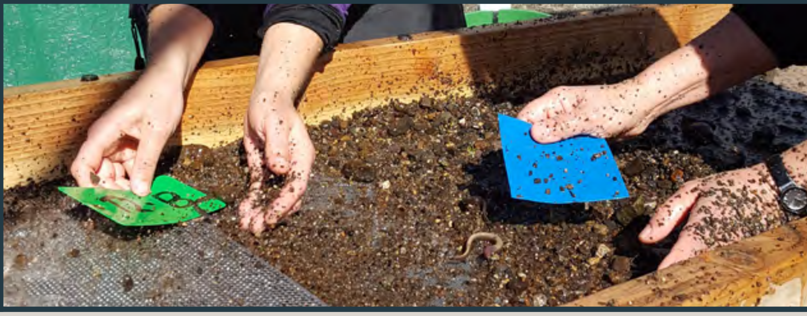
Prepared in cooperation with the U.S. Fish and Wildlife Service

Collection of Larval Lampreys (*Entosphenus tridentatus* and *Lampetra* spp.) Using a Portable Suction Dredge—A Pilot Test



Open-File Report 2021–1116

U.S. Department of the Interior
U.S. Geological Survey

Cover:

Top. Operating a portable suction dredge to collect larval lamprey in the Wind River, Washington. Photograph by Joseph Skalicky, U.S. Fish and Wildlife Service, December 2, 2020.

Bottom Left. Dredge discharge directed over the sluice box to separate sediment and lamprey. Photograph by Theresa Liedtke, U.S. Geological Survey, April 9, 2021.

Bottom Right. Larval lamprey being collected from the sluice box screens during the laboratory test. Photograph by Theresa Liedtke, U.S. Geological Survey, April 9, 2021.

Collection of Larval Lampreys (*Entosphenus tridentatus* and *Lampetra* spp.) Using a Portable Suction Dredge—A Pilot Test

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
	Area	
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)
	Volume	
mL (milliliter)	0.0381402	ounce, fluid (fl. oz)
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

USGS	U.S. Geological Survey
VIE	Visual Implant Elastomer

Collection of Larval Lampreys (*Entosphenus tridentatus* and *Lampetra* spp.) Using a Portable Suction Dredge—A Pilot Test

By Theresa L. Liedtke[1], Joseph J. Skalicky[2], and Lisa K. Weiland[1]

Executive Summary

A portable suction-dredge and sluice-box system were used to collect larval lampreys (*Entosphenus tridentatus* and *Lampetra* spp.) from fine and coarse sediment in field and laboratory tests. We evaluated the injury rate, survival, and burrowing capability of lamprey following passage through the dredge system and used collection of lamprey from water without sediment as a control. The system used a hydraulic eductor (also known as a Venturi valve) to create suction so that sediment and lamprey avoided passage through the pump impeller. For the field test, lamprey were tagged with visible elastomer implants based on small (89 millimeter [mm] or less) and large (92 mm or more) size categories and stocked into mesh enclosures over fine or coarse sediment. The dredge was used inside each enclosure to collect lamprey and they were transported to the laboratory for evaluation and holding. The mean time to burrow was recorded for each study group (3 fine, 3 coarse, 3 controls) on the day of the field test; injury was evaluated at 24 hours; and survival was evaluated at 24 hours, and at 7 and 14 days after the test. The suction dredge collected 32 lamprey in fine sediment, 21 lamprey in coarse sediment, and 28 lamprey in the control group, including 30 lamprey that were not initially stocked. One lamprey died the day of the test (fine sediment) and 24 hours later, three lamprey were found to be injured (2 in fine and 1 in coarse sediment). No injuries or mortalities occurred in the control group. Lamprey burrowing performance was similar across the two treatment groups and the controls. The mean time for all fish in a group to burrow was highly variable. For all groups in a treatment combined, the mean burrow times were fastest for the fine treatment (9.8 minutes), followed by the controls (11.4 minutes) and the coarse treatment (11.6 minutes). The mean times to burrow for the main group of fish in each treatment group (those that burrowed in quick succession) were similar: 4.3 minutes for the fine group, 4.4 minutes for the coarse group, and 4.5 minutes for the controls. The laboratory test collected 147 lamprey (73 small and 74 large size category) from coarse sediment using the same procedures as the field test. One fish (small) was killed the day of the test, and six lamprey (3 small and 3 large) were found with injuries during the 24-hour exams. No mortalities were recorded 7 days after the test, when monitoring was terminated. The overall injury rate for the laboratory test was 4.1 percent and the mortality rate was 0.7 percent. Injuries in the field and laboratory tests were localized minor hemorrhages or red, irritated areas. The suction- dredge system appears to be a safe option to collect larval lamprey from sediment and will be a useful addition to lamprey assessment and salvage tools.

Introduction

Pacific lamprey (*Entosphenus tridentatus*) numbers in the Columbia River Basin have decreased from historical levels (Close and others, 2002; Wang and Schaller, 2015; Clemens and others, 2017), which has raised concerns from managers of Federal, State, and Tribal entities. Worldwide, lampreys are ecologically and culturally important and of conservation concern (Maitland and others, 2015; Clemens and others, 2020). Native lampreys face various threats, and improved data on distribution, behavior, status, response to environmental changes, and management actions could inform conservation efforts (Maitland and others, 2015; Clemens and others, 2020; Lucas and others, 2020).

Larval lamprey live for 3–10 years burrowed in river sediments, where they filter feed on detritus and organic matter. This life-history pattern makes larval lamprey more difficult to study than many other fishes. Development of methods for collecting burrowed lampreys is needed to evaluate their distribution, behavior, and status. Much of the existing data on larval lamprey abundance and distribution have been collected during fish surveys that did not specifically target lamprey (Moser and others, 2007). The most common method for capture of burrowed larvae is backpack electrofishing (Moser and others, 2007); however, this approach has limitations. For example, most backpack electrofishing units will not function in salinities greater than 1 part per thousand or when conductivity is low (less than 25 microsiemens per

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[1] U.S. Geological Survey

[2] U.S. Fish and Wildlife Service

centimeter [cm]). Additionally, high turbidity limits the ability to capture fish and the units can be cost-prohibitive. The presence of protected fishes can also limit the use of electrofishing in some locations. Suction dredges, with and without the use of electricity, have also been used to assess larval lampreys (Bergstedt and Genovese, 1994; Taverny and others, 2012; Bull and others, 2018). Lamprey can be injured or killed as they pass through pump hose lines with the dredged sediment, or over screening devices used to separate the fish from the sediment. Effects on fish from dredge use are a primary concern (Griffith and Andrews, 1981; Wenger and others, 2017), but have not been widely assessed for lampreys. Only a single published study (Bull and others, 2018), to our knowledge, has assessed survival of lamprey passing through a suction pump and screening device system. These authors reported 10 percent mortality for larval sea lamprey (*Petromyzon marinus*) and a reduced collection efficiency of large larvae compared to electrofishing.

To help fill the information gap on the direct effects of using a suction dredge to collect larval lamprey, we conducted a pilot test with a portable suction dredge in two sediment types. Although larval lamprey prefer a mixture of sand and fine organic matter, they are also found in coarser sediments such as a mixture of sand and gravel (Moser and others, 2007). The coarser materials may have greater potential to injure fish as they travel together through the dredge hose lines and over the screening device. The objective of our evaluation was to compare the injury rate, survival, and burrowing capability of lamprey collected using a suction-dredge and sluice-box screening device with water only (control), fine sediment, and coarse sediment.

Methods

The pilot field test of the suction dredge was done in known lamprey habitats in the lower Wind River, Washington (fig. 1). The fine and coarse sediment treatments were within the range of sediment types commonly used by larval lamprey for burrowing. The fine and coarse treatments and a control (collected out of water by the suction dredge) were each replicated three times. To control for the potential presence of injured or dead lamprey prior to the start of our test, we used mesh enclosures for each replicate study group and stocked marked lamprey in each enclosure. The field test then attempted to re-collect the stocked larval lamprey using the dredge and screening system.

To increase the number of larval lamprey in our evaluations, we did a brief follow-on test of the dredge in the laboratory after the pilot field test. The goal of the laboratory dredge test was to pass large numbers of lamprey through the dredge to improve the rigor of our estimates of injury and mortality.

Suction Dredge

Sampling was done using a portable suction dredge (Keene Engineering Model 2004PJF centrifugal jet pump, Honda Model GX50 2.0 HP engine). The dredge was constructed with an aluminum frame, supported with hard cross-linked polyethylene pontoon floats (fig. 2A). The 5.1 cm diameter suction hose was 6 m long and was equipped with a 68 cm long section of steel pipe at the intake. The pressure hose (3.2-cm diameter) was 1.2 m in length and merged with the suction hose at the Venturi valve, terminating in a 49.5-cm-long steel discharge nozzle (fig. 2A). The system used a hydraulic eductor (also known as a Venturi valve) to create suction so that sediment and lamprey avoided passage through the pump impeller (fig. 3). The complete system weighed about 36 kg and was designed to be transported to field sites as two pieces on backpack frames This engine and pump combination can transport 379 liters per minute (L/min), with a capacity of 1.2 cubic meters per hour (m^3/h).

The dredge discharge was directed over a wooden frame sluice box (fig. 2B) to separate the water and sediment from the fish using screens. The sluice box was 335 cm long by 61 cm wide, with four stainless steel (type 304) panels. The first (uppermost) and fourth panels were solid plate (61×61 cm), the second panel (61×91 cm) was perforated round plate on 24-mm staggered centers with 1.6-mm holes, and the third panel (61×91 cm) was perforated round plate on 48-mm staggered centers with 0.8-mm holes. Both perforated plates had a 40-percent open area. The discharge nozzle was positioned over the lower 30 cm of the second panel and moved continuously in a side-to-side motion to evenly distribute water, sediment, and lamprey for sorting.

Fish Collection, Holding, and Marking

Larval lamprey for the suction-dredge field test were initially collected using lamprey-specific electrofishing settings from the Wind River, Washington (fig. 1) in November 2020. Fish were transported to the U.S. Geological Survey (USGS) Columbia River Research Laboratory in Cook, Washington, and held in fiberglass tanks (51×43×27 cm) with beach sand for burrowing at a depth of about 5 cm and supplied with filtered water (1.5 L/min) from the Little White Salmon River. Lamprey were fed a slurry of active yeast and commercial fry food (Gemma Wean 0.1; Skretting, Vancouver, British Columbia, Canada) using methods modified from Rose and Mesa (2012). Fish were not identified by species but were based on previous collections in the Wind River (Liedtke and others, 2020); the lamprey were likely to be predominantly Pacific lamprey.

Visible Implant Elastomer (VIE, Northwest Marine Technology, Anacortes, Washington) tags were used to identify lamprey in two size categories: small (89 mm or less) and large (92 mm or more). Fish were anesthetized in a solution of tricaine methanesulfonate (100 milligrams per

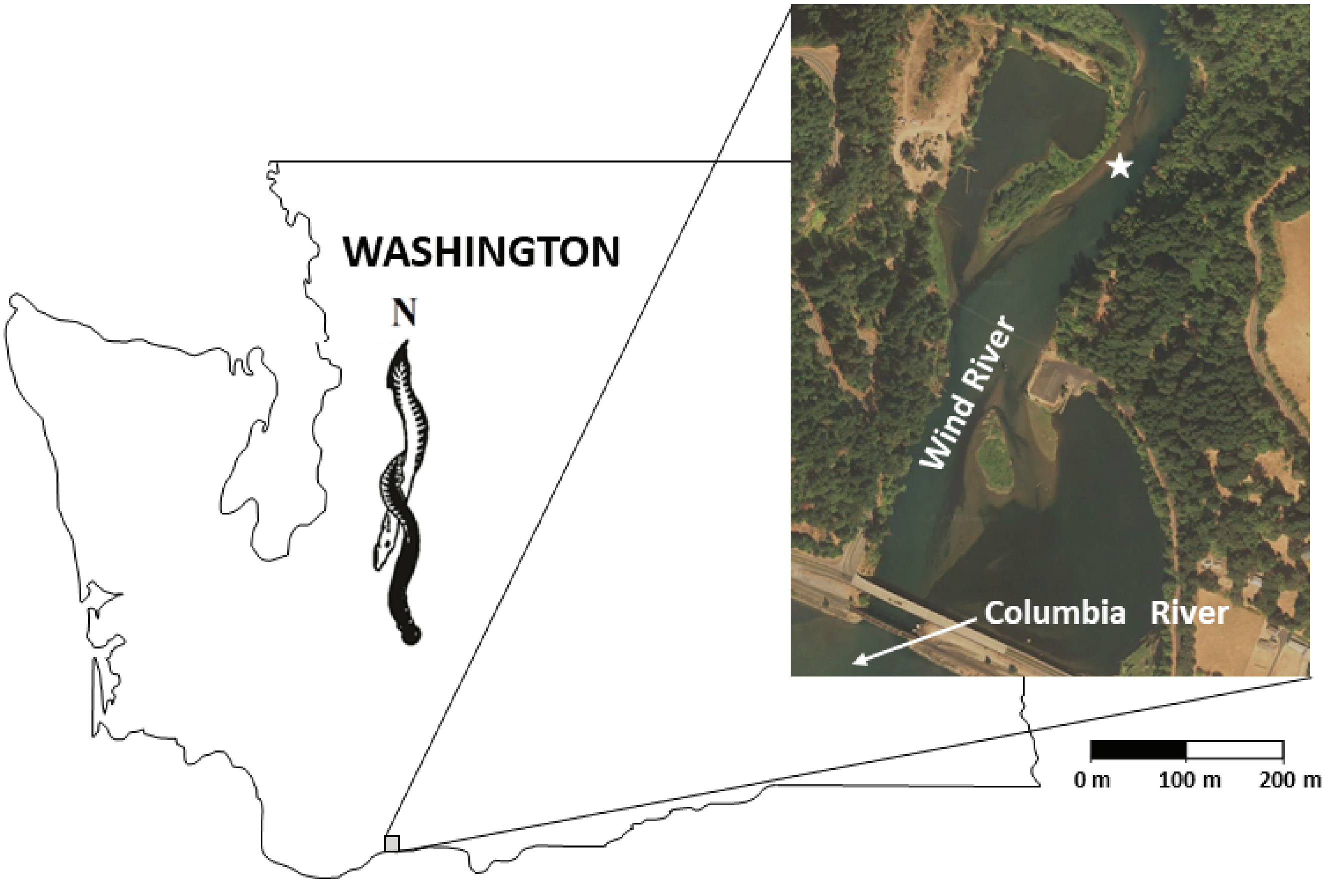

Figure 1. Location of the suction-dredge field test in the Wind River, Washington. Star marks the test location, approximately 0.5 kilometers upstream from the confluence with the Columbia River. Satellite Image from 2021 Google Earth™; Washington outline from printablemap.net; and "North" arrow designed by David Hines, U.S. Fish and Wildlife Service—used with permission.

liter) and buffered with an equal amount of sodium bicarbonate to facilitate handling. Tags were dispensed with a 0.3-mL injection syringe loaded with uncured elastomer (Silver and others, 2009). The needle of the syringe (29-gauge) was inserted just beneath the surface of the skin along the midline of the fish and 2–4 mm of the elastomer material was injected as the syringe was removed. After the syringe was removed, the puncture was gently wiped clean of any external elastomer. Following marking, lamprey were held for 2 days prior to the field test.

Field Dredge Test

The field test was done on December 2, 2020. Nine, 15-liter (L) coolers, one for each test group, were loaded with 10 VIE-marked lamprey—five small fish and five large fish. Fish were provided aeration and transported from the USGS laboratory, approximately 30 minutes to the Wind River.

We used a circular mesh enclosure system for each test group (fig. 4). Enclosures were approximately 1.1 m in diameter (approximately 1.0 square meters), with a solid, weighted ring (height 11.4 cm) that slightly penetrated the sediment (5–10 cm). The weighted ring was attached to a 0.8-mm, knotless, polyester netting that extended through the water column, supported by a 31.8-mm diameter floating upper ring. Foam pipe insulation was positioned over the top ring to improve flotation and prevent lamprey from escaping the enclosure (fig. 4).

In the Wind River, six enclosures were positioned in shallow water (20–40 cm deep), three over fine sediment and three over coarse sediment. Each enclosure was stocked by gently releasing the 10 VIE-marked lamprey (five small and five large) from a cooler. A 1-hour wait period was used after stocking and before testing to allow lamprey time to burrow.

Lamprey in the control groups were collected from water with the suction dredge, without any collection of sediment. The first control group (Control 1) was stocked in a large tub (122×91 cm), suctioned through the dredge and directed over the sluice box. The water was quickly removed from the tub and the dredge lost suction before all tagged lamprey were recovered. To improve recovery of fish, control groups 2 and 3 were suctioned from a 79-L mesh basket submerged in the river. The mesh basket provided the dredge with an unlimited

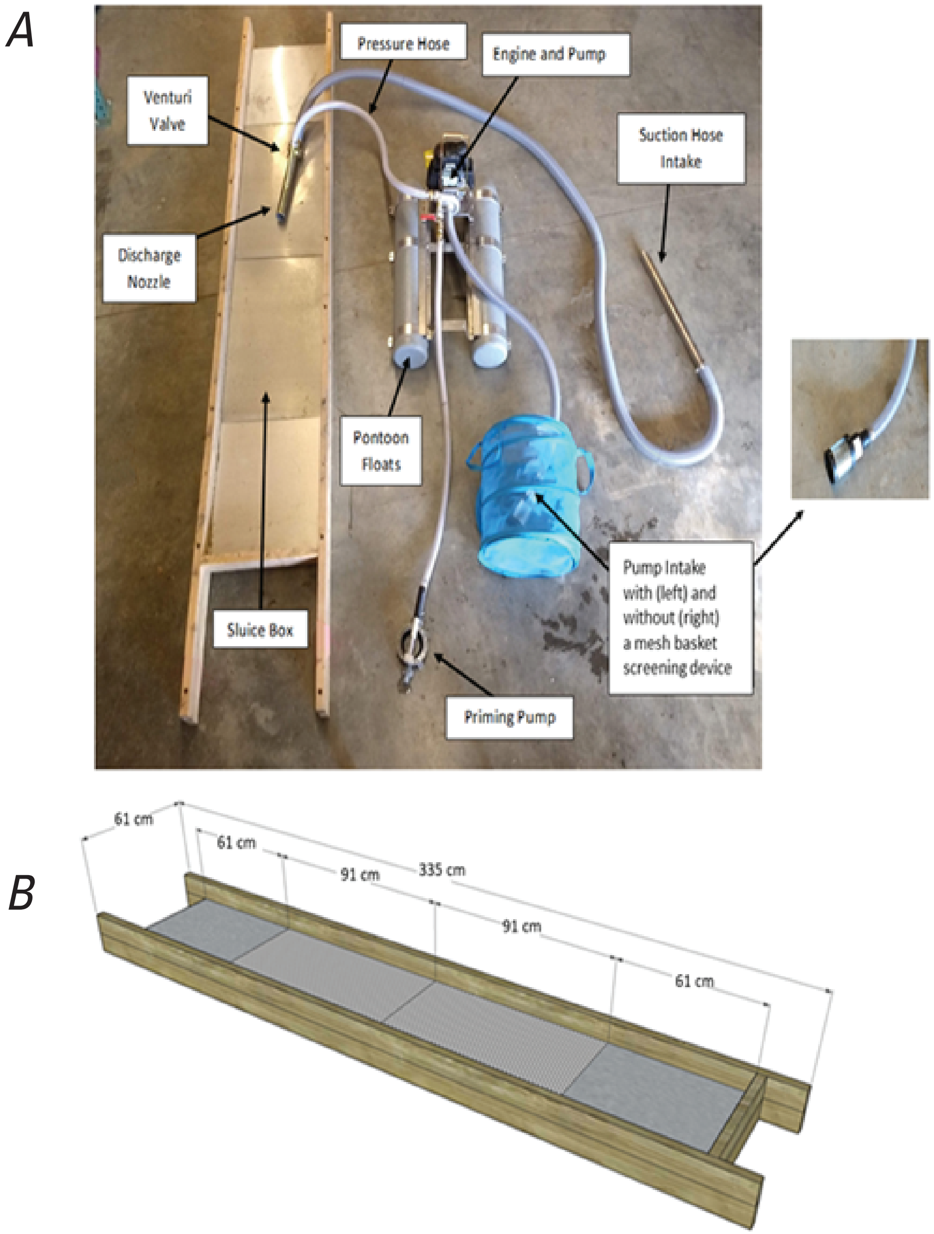

Figure 2. Suction-dredge system (*A*) and schematic showing sluice box (*B*). The pump impeller is located within the pump, labeled in the photograph as "Engine and Pump." Photographs by Lisa Weiland, U.S. Geological Survey.

water supply to maintain suction. Collected control fish were placed in 15-L coolers with aeration until the completion of the field test.

For the test groups, the suction dredge was operated with 4–5 people. One person guided the suction intake in the sediment and another person controlled the discharge nozzle, moving it horizontally across the screens in the sluice box to distribute the collected material. Two to three other team members were positioned around the sluice box to sort debris and locate and remove lamprey. The pump intake would occasionally be restricted by impingement of large debris or vegetation, reducing dredge performance. To reduce impingement, we intermittently positioned the pump intake in a mesh basket (fig. 2A). The suction intake of the dredge was operated by hand using a slow side-to-side sweeping motion, removing a horizontal section of sediment. The steel intake pipe, in contact with the sediment, was held and operated from 20 to 45 degrees from horizontal. The amount of material removed during each pass varied but was about 6–8 cm in depth. This

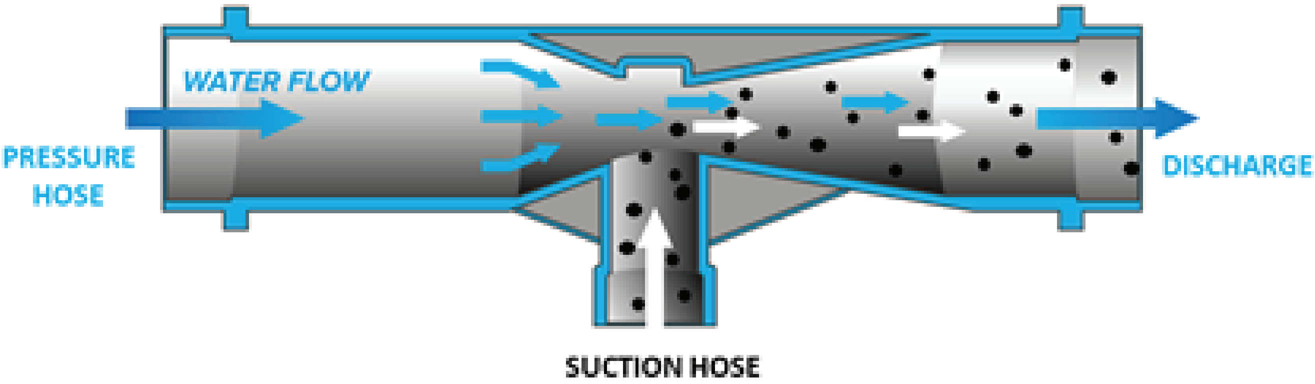

Figure 3. Hydraulic eductor, also known as a Venturi valve, that creates suction for the suction dredge (FennecLabs, 2021).

Figure 4. Circular mesh enclosure system used to evaluate effects on larval lamprey following passage through a suction dredge. Photograph by Lisa K. Weiland, U.S. Geological Survey.

process was repeated, moving from one side of the enclosure to the other side until sediment had been removed down to a depth of 15 cm throughout the enclosure.

Laboratory Evaluation of Lamprey Condition

Fish collected from the control groups and in each enclosure during the field test were placed in coolers with aerated river water and transported back to the laboratory. At the time of arrival, each group was evaluated for overall group burrowing time. To do the burrowing evaluation, fish from each test group were netted out of their cooler and placed in a 7.6–L plastic pail with about 5 cm of beach sand. The time from release in the pail until all lamprey in the group were burrowed was recorded. When released in the pail the lamprey generally showed minimal searching behavior and the group of fish commonly burrowed in rapid succession. Occasionally, one or a few lamprey in a group would spend more time swimming, such that they tended to burrow after the main group. To account for this behavior, which could artificially inflate the mean group burrow time, we recorded the burrow time for any group that burrowed in rapid succession (hereinafter referred to as the main group), and then noted separately the burrow times for any delayed individuals. Timing continued for a maximum of 15 minutes. Mean treatment burrow times were calculated using a time of 15 minutes for any fish that had not burrowed when the maximum monitoring time was complete. After burrow testing, pails were covered with mesh and placed inside a large, 1.5-m-diameter fiberglass tank with a 46-cm water depth with circulating water.

About 24 hours after the field test, pails were removed from the tank and checked for lamprey on the surface of the sediment. Fish were gently removed from the sediment and observed for any irregular swimming behavior. Lamprey were anesthetized in the same manner as described in section, “Fish Collection, Holding, and Marking,” measured for length and weight, and examined for any visible signs of injury. Lamprey were examined under a magnified (2×) lamp to help visualize minor injuries. Fish were returned to their study group pails and placed back in the holding tank. At 7 and 14 days after dredge testing, fish were gently removed from the sediment to assess mortality. Injury was not assessed during the 7- and 14-day examinations. Monitoring was complete following the 14-day examination.

Laboratory Dredge Test

Larval lamprey used in the laboratory test were collected from a range of sources (including the Wind River, and Wapato and Sunnyside irrigation diversions in the Yakima River) and had been held in the laboratory for at least 6 months. Prior to the test, lamprey were anesthetized (as described in section, “Fish Collection, Holding, and Marking”), measured, and examined for any preexisting injuries. Only lamprey without obvious injuries or malformations were used for testing. Fish were divided into two size classes based on total length, using the same criteria as for the field test: small (less than 86 mm) and large (92 mm or greater). Unlike in the field test, lamprey used in the laboratory dredge test were not marked with VIE tags.

The laboratory dredge test was done on April 9, 2021, with a single treatment group (coarse sediment) and no controls. A control group was not included because it would have been executed following the same procedures as the field test. Coarse sediment was selected for this test to provide the greatest potential for injury as the lamprey traveled with the sediment through the hoses of the dredge system. Water temperature was adjusted to match the approximate temperature during the field test. Coarse sediment was collected from the Wind River, near the location of the field test, and transported to the laboratory. A subsample of sediment was dried and sorted to describe mean grain size (see section, “Sediment Grain-Size Analysis”).

Sediment was placed in a tank (125×61×52 cm) to a depth of 15 cm. The dredge and sluice box were positioned near the test tank and the pump intake and priming pump accessed water from an adjacent tank. We stocked 150 lamprey (75 small and 75 large) in the tank and allowed them to burrow. Using the same procedures described for the field dredge test, the suction hose intake was used to evacuate the tank of sediment and lamprey were collected from the screens in the sluice box.

Following passage through the suction dredge, lamprey were stocked in containers (51×43×27 cm) with sand for burrowing. Following the same procedures used in the field test, lamprey were examined for injuries and mortalities 24 hours after the test and mortality was assessed again after 7 days. No burrow performance testing was done.

Sediment Grain-Size Analysis

To describe the sediment composition for dredge tests, sediment samples were collected in the Wind River. For the field test, sediment sample sites were adjacent to each study group enclosure. Six samples were collected: three from coarse sediment and three samples were collected from fine sediment. For the laboratory dredge test, a sample was collected as a subsample of the sediment transported to the laboratory. Each sediment sample was subsampled for grain size determination, and we present the mean for each treatment group. Samples were desiccated at 60 degrees Celsius (°C) for 48 hours in a drying oven. Sediment size and composition were determined by standard dry sieving techniques (Folk and Ward, 1957) using test sieves and a Meinzer IITM sieve shaker. Physical analysis of sediment size and composition was calculated using GRADISTAT (Version 6.0; Blott and Pye, 2001). Statistical parameters for grain size were calculated by the Folk and Ward (1957) graphical method, and a qualitative description of the dominant sediment size at each sample site was classified according to the Udden-Wentworth scale (Udden, 1914; Wentworth, 1922).

Results

Water temperature was 4.9 °C in the Wind River for the field test. Other than larval lamprey, no other fish species were observed during the field test. Use of the suction dredge caused an increase in turbidity locally, but water clarity quickly improved both temporally and spatially. The mean water temperature during the 14-day laboratory holding period was 5.0 °C (range, 4.5–6.0 °C). The water temperature for the laboratory dredge test was 5.9 °C, and the temperature during the 7-day holding period ranged from 6.1 to 6.5 °C.

The sediment grain size analyses for the field and laboratory dredge tests are presented in table 1. For the field test, the mean grain size for the three fine sites (0.71 mm) was much smaller than the mean grain size for the three coarse sites (4.04 mm; table 1). Samples from the three fine sediment sites included conifer needles and other large organic debris, but similar material was lacking in the coarse sediments. In the samples from groups Fine 2–3, the mean grain size was larger than that of the group Fine 1 samples because of a few

Table 1. Sediment characteristics (percentage of gravel, sand, and mud; and mean grain size) for the fine and coarse field test locations and the coarse sediment used in the laboratory test of a suction dredge.

[**Abbreviation:** mm, millimeter]

Group	Gravel (percent)	Sand (percent)	Mud (percent)	Mean grain size (mm)
Fine 1	1.5	91.0	7.5	0.19
Fine 2	29.5	66.8	3.7	1.00
Fine 3	28.5	67.0	4.5	0.94
Overall	**19.8**	**74.9**	**5.2**	**0.71**
Coarse 1	27.9	71.9	0.2	1.29
Coarse 2	68.8	31.1	0.1	4.82
Coarse 3	77.9	21.9	0.2	6.02
Overall	**58.2**	**41.6**	**0.2**	**4.04**
Coarse laboratory	**68.7**	**29.0**	**2.4**	**3.15**

particles ranging in size from 2 to 64 mm. Overall, the three fine group sites were mainly sand (74.9 percent) and gravel (19.8 percent; table 1). The coarse sites overall were mainly gravel (58.2 percent) and sand (41.6 percent). The coarse sediment for the laboratory dredge test had a mean grain size of 3.15 mm and was composed primarily of gravel (68.7 percent).

During the field test, the suction dredge collected 32 lamprey in fine sediment, 21 lamprey in coarse sediment, and 28 control lamprey in water (table 2). Our planned collection techniques had to be modified for some groups to adjust to observations during testing and changing field conditions. The control groups were initially planned to be suctioned out of a container full of river water, but during the test with the first control group (Control 1), the dredge evacuated the water in the container and lost suction prior to collecting the full group. Eight lamprey were recovered (table 2), one was left in the container, and one was lost (likely in the dredge hose lines). We modified our approach for the remaining control groups, stocking the lamprey in a mesh container positioned in the river. The dredge recovered all 20 stocked lamprey from groups Control 2–3 (table 2). Like the adjustments to procedure enacted for the control groups, we adaptively modified the plan for the fine sediment groups. For the first fine group (Fine 1), the dredge quickly evacuated the enclosure of water and lost suction. To access more water and continue dredging, we marked the perimeter of the enclosure, removed it, and continued dredging. A total of four VIE-marked fish were recovered from group Fine 1 (table 2). Similar procedures were used for two remining fine groups. We removed the enclosure and dredged within the perimeter of where the enclosure had been positioned, and in adjacent areas to collect either the VIE-marked lamprey that were stocked or untagged lamprey present in the sediment. We did not recover any of the stocked lamprey in groups Fine 2 or Fine 3 but collected 14 untagged fish (table 2). For the three coarse sediment enclosures, dredging operations proceeded as planned, with lamprey collected from within the stocked enclosures. Seven lamprey were recovered from each of groups Coarse 1–3, including 2 untagged lamprey (table 2).

The suction dredge recovered similar proportions of the stocked small and large lamprey for both the fine and coarse treatment groups. Few stocked fish (4 of 30) were recovered in the fine sediment treatment groups, but they were evenly split between small and large lamprey (table 2). In the coarse

Table 2. Summary of tagged larval lamprey in small and large size categories and untagged larval lamprey collected after passing through a suction dredge during the field test, including the number of fish and mean total length and standard deviation by group.

[**Abbreviations and symbol:** SD, standard deviation; mm, millimeter; —, not applicable]

Group	Number of fish stocked	Small		Large		Untagged fish		Total number of fish collected
		Number of fish collected	Mean total length (SD, in mm)	Number of fish collected	Mean total length (SD, in mm)	Number of fish collected	Mean total length (SD, in mm)	
Fine 1	10	2	63.0 (12.7)	2	102.5 (0.7)	0	—	4
Fine 2	10	0	—	0	—	14	57.2 (16.7)	14
Fine 3	10	0	—	0	—	14	41.9 (12.5)	14
Coarse 1	10	4	62.0 (9.3)	3	117.0 (22.6)	0	—	7
Coarse 2	10	1	60.0	5	106.2 (8.9)	1	48.0	7
Coarse 3	10	4	81.3 (8.4)	2	140.5 (7.8)	1	31.0	7
Control 1	10	3	61.7 (2.5)	5	109.0 (12.6)	0	—	8
Control 2	10	5	70.8 (9.4)	5	105.4 (3.4)	0	—	10
Control 3	10	5	63.0 (6.9)	5	115.8 (20.4)	0	—	10

treatment groups, we collected 19 of the 30 lamprey that were stocked, 60.0 percent (9 of 15) from the small size category and 66.7 percent (10 of 15) from the large size category.

One lamprey died and three were injured following the field test (table 3). The mortality was an untagged lamprey, 46 mm in length, recovered alive from the Fine 2 study group. It was found dead shortly after arrival at the laboratory, and prior to burrow testing. The lamprey had a small wound on its lateral surface, with some hemorrhaging. This single mortality represented 7.1 percent of the Fine 2 group (1 of 14) and 3.1 percent of the fine sediment treatment overall (1 of 32; table 3). No mortalities from any study group were detected at 24 hours, 7 days, or 14 days post-testing. The three lamprey with visible injuries, detected during the 24-hour examination, included two untagged lamprey from group Fine 3 and one VIE-marked (stocked) lamprey from group Coarse 1 (table 3). In the Fine 3 group, a 44-mm fish had a small, red wound on its side and a 40-mm fish had hemorrhaging on both sides of the body near the tip of the tail. The injured fish represented 14.3 percent of the Fine 3 group (2 of 14) and 6.3 percent of the fine sediment treatment overall (2 of 32). The one injured lamprey from group Coarse 1 was 53 mm in length and had a red wound on its side, representing 14.3 percent of the Coarse 1 group (1 of 7) and 4.8 percent of the coarse sediment treatment overall (1 of 21; table 3). All lamprey were swimming normally at the 24 hours, 7-day, and 14-day examinations, except one small fish in group Coarse 3 that appeared lethargic at 7 and 14 days post-test. No lamprey were found on the surface of the sediment when they were removed for examinations, and all fish burrowed successfully after each check. No injuries or mortalities occurred in any of the control groups.

Burrowing performance was similar across the two treatment groups and the controls. The mean time for all fish in a treatment group to burrow was fastest for the fine treatment (9.8 minutes; table 4). The mean burrow times for the control groups (11.4 minutes) and the coarse treatment groups (11.5 minutes) were slower by about 1.5 minutes, and within a few seconds of each other (table 4). All groups had lamprey that spent time swimming around in the test container prior to burrowing, and one group in each of the fine and coarse treatments had at least one fish exceed the 15-minute maximum monitoring time. The burrowing times were highly variable, both within and among the study groups. The main group of fish in each group (those that burrowed in quick succession) represented 62–87 percent of their respective groups (table 4). The mean burrow times for the main groups for each treatment were very similar, ranging from 4.3 minutes for the fine groups to 4.5 minutes for the control groups (table 4). Overall, there was little evidence that the burrowing performance of lamprey that passed through the suction dredge with fine or coarse sediment was different from lamprey that passed through the dredge with just water (the controls).

During the laboratory test of the suction dredge, 147 lamprey were collected off the sluice-box screens (table 5). One small lamprey (54 mm) was found dead shortly after the test, with hemorrhages near the head. During the exams 24 hours after the test, three small and three large lamprey were found with injuries. All the recorded injuries were minor hemorrhages or red, irritated patches and affected only discrete body regions, most commonly the head and tail. Example injuries from 2 of the 6 injured fish are shown in figure 5. No mortalities were observed during the 7-day exams. Overall, combining the small and large size categories for the laboratory test, the injury rate was 4.1 percent and the mortality rate was 0.7 percent (table 5). All lamprey were swimming normally immediately after the test and during the 24-hour and 7-day examinations. During the examinations following the test, no lamprey were found on the surface of the sediment and all fish burrowed successfully after each check.

Table 3. Number of mortalities and injuries by group for lamprey 24 hours, 7 days, and 14 days after passing through a suction dredge during a field test.

Group	Number of fish	Total number of mortalities	24-hour mortalities	Day-7 mortalities	Day-14 mortalities	24-hour injuries
Fine 1	4	0	0	0	0	0
Fine 2	14	1	0	0	0	0
Fine 3	14	0	0	0	0	2
Fine total	**32**	**1**	**0**	**0**	**0**	**2**
Coarse 1	7	0	0	0	0	1
Coarse 2	7	0	0	0	0	0
Coarse 3	7	0	0	0	0	0
Coarse total	**21**	**0**	**0**	**0**	**0**	**1**

Table 4. Summary of time to burrow by group for lamprey that passed through a suction dredge during a field test

[Within each group, lamprey that burrowed in quick succession were considered the main group and burrow time was recorded for the group. The remaining lamprey were considered delayed and their burrow times were reported individually. **Abbreviation and symbols:** min, minutes; >, greater than; —, not applicable]

Group	Number of fish	Time for all fish to burrow (min)	Number of fish in main group (percent)	Time for main group to burrow (min)	Time for delayed fish to burrow (min)			
					Fish 1	Fish 2	Fish 3	Fish 4
Fine 1	4	8.3	3 (75)	3.8	8.3	—	—	—
Fine 2	13	6.1	13 (100)	6.1	—	—	—	—
Fine 3	14	>15.0	12 (86)	3.0	8.5	>15.0	—	—
Mean	—	**9.8**	**(87)**	**4.3**	—	—	—	—
Coarse 1	7	6.9	5 (71)	2.7	3.5	6.9	—	—
Coarse 2	7	>15.0	4 (57)	9.0	>15.0	>15.0	>15.0	—
Coarse 3	7	12.8	4 (57)	1.7	3.4	7.5	12.8	—
Mean	—	**11.5**	**(62)**	**4.4**	—	—	—	—
Control 1	8	14.8	5 (63)	4.0	6.4	12.3	14.8	—
Control 2	10	11.8	6 (60)	2.0	4.3	4.3	8.0	11.8
Control 3	10	7.6	10 (100)	7.6	—	—	—	—
Mean	—	**11.4**	**(74)**	**4.5**	—	—	—	—

Table 5. Summary of the mean total length of larval lamprey used in the laboratory test of the suction dredge and the injuries and mortalities observed 24 hours and 7 days after the test.

[**Abbreviations:** SD, standard deviation; mm, millimeter]

Size category	Number of fish	Mean total length (SD, in mm)	Range	Total number of mortalities (percent)	24 hours		7 days
					Number of injuries (percent)	Number of mortalities	Number of mortalities
Small	73	61.7 (12.5)	32–85	1 (1.4)	3 (4.1)	0	0
Large	74	110.6 (11.2)	92–145	0	3 (4.1)	0	0
Overall	**147**	**86.3 (27.1)**	**32–145**	1 (0.7)	**6 (4.1)**	**0**	**0**

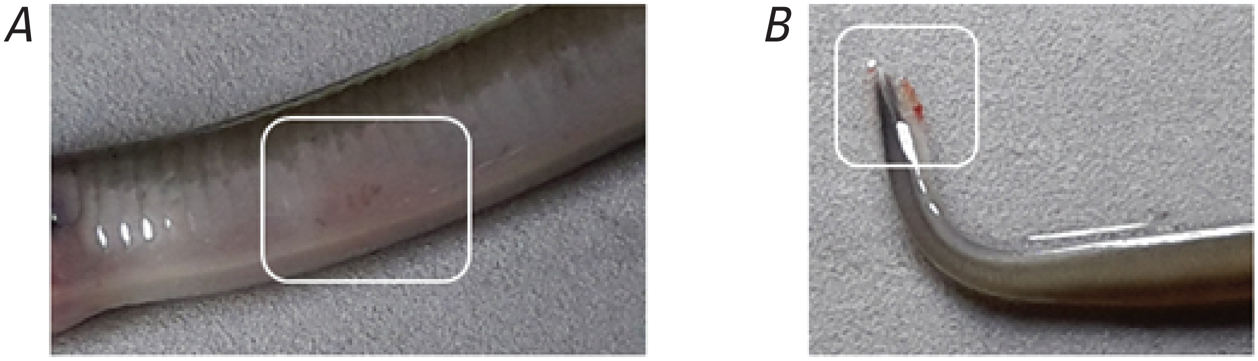

Figure 5. Photographs of larval lamprey injured following passage through a suction dredge during the laboratory dredge test, with photograph *A* showing a light hemorrhage on the ventral surface, and photograph *B* showing a hemorrhage on the tip of the tail. Photographs by Brad Liedtke, U.S. Geological Survey.

Discussion

Use of a suction dredge to collect larval lamprey from fine and coarse sediment during the field test resulted in minimal mortality (1 of 81) and injury (3 of 81). The dead lamprey was not one of the VIE-marked fish that we stocked for the field test but was residing in the sampled sediment from the Fine 2 study group. It was recovered alive during the field test but was found dead when fish arrived at the laboratory. Two of the three injured fish were untagged, so we have no knowledge of their condition prior to passage through the dredge system. Their injuries, however, appeared to be fresh, suggesting that they were sustained during the field test. The mean grain size of the coarse sediment was more than 5 times larger (4.04 mm) than the fine sediment (0.71 mm), which could result in more injuries as fish and sediment move together through the suction-dredge and sluice-box system. Our findings, however, showed the opposite trend. The combined mortality-injury rate was lower for the coarse sediment (1 of 4 dead/injured fish) than for the fine sediment (3 of 4 dead/injured fish). No mortalities or injuries occurred in the control group that moved through the dredge system and sluice box without sediment, suggesting that the likely source of injury was the sediment or that lamprey were injured during the intake process. The suction intake was a steel pipe and moving it through the sediment blindly was a probable cause of lamprey injury. This causality may have been especially true if the motion involved inserting and removing the intake from the sediment as compared to a single insertion of the intake, followed by moving it from side to side laterally in the sediment. Our field tests sampled the fine sediment enclosures first while the sampling crew was familiarizing itself with the dredging process. Perhaps the imperfect technique used with the suction intake during the test with the fine treatment had a larger influence on the number of lamprey that were negatively affected than the physical characteristics of the fine sediment. Considering the nominal injury and mortality observed in our field tests, the suction dredge holds promise overall as a collection approach for larval lamprey.

The laboratory test of the suction dredge supported the findings of the field test, with minimal mortality (1 of 147) and injury (6 of 147) to lamprey. The coarse sediment used for the laboratory test had a smaller mean particle size (3.15 mm) than the coarse sediment from the field test (4.04 mm) but had a higher proportion of gravel (68.7 compared to 58.2 percent). The high gravel content during the laboratory test was a challenge in that the suction hose became occluded frequently when rocks in the hose bound against each other. The incidence of hose blockage was not specifically measured but occurred more commonly in the laboratory test than the field test. Taken together, the percentage of gravel and the frequent hose blockages suggest that we tested a sediment that was likely to cause injury and, on the upper limit of sediment sizes, to be inhabited by larval lamprey. Realistic field applications of the suction dredge would generally target habitats with fine sediments and only a small proportion of gravel. The laboratory test, therefore, might be considered a worst-case scenario, with the expectation that future field applications would be less likely to cause injuries to lamprey.

Dredging activities can directly injure fish, whether they are entrained (Griffith and Andrews, 1981) or just present in areas where dredging occurs (Wenger and others, 2017). Dredging effects often are most severe for the early life stages of fishes (Griffith and Andrews, 1981; Wenger and others, 2017). For example, cutthroat trout (*Oncorhynchus clarkii)* eggs entrained through a suction dredge had 100-percent mortality at the un-eyed stage and as much as 35-percent morality at the eyed stage (Griffith and Andrews, 1981). Lampreys, being cartilaginous, may respond differently than bony fishes to dredge entrainment. Bergstedt and Genovese (1994) and Taverny and others (2012) reported that lampreys lacked visible injuries and were alive following passage through a suction dredge. Bull and others (2018), however, tested a dredge and reported 10 percent mortality for larval lamprey. These authors did not do an injury assessment and offered no potential explanations for the mortalities. They noted that the dredge processed a substantial amount of sediment, and that the lamprey may have been dead prior to collection. Because they could not determine whether or not the dredge was the cause of the elevated mortality and because they thought dredging was resource-intensive relative to other sampling methods, they terminated their tests (Bull and others, 2018). In our tests, the two mortalities were known to be collected alive and the injuries were attributable to the dredging process. Because the incidence of mortalities and injuries was low, however, we see value in having the option to use suction dredging to collect larval lamprey as an assessment or salvage tool.

Burrowing performance testing did not indicate any harmful effects of suction dredging. Burrowing time, as an indicator of fish performance (Quintella and others, 2007), might be expected to differ between the treatment groups if larvae were injured, fatigued, stressed, or otherwise sublethally compromised. Group burrowing times varied substantially overall, with some lamprey in both the fine and coarse groups exceeding the 15-minute maximum monitoring time. A main group of larvae commonly would burrow in quick succession after being released in the test container, but 1–3 fish would swim around near the water's surface, not seeming to be immediately interested in burrowing. Alternately, larvae might lie on the surface of the substrate, appearing lethargic or unable to burrow. Our approach, recording the total time needed for the whole group to burrow, could not distinguish between these two types of outliers, but we did not observe many lethargic lamprey in any of the groups. The dominant outlier type was active swimming and exploring. The mean main group burrow times, which describe the burrowing performance of 62–87 percent of the fish from each group, differed by less than 30 seconds between the fine, coarse, and control groups. In addition to the formal tests of burrowing time done for the lamprey in the field test, we observed that lamprey in all groups (field and laboratory tests) burrowed readily after they were removed from the sediment for exams.

This is a simplistic, but encouraging finding based on our 10-plus years of working with larval lamprey in laboratory settings. We have observed that lamprey exposed to a significant stressor (for example, extended dewatering or screen impingement) commonly have a delayed burrowing response. Therefore, in this evaluation, the finding that lamprey burrowed readily after the exams suggests limited effects from the field and laboratory dredge tests.

Our pilot test of a suction dredge was not able to rigorously evaluate potential size selectivity of this collection method. Some evidence suggests that suction dredges collect smaller lamprey more effectively than larger ones, possibly owing to an increased likelihood of escape (Bergstedt and Genovese, 1994; Bull and others, 2018). Our study objectives did not include an assessment of dredge efficiency, but we stocked both small and large lamprey because we hypothesized that fish size might influence injury or mortality risk or burrowing performance. Few VIE-marked lamprey were recovered from the fine treatment, but 63 percent of the stocked lamprey were recovered from the coarse treatment. In both cases, approximately equal numbers of small and large fish were recovered. Our test, therefore, did not provide any evidence for size selectivity, but our sample size was limited, and the test was not designed to compare collection efficiency for small and large lamprey.

Some modifications to our suction-dredge operations would be useful for future applications. The elevation of the sluice box should be adjustable and positioned very near the water surface, minimizing the head differential to the pump to optimize suction. The pump intake would occasionally become obstructed during our tests. We suggest that the intake be positioned in at least 0.5 m of water, and that the use of a screen or mesh enclosure would reduce impingement of large vegetation or debris and aid in consistent suction. Extending the pump intake hose and the pressure hose would improve the ease of operating the dredge and allow the pump intake to be more distant from the targeted collection area. This extension would be useful, for example, to avoid vegetated areas or to locate deeper, cooler water. The suction hose could also be extended and might be useful to increase the sampling range. The suction hose, unlike the pump intake and pressure hoses, conveys lamprey, so the total hose length could influence the risk of injury. Finally, our experience matches that of Bull and others (2018) in that we suggest that the intake of sediment be periodically paused, allowing only water to be pumped through the dredge, to help clear material and fish from the sluice box and aid fish sorting and collection efforts.

A portable suction dredge seems to be a safe option for collecting larval lamprey from sediment and would be a useful addition to the limited set of lamprey assessment tools. In settings where electrofishing may not function effectively (that is, high salinity or low conductivity) or be authorized (for example, when threatened or endangered species are present), the suction dredge may be a suitable alternative. The number of personnel needed to operate the dredge and the noise level it generates are likely to limit the potential to entrain bony fishes that generally move away from disturbances. Depending on the location and (or) presence of listed species, a permit may be required to operate a suction dredge as they locally disturb stream sediment. Turbidity associated with dredge activity should be monitored and mitigated where necessary. Additional testing is needed to evaluate size selectivity and collection efficiency before a suction dredge is deemed useful for some assessment types such as estimating abundance. In some settings, the suction dredge may be the preferred collection tool. For example, when irrigation diversions are seasonally dewatered, high densities of lamprey often are present in and around the screening systems. Agencies commonly work to salvage the lamprey by collecting them from the sediment and relocating them to adjacent water bodies. Suction dredging could be a powerful addition to these efforts. It could be used either in addition to standard techniques like electrofishing (for example, collecting lamprey that did not emerge from the sediment after electrofishing) or as a stand-alone option, with perhaps several suction dredges working the dewatered area. Additions to the available options to collect larval lamprey support the efforts to protect and restore these unique fish.

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