, so the capture efficiency rates we report here are likely inflated compared to electrofishing of lampreys under natural conditions.

Thirty minutes after all lampreys were again released back into each enclosure and burrowed again, 9-13 cm of fine sediment (primarily sand, secondarily silt) was deposited inside each enclosure (to 2 cm above the surrounding water depth) to test "dry shocking" method of electrofishing using three duty cycle settings (10%, 25%, and 50%) (see C in Figure A-8 and A in Figure A-11). Within 30 min after the sediment was added, at least a portion of the lampreys emerged to the top based on the appearance of 5-7 lamprey filter feeding holes in each enclosure (see B in Figure A-11) and prior to electrofishing two larvae emerged out of the sediment (see C in Figure A-11). Electrofishing was conducted 80-90 min after the last load of sediment was deposited. Based on the first pass results, the 25% duty cycle setting performed the best (18% capture efficiency; Figure A-10). However, when captures from all four passes were combined, the results were relatively similar and only 21-26% of the total number of lampreys were recaptured.

Due to the low overall recapture rates (with 74-79% still remaining in the enclosures), we systematically excavated/dredged the deposited fine sediment in each enclosure in 1.5-2.0 cm increments to assess the final depth profile of lampreys within the enclosure. Lampreys were found at various depth profile all the way down to 10-11.5 cm depth (Figure A-11). The mortality rates of the excavated lampreys were generally high in the 4-5.5 cm and deeper sediment profile (50-88%). Altogether 25% of the lampreys were unaccounted (i.e., never found at the end of the study); these lampreys may have 1) burrowed into deeper sediment, 2) escaped the enclosure, or 3) been consumed overnight by avian / mammalian predators. Mortality rates were highest for the small larvae (48%), whereas no mortalities were observed for transformed lampreys, indicating they may be more resilient to sediment weight and pressure (Figure A-12). On the other hand, confirmed survival rates were similar across all size classes and species.

In summary, approximately one third of the lampreys were able to traverse ~10 cm of newly deposited sediment to the top, but many others remained in between the original depth and the sediment surface. Some caution is advised with the interpretation of these data. Because fine sediment was deposited above the water line (by 2 cm) in our study, this distinguishes this operation from a standard sediment deposition operation that occurs all under water. The canal water was 3.7 C in the morning of the second day and this very low temperature conditions may also have contributed to higher rates of immobilization and mortality within the fine sediment.

Figure A-7. Overview of the initial setup with the three enclosures on shallow fine sediment larval lamprey habitat.

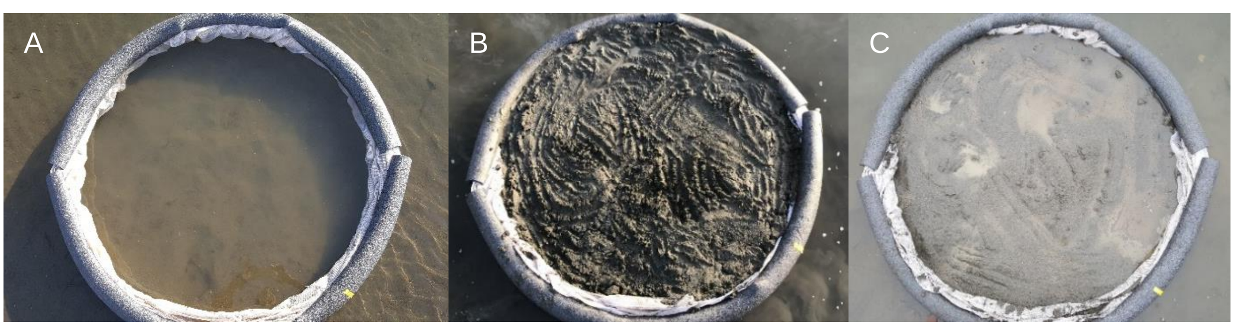

Figure A-8. Examples of the sediment levels at various points of the study: A) the starting condition prior to any sediment addition, B) after ~10 cm of fine sediment was added, C) after the top 2 cm of fine sediment was excavated down to the surrounding water level.

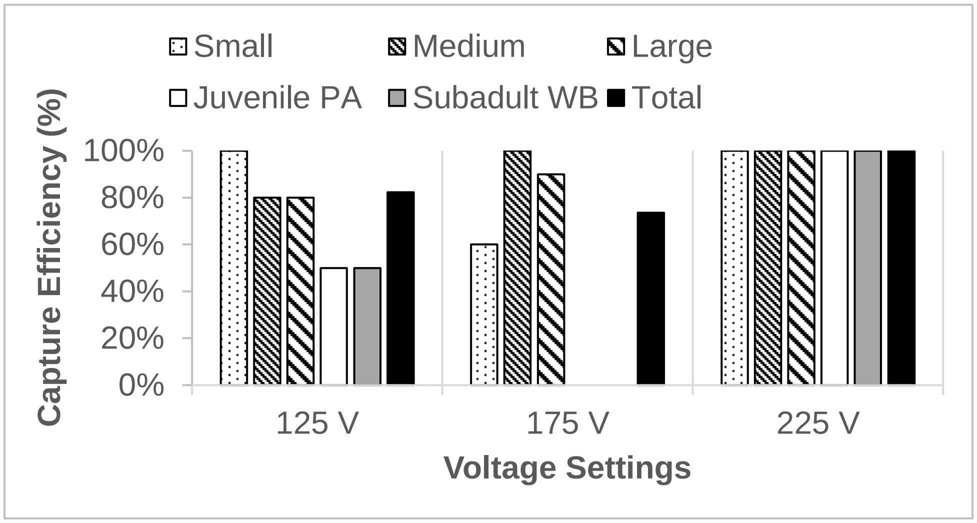

Figure A-9. Capture efficiency of lampreys with 125, 175, and 225 volt settings using ETS ABP-2 (larval lamprey) backpack electrofisher. Aside from the voltage gradient, we used the standard lamprey setting of 3 bursts/s slow pulse, 30 bursts/s fast pulse, 25% duty cycle, and 3:1 train pulse. PA = Pacific Lamprey and WB = Western Brook Lamprey.

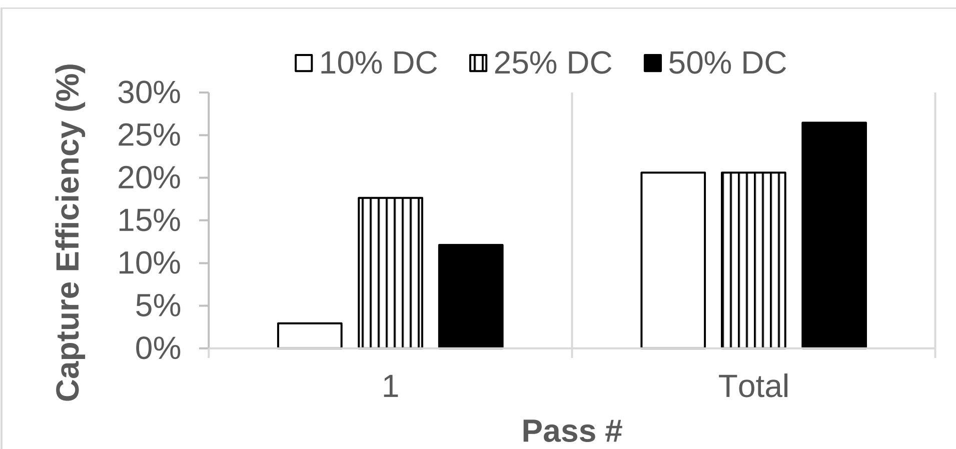

Figure A-10. Capture efficiency of “dry shocking” using three different settings of duty cycle (10, 25, 50%) after one pass and the cumulative total after four passes (“Total”). A voltage of 200 volts (instead of 125 volts) was used for all treatments due to the low water temperature conditions. Aside from the duty cycle gradient and voltage, we used the standard lamprey setting of 3 bursts/s slow pulse, 30 bursts/s fast pulse, and 3:1 train pulse.

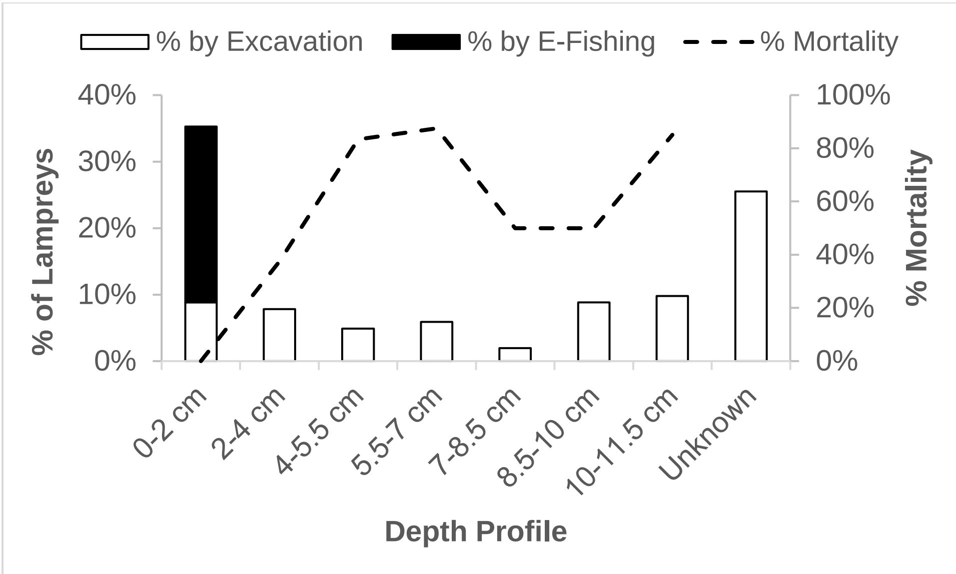

Figure A-11. Percent of lampreys captured by depth profile during sediment dredging and the associated mortality rates of the lampreys. “Unknown” denotes the unaccounted lampreys that were never found. The 0-2 cm excavation took place on the first day while the rest of the dredging took place the following morning.

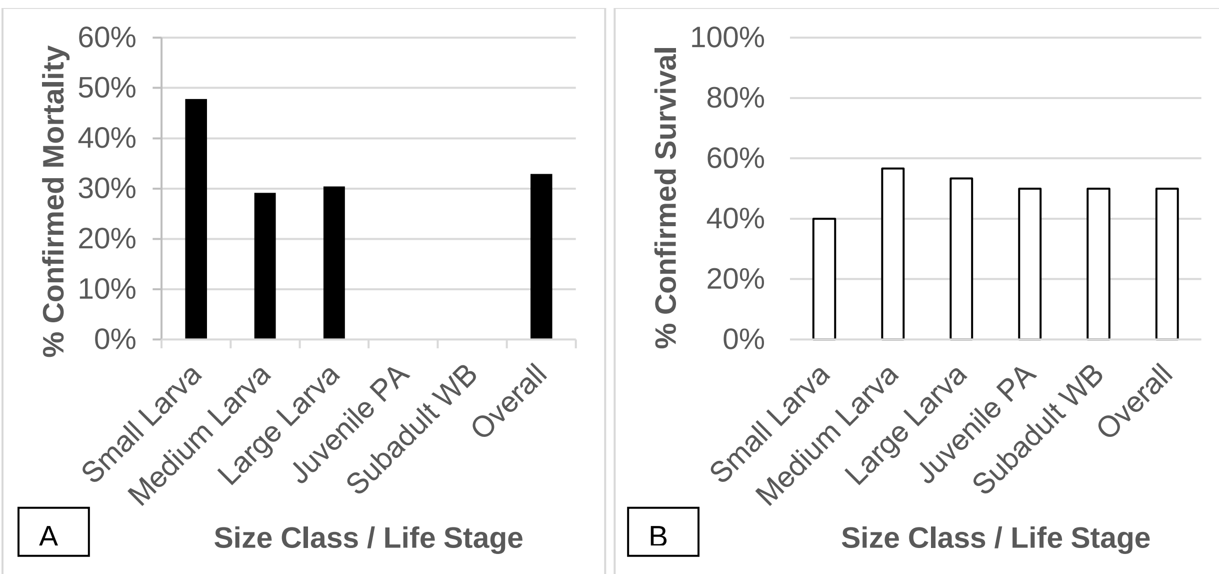

Figure A12. A) Percent confirmed mortality and B) percent confirmed survival by size class and life stages. PA =Pacific Lamprey and WB = Western Brook Lamprey.

Figure A-13. A) Dry shocking in one of the enclosures. B) Examples of larval lamprey holes that emerged on the dry surface soon after fine sediment was deposited. C) Larval lamprey tracks left on the fine sediment surface after lamprey emergence. D) Fresh mortalities of curled larval lamprey found in deep profile fine sediment.

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