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U.S. Fish & Wildlife Service

Evaluation of Larval Pacific Lamprey Occupancy of Habitat Restoration Sites in the Portland Harbor Superfund Area

2020 Annual Report

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On the cover: *Photograph of the deepwater electrofishing platform in preparation for deployment at the Oswego Creek reference site. (Photo by M. Blanchard).*

The correct citation for this report is:

Blanchard M.R., Skalicky, J.J. and T.A. Whitesel. 2021. Evaluation of Larval Pacific Lamprey Occupancy of Habitat Restoration Sites in the Portland Harbor Superfund Area. 2020 Annual Report, U.S. Fish & Wildlife Service, Columbia River Fish & Wildlife Conservation Office, Vancouver, Washington. 51 pp.

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funded by

Linnton Water Credits, LLC
Portland Harbor Holdings II, LLC
Rinearson Natural Area, LLC
U.S. Fish & Wildlife Service

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July, 2021

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Abstract – Habitat restoration actions focused on the recovery of juvenile Chinook salmon *Oncorhynchus tshawytscha* are being implemented in the Portland Harbor Superfund area of the Willamette River. These actions may also have effects on co-occurring Pacific Lamprey *Entosphenus tridentatus*. Use of restored habitats by lampreys, particularly the larval life stage has not been extensively studied. As such, there is a need to monitor the effectiveness of these efforts, in part, relative to larval Pacific Lamprey. Determining the effects of habitat restoration actions on Pacific Lamprey requires evaluation of lamprey occurrence before and after project implementation. Currently, this study is focused on the occupancy of larval Pacific Lamprey and *Lampetra* spp. in shoreline, confluence, and tributary habitats at five restoration sites being constructed to provide compensation for injuries to natural resources as part of the Portland Harbor Natural Resource Damage Assessment (NRDA): Alder Point, Harborton, Linnton, Triangle Park, and Rinearson. In addition, the study is evaluating the occupancy of lamprey at a non-NRDA site, PGE 13.1, located in a reach of the Willamette River that bisects the city of Portland. In 2019, post-project sampling at restoration sites was conducted at Alder Point and Rinearson and in 2020 post project sample began at Linnton. We also evaluated whether larval Pacific Lamprey occupied corresponding habitats at six reference sites in the Portland Harbor Superfund area (McCarthy Creek, Columbia Slough, Ross Island, Cemetery Creek, Oswego Creek, and Miller Creek). A generalized random tessellation-stratified approach was used to select random, spatially-balanced sample quadrats (30 m x 30 m square) across the lower Willamette River, Multnomah Channel as well as reaches (50 m) in wadeable tributaries. At the Alder Point site, no larval lamprey were detected at the thirty confluence quadrats, the ten slough sites, or the ten shoreline quadrats (detection probability, *d*, = 0.00 for each). No lamprey were detected in any of the ten confluence quadrats or the ten shoreline and ten confluence quadrats in the newly constructed Linnton restoration site (*d* = 0.00 for each). At the Rinearson site, one larval lamprey was detected in one of the seven tributary reaches (*d* = 0.14) and three larval lamprey were detected at one of the 10 confluence quadrats (*d* = 0.10). At the six reference sites sampled in 2020, larvae were detected at Columbia Slough, Cemetery Creek, Oswego Creek and Miller Creek. A total of 56 larval lamprey were captured and quadrat-specific *d* ranged from 0.00 to 0.83. This information is being used as part of a long-term evaluation of the effects of habitat restoration on occupancy and distribution of larval lamprey in the Portland Harbor Superfund area.

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Introduction

Pacific Lamprey *Entosphenus tridentatus* in many areas, such as the Columbia River Basin (CRB), appear to have experienced a decline in abundance (Close et al. 2002) and have been given protected status within Oregon (Kostow 2002). Lamprey are culturally important to Native American tribes, are ecologically important within the food web, and are an indicator species whose decline provides further insight into the impact of human actions on ecological function (Close et al. 2002). Much information is lacking on the basic biology, ecology, and population dynamics that is required for effective conservation and management.

Pacific Lampreys have a complex life history that includes a multiple year larval, migratory juvenile, and adult marine phase (Scott and Crossman 1973). Larvae are strongly associated with stream and river sediments. Larvae live burrowed in stream and river sediments for multiple years after hatching, where they filter feed detritus and organic material (Sutton and Bowen 1994). Larval metamorphosis into juveniles occurs from July to December (McGree et al. 2008) and major migrations of juveniles are made downstream to the Pacific Ocean in the fall and spring (Beamish and Levings 1991). The sympatric Western Brook Lamprey *Lampetra richardsoni* does not have a major migratory or marine life stage although adults may exhibit local upstream migrations before spawning (Renaud 1997). For both species, the majority of the information on distribution and habitat preference of larvae comes from CRB tributary systems (Moser and Close 2003; Torgersen and Close 2004; Stone and Barndt 2005; Stone 2006) and coastal basins (Farlinger and Beamish 1984; Russell et al. 1987; Gunckel et al. 2009).

Larval lamprey are known to occur in sediments of low-gradient streams (<5th order [1:100,000 scale]; Torgersen and Close 2004) but their use of relatively large river habitats and deep areas is not well understood. Downstream movement of larvae, whether passive or active, appears to occur year-round (Nursall and Buchwald 1972; Gadomski and Barfoot 1998; White and Harvey 2003). Larval Sea Lamprey *Petromyzon marinus* have been documented in deepwater habitats in tributaries of the Great Lakes, within the lakes in proximity to river mouths (Hansen and Hayne 1962; Wagner and Stauffer 1962; Lee and Weise 1989; Bergstedt and Genovese 1994; Fodale et al. 2003), and in large water bodies associated with the St. Marys River (Young et al. 1996). However, references to other species occurring in deepwater or lacustrine habitats are scarce (American Brook Lamprey *L. appendix*; Hansen and Hayne 1962). In the Pacific Northwest, observations of larval lamprey occurrence in large rivers have been made, for example during smolt monitoring operations at Columbia River hydropower facilities, impinged on screens associated with juvenile bypass systems (Moursund et al. 2003; CRITFC 2008), or through observation during dewatering events. Specific collections of larvae have been made in large river habitats in British Columbia, which are thought to be representative of larvae dispersing downstream (Beamish and Youson 1987; Beamish and Levings 1991). More recently, evaluations of larval Pacific Lamprey occupancy and distribution in mainstem river habitats have suggested widespread occurrence in certain areas of the Columbia River and Willamette River mainstem (Jolley et al. 2012; Harris and Jolley 2017, Arntzen and Mueller 2017).

A portion of the mainstem of the lower Willamette River, an area that is known to be occupied by larval Pacific and Western Brook Lamprey (Jolley et al. 2012), was declared a Superfund Site in 2000 by the U.S. Environmental Protection Agency. The Superfund study area extends from river kilometer 3.2 to river kilometer 18.9 and has a broader focus area extending from the Columbia River to Willamette Falls (Figure 1). To compensate for past environmental damage being identified through the Natural Resource Damage Assessment (NRDA) process, this area is subject to various habitat restoration projects as well as assessments of the effectiveness of these projects. For context, restoration is being used as a broad and general term intended to capture efforts to revitalize, rehabilitate, replace, or acquire the equivalent (see Rosenzweig 2003; Roni et al. 2008) of those natural resources injured as the result of hazardous substance and oil releases from the Portland Harbor Superfund site (NOAA 2017). Presently, the projects in the aquatic environment are focused on recovering juvenile Chinook Salmon *Oncorhynchus tshawytscha*. It is unclear whether any of these projects will provide benefits to other co-occurring species including larval and juvenile Pacific Lamprey. However, these projects provide an opportunity to understand the potential effects of habitat restoration on larval and juvenile lampreys. As such, there is interest in monitoring the effectiveness of the projects, in part, relative to larval Pacific Lamprey.

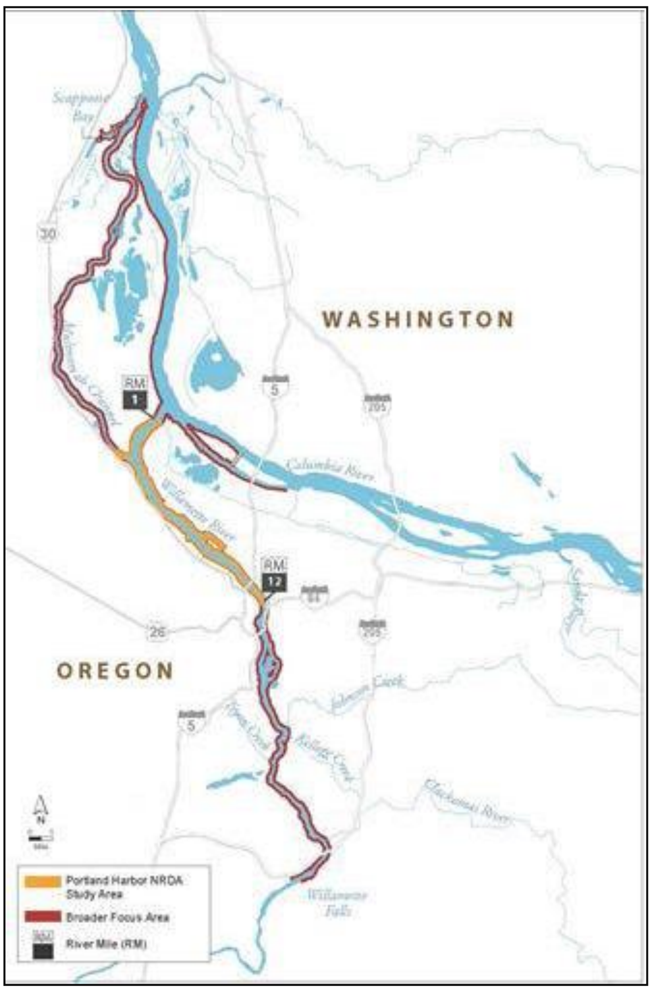

Figure 1. Portland Harbor Superfund study area (orange outline) and the broader focus area (red outline) on the lower Willamette River.

A lamprey monitoring plan (LMP) for habitat restoration projects in the Portland Harbor Superfund area was developed based on a set of monitoring goals and objectives that were identified by the Trustee Council and lamprey biologists over two workshops held in the fall of 2011. The LMP priorities included (i) monitoring the impact of projects on larval and juvenile lamprey populations and health in Portland Harbor, and (ii) gathering information about larval and juvenile lamprey life history, biology, and habitat requirements that could be used by the Trustee Council to inform future design and evaluation of habitat restoration projects targeting lamprey. Since lamprey biology and life history are different from many other aquatic biota, the overlap between the LMP and the general monitoring and stewardship plan is not extensive. The LMP differs from the general monitoring and stewardship plan, in part, because the lamprey monitoring is proposed to continue for a period of 20 years. In most cases, the metrics proposed for collection as part of the lamprey monitoring effort need to be co-located with lamprey sampling. To maximize efficiencies, the Trustee Council will, to the extent possible, use data collected as part of the LMP for general monitoring and stewardship. Biologists recommended monitoring lamprey for 20 years after the completion of a habitat restoration project, with the goal of capturing data for one to two complete generations. Pre-implementation monitoring will be conducted to the extent practical at each project site. Lampreys have the ability to colonize habitats rapidly. Therefore, monitoring will be conducted on a yearly basis for the first five years after project implementation, and every five years thereafter. In general, the proposed work is guided by the LMP. However, due to site-specific conditions and constraints, the specific metrics and timing of monitoring proposed for any given site may differ slightly from those outlined in the LMP.

Understanding larval lamprey usage of areas in and adjacent to rehabilitated habitat is critical to gauging the effectiveness of these projects. At present, little specific information is available on whether lampreys will colonize rehabilitated habitats, which life stages may use these habitats, or how quickly and for how long they will use these habitats. A before-after control-impact (BACI) approach is being used to evaluate the effectiveness of habitat restoration projects. The BACI approach allows us to make inferences about whether observed changes in lamprey occupancy are the result of the habitat restoration projects. Our sampling in 2020 was part of an ongoing effort to determine whether larval Pacific Lamprey occupy restoration sites and reference sites both prior to and after project implementation. Our specific objectives for this phase of NRDA monitoring were as follows:

1. Determine whether lamprey occupy restoration sites in the lower Willamette River and Multnomah Channel.
2. Determine whether lamprey occupy reference sites in the lower Willamette River and Multnomah Channel.
3. Determine the types of habitat available at each site and in which habitat types lamprey are detected.
4. Characterize lamprey species and life history stage that occupy each site.
5. Evaluate the health of lamprey detected at each site.

Study Sites

Restoration Sites

Alder Point

The Alder Point site is located at the southern tip of Sauvie Island (Multnomah County, OR), and thus is bordered on the east side by the Willamette River (at approximately river km 6), and on the west side by Multnomah Channel (Figure 2). As part of a habitat restoration project, slough habitat (henceforth Alder Slough) was constructed through the site, connecting the Willamette River and Multnomah Channel. Unlike the typical confluence habitat in the Superfund area (a tributary or slough having a single confluence with the mainstem), Alder Slough (one water body) has three distinct confluence habitats, two in the main Willamette River and one in the

Multnomah Channel. Restoration of shoreline habitat (i.e., levee removal) also occurred along both the Willamette River and Multnomah Channel (Figure 3). Pre-implementation sampling was conducted in 2014. Post-implementation sampling began in 2016.

Harborton

The Harborton site is located on the southwest side of the Willamette River at river km 5.1, near the confluence of Multnomah Channel (Figure 2). The site contains the Harborton Wetlands, a remnant black cottonwood and ash floodplain forest wetland area that provides off-channel habitat, floodplain function, and habitat connectivity between the river and Forest Park. Currently the site has wadeable tributary or slough habitat (henceforth referred to as tributary habitat) as well as a confluence and shoreline habitat (Figure 4). Proposed actions include improvements to the tributary habitat. In the case of the Harborton site, monitoring needs include tributary habitat (since this habitat is currently believed to be inaccessible to fish, monitoring would be post-implementation only) and the confluence habitat (pre- and post-implementation). Pre-implementation sampling was conducted in 2017. Post-implementation monitoring is scheduled to begin in 2021.

Linnton

The Linnton site is located on the southwest side of the Willamette River at river km 7.5 just upstream of Sauvie Island (Figure 2). It was an industrial property that contained an inactive plywood company and consists of confluence and shoreline habitat (Figure 5). Restoration work was completed at this site in 2019 and included removal of multiple buildings, pilings, and docks. The lower 200 m of Linnton Creek were daylighted to allow fish access, though there is no habitat connectivity past HWY 30, just upstream of the project site. Shallow water habitat was created at the confluence of Linnton Creek and the Willamette River as well as along the banks of the Willamette River. Wood structures, rock piles, and snags were constructed to improve in-water and terrestrial habitat for native species. In the case of the Linnton site, monitoring will include the newly restored tributary habitat (post-implementation only, scheduled to begin in 2021), as well as the confluence and shoreline habitat (pre- and post-implementation). Pre-implementation monitoring was conducted at confluence and shoreline habitats in the Willamette River in 2017 (Skalicky et al. 2018). Post-implementation monitoring began in 2020 and consisted of sampling shoreline and confluence habitats in the Willamette River.

Triangle Park

The Triangle Park site is located on the east side of the Willamette River, near the University of Portland, Oregon (Figure 2). There is a proposed action to improve shoreline and riparian habitat at and remove pilings from the site (Figure 6). In the case of the Triangle Park site, monitoring needs include shoreline habitat and habitat areas around the existing pilings (pre- and post-implementation). Pre-implementation monitoring was conducted at shoreline and piling habitats in the Willamette River in 2017 (Skalicky et al. 2018). Post-implementation monitoring would consist of sampling shoreline habitats in and areas where pilings had been removed from the Willamette River. This site was not sampled in 2020.

Rinearson Natural Area

The Rinearson Natural Area (RNA) site is located at river km 39. Rinearson Creek flows through the RNA (Clackamas County, OR) and enters the Willamette River from the east, just downstream of the mouth of the Clackamas River (Figure 2). The site has tributary habitat that drains into the Willamette River, as well as associated confluence habitat in the mainstem Willamette River (Figure 7). A project has been implemented to improve and redirect tributary habitat at this site but a major fish passage barrier exists 600 m upstream of the mouth. Pre-implementation monitoring was conducted at confluence habitat in the Willamette River mainstem as well as wadeable depth tributary habitat in Rinearson Creek in 2015 (Silver et al. 2016). Post-implementation monitoring began in 2019 and consisted of sampling for larval lamprey in tributary reaches in Rinearson Creek as well as confluence habitats in the mainstem Willamette River.

PGE 13.1

In addition to the NRDA restoration sites described above, Portland General Electric (PGE) requested that the FWS evaluate a similar, non-NRDA restoration action. The PGE 13.1 restoration site is near kilometer 21.1 of the Willamette River (Figure 2). Although restoration at PGE 13.1 is not specifically related to the NRDA process and outside of the formal Superfund area, it is within the reach of the Willamette River that bisects the city of Portland.
The PGE 13.1 restoration site and the NRDA restoration sites have many commonalities in regard to the types of habitats being restored and the biological questions being addressed. As such, the FWS is applying a similar lamprey monitoring approach at the PGE 13.1 and the NRDA restoration sites as well as including all results in this report.

The PGE 13.1 site is located on the east side of the Willamette River. Portland General Electric has proposed a project to rehabilitate the habitat on the east bank of the Willamette River. This site has shoreline habitat with associated city effluents (Figure 8). It was unknown whether lamprey occupied the site. In the case of the PGE 13.1 site, monitoring needs include shoreline habitat (pre- and post-implementation). Pre-implementation monitoring was conducted at shoreline habitats in the Willamette River in 2017 (Skalicky et al. 2018). Unlike the design for the NRDA projects, post-implementation sampling for this PGE project was designed to occur in years 2, 4, 6, and 8 post-implementation. As such, post-implementation monitoring was conducted in 2019 and is scheduled to be conducted in 2021, 2023 and 2025.

Reference Sites

Seven reference sites have been identified throughout the lower Willamette River and Multnomah Channel (Figure 2). Initially, we attempted to monitor habitats from six of these reference sites. However, after various attempts to sample some of the habitats at these sites, it became clear that all the desired reference habitat was not available (e.g. barriers near tributary mouths, unwadeable conditions, private ownership with lack of access). Thus, in 2019 we began sampling tributary habitat at the Oswego Creek reference site and one additional reference site (Miller Creek). Currently, various habitat combinations from seven different sites are being used for reference. Reference sites were selected in locations that contained confluence, shoreline, or tributary habitats and in sites not proposed for habitat restoration in the immediate future. The reference sites were chosen in an attempt to provide confluence, shoreline, or tributary habitats that are similar to those which may exist at restoration sites following project implementation.

Multnomah Channel (Shoreline)

The Multnomah Channel site is located just downstream of the McCarthy Creek (near river km 24; Figure 2). The Multnomah Channel reference site contains shoreline habitat (Figure 9). The Multnomah Channel site is not currently paired with a specific restoration site, but currently serves as a reference site for shoreline habitat.

McCarthy Creek (Confluence and Shoreline)

The McCarthy Creek site is located where McCarthy Creek enters the Multnomah Channel from the southwest, downstream of the Sauvie Island Bridge (near river km 29; Figure 2). The McCarthy Creek reference site provides confluence and shoreline habitats in Multnomah Channel (Figure 10). Although the McCarthy Creek site has a tributary, this habitat is not conducive to sampling (e.g. poor flows, not wadeable) and was discontinued as a tributary reference. The McCarthy Creek site serves as a specific reference for the Linnton site.

Columbia Slough (Confluence)

The Columbia Slough site is located where the Columbia Slough enters the Willamette River from the east, near the confluence of the Willamette and Columbia Rivers (near river km 2; Figure 2). Confluence habitat occurs in the mainstem Willamette River associated with the mouth of Columbia Slough (Figure 11). The Columbia Slough site serves as a specific reference for the Harborton site.

Ross Island (Shoreline)

The Ross Island site, located just upstream of the Ross Island Bridge near downtown Portland (near river km 24; Figure 2), contains shoreline habitat (Figure 12). The Ross Island site serves as a specific reference for the Alder Point site.

Cemetery Creek (Confluence and Shoreline)

The Cemetery Creek site is located where enters the Willamette River from the west, upstream of Ross Island (near river km 27; Figure 2). The Cemetery Creek reference site has confluence and shoreline habitats in the mainstem Willamette River (Figure 13). The Cemetery Creek site, specifically the tributary and confluence habitat, was selected to serve as a specific reference for the RNA site. Although the Cemetery Creek site has a tributary, this habitat is not conducive to monitoring (e.g. lack of Type I habitat and a putative passage barrier) and was discontinued as a tributary reference. In place of the Cemetery Creek tributary habitat as a reference, in 2019 we began sampling the tributary habitat at the Oswego Creek site. The confluence habitat at the Cemetery Creek site continues to serve as a reference for the RNA site.

Oswego Creek (Confluence and Tributary)

The Oswego Creek site is located where Oswego Creek enters the Willamette River from the west, near the town of Lake Oswego (near river km 34; Figure 2). Confluence habitat occurs where the tributary habitat enters the mainstem Willamette River (Figure 14). Prior to 2019, sampling focused on the confluence habitat at the Oswego Creek site. In 2019, we began sampling the tributary habitat to supplement existing tributary reference sites. The tributary habitat associated with the Oswego Creek site (Cemetery Creek site replacement) was added to serve as a specific reference for the tributary habitat at the RNA restoration site. The confluence habitat associated with the Oswego Creek site is not currently paired with a specific restoration site but serves as a general reference site for confluence habitat.

Miller Creek (Tributary)

Miller Creek enters the Multnomah Channel (Figure 2) from the south and just opposite of the upstream end of Sauvie Island (Figure 15). In 2019, we began sampling this habitat to supplement tributary reference sites. The Miller Creek site was added to serve as a specific reference for the Linnton site (McCarthy Creek replacement).

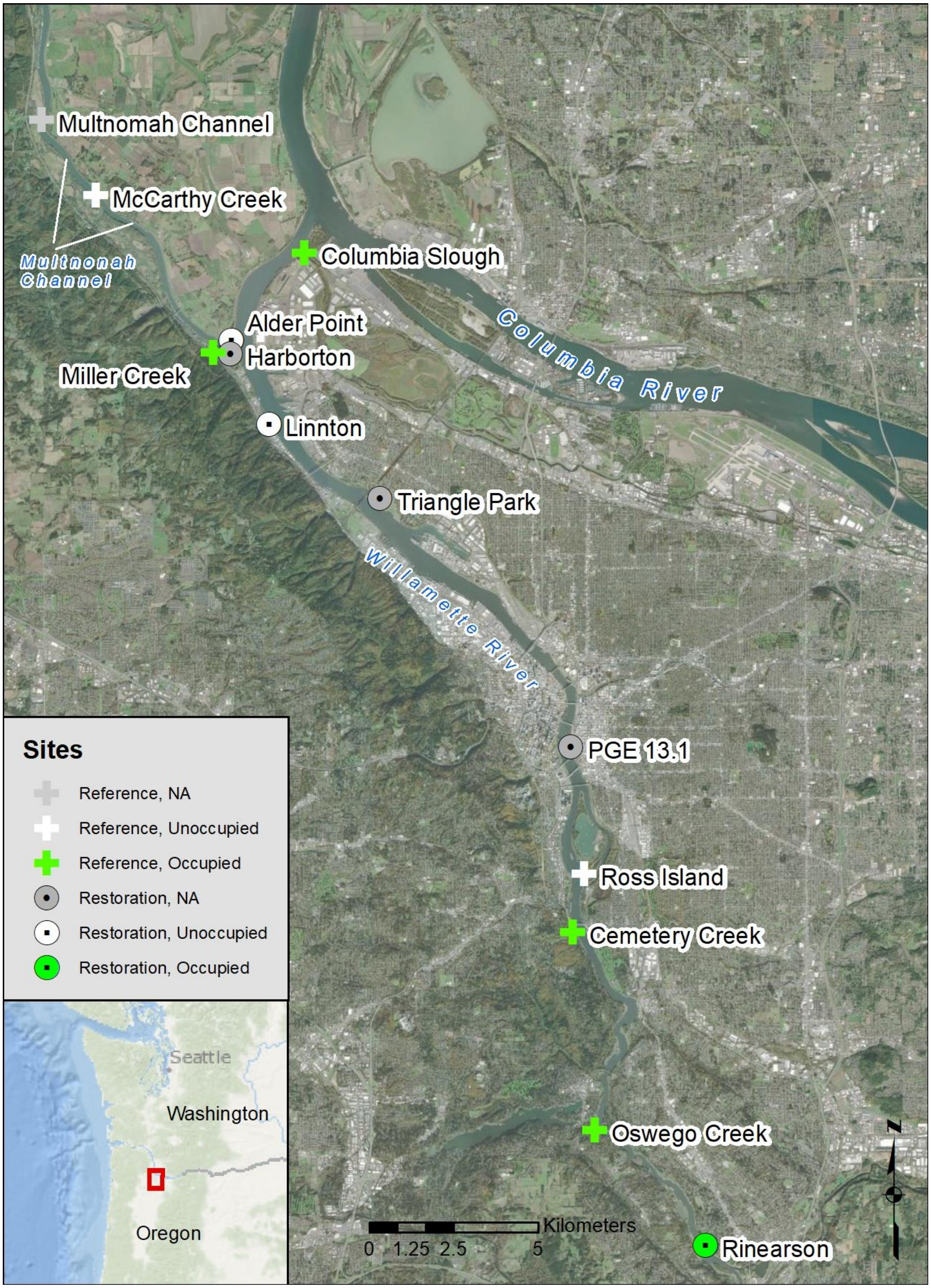

Figure 2. Locations of the restoration (circles) and reference (crosses) sites sampled in 2020. Occupied sites are green. Unoccupied sites are in white. NA (not applicable) sites are in gray and were not sampled during 2020. *Note: PGE 13.1 is not a NRDA restoration site.*

Methods

Sample Framework

We evaluated occupancy of larval lamprey in the restoration and reference sites by adapting an approach that has been applied previously to studies of larval lamprey occupancy in the Columbia River basin in both mainstem and tributary habitats (Silver et al. 2010; Jolley et al. 2012; Jolley et al. 2013; Jolley et al. 2014). The approach has several requirements: 1) a unit- and gear-specific detection probability (assumed or estimated); 2) the probability of presence (given no detection) at a predetermined acceptably low level; and 3) random identification of spatially balanced sample units that allow estimation of presence and refinement of detection probabilities. A unit-specific probability of detection, d_{unit}, was calculated as the proportion of sample quadrats or reaches in which larvae were captured. The posterior probability of area occupancy, given a larval lamprey was not detected, was estimated as:

$$(1)\ P(F|C_o) = \frac{P(C_o|F)\cdot P(F)}{P(C_o|F)\cdot P(F) + P(C_o|{\sim}F)\cdot P({\sim}F)},$$

where P(F) is the prior probability of larval lamprey presence. Although in this case we knew the lower Willamette River was occupied with larval lamprey, a P(F) of 0.5 (uninformed) was used for future study design (i.e., P[$F|C_o$]) in areas where larval lamprey presence is unknown. P(~F), or 1 – P(F), is the prior probability of species absence, and P($C_o|F$), or 1 – d, is the probability of not detecting a species when it occurs (C_0 = no detection; Peterson and Dunham 2003). Random identification of spatially-balanced sample units was achieved by using a generalized random-tessellation stratified (GRTS) approach to delineate sample units in an ordered, unbiased manner (Stevens and Olsen 2004).

Tributary (Wadeable Water) Sample Framework

Evaluation of larval lamprey occupancy of wadeable depth tributary habitats was conducted at restoration sites pre- and post-restoration. For each tributary habitat longer than 400 m, we developed a layer of 50 m-long sample reaches for subsampling. The GRTS approach was again used to delineate sample reaches in a random, spatially-balanced order (Stevens and Olsen 2004). The GRTS method assigns a hierarchical order to the reaches within the creek which is used as an unbiased method of ranking the priority of reaches for sampling. Delineation of sample reaches that are unbiased, randomly selected, and spatially-balanced within a sample universe allows for calculation of unit-specific detection probabilities. In turn, unit-specific estimates of detection probability can be applied to determine sample effort necessary for achieving a desired level of certainty that a tributary is not occupied by lamprey when they are not detected. As they are selected in the GRTS approach, the lower numbered reaches are given highest priority for sampling. Here we used a subsampling effort (number of sample reaches) that would allow for at least 80% certainty that larval lampreys do not occupy at least 20% of a tributary habitat when they were not detected (see Bayley and Peterson 2001; Peterson and Dunham 2003). The amount of effort was based, in part, on estimates of reach-specific detection probabilities generated from previous work (Silver et al. 2010; USFWS unpublished data). Sample effort was also dependent, in part, on total area. For wadeable depth tributaries, if the area of interest was less than 400 m in length, we sampled all reaches (contiguous 50 m reaches). If the area of interest was 400 m or longer, we sampled seven reaches.

Confluence and Shoreline (Deep Water) Sample Framework

Sample quadrats at confluence and shoreline habitats were derived from the work of Jolley et al. (2012). Quadrats were delineated using the generalized random-tessellation stratified (GRTS) approach scripted in Program R (Stevens and Olsen 2004; Jolley et al. 2012; R Core Team, 2013). The GRTS method assigns a hierarchical order to quadrats, which can be used as an unbiased method of ranking the priority of quadrats for sampling. Delineation of quadrats that are unbiased, randomly selected, and spatially-balanced within a sample universe allows for calculation of unit-specific detection probabilities. In turn, unit-specific estimates of detection probability can be applied to determine sample effort necessary for achieving a desired level of certainty that an area is not occupied by lamprey when they are not detected. Here we used a sampling effort (number of sample quadrats) that we estimated would allow for at least 80% certainty that larval lampreys do not occupy at least 20% of a confluence or shoreline habitat when they were not detected (see Bayley and Peterson 2001; Peterson and Dunham 2003). The amount of effort was based, in part, on estimates of quadrat-specific detection probabilities generated from previous work (Jolley et al. 2012). Sample effort was also dependent, in part, on total area. This sample effort corresponded to sampling of 10 quadrats at each confluence and/or shoreline habitat at both restoration and reference sites. In the case where slough habitat was deep and not wadeable, the sample framework described above was also applied to the slough (as a sample unit).

Restoration Sites

Alder Point (Slough, Confluence and Shoreline)

Confluence quadrats at the Alder Point site comprised a subset of quadrats filtered from the lower Willamette River and Multnomah Channel layers (described above). Quadrats were filtered from the larger layers according to the placement of a semicircular buffer of 100 m radius centered on each confluence of the Alder Slough and the Willamette River or Multnomah Channel (Figure 3). The three branches of Alder Slough each form a distinct confluence habitat at Alder Point, two occur on the Willamette River and one occurs on Multnomah Channel. In this case, the confluence quadrat selection process was duplicated at each of the three confluence habitats , resulting in 60 total sample quadrats at the three Alder Slough confluence habitats. At each of the three confluence locations, the 10 lowest numbered of each of the confluence quadrats as ordered by the GRTS method were assigned the highest priority for sampling.

Shoreline quadrats at the Alder Point site also comprised a subset of quadrats filtered from the lower Willamette River and Multnomah Channel layers (described above). Quadrats were filtered from the larger layers according to the placement of a 100 m-wide polygon, from the waterline perpendicular 100 m into the Willamette River or Multnomah Channel. The length of the shoreline polygon was determined by the project area boundaries (Figure 3). The shoreline quadrat selection process resulted in 117 total sample quadrats adjacent to restored shorelines at Alder Point. The 10 lowest numbered shoreline quadrats as ordered by the GRTS method were assigned the highest priority for sampling.

To evaluate larval lamprey occupancy of Alder Slough, a layer of 30 m x 30 m quadrats was developed and overlaid on the newly constructed channel at Alder Point (Figure 3). Using the GRTS approach, quadrats in Alder Slough were delineated in a random spatially-balanced manner. The lowest 10 numbered quadrats were assigned the highest priority for sampling.

Harborton (Tributary and Confluence)

At the Harborton restoration site (Figure 4), the sample effort will correspond to 10 confluence quadrats in each of three confluence habitats (30 total quadrats, to be done pre- and post-restoration). The sample effort will also correspond to seven, 50 m tributary reaches in the newly created northern tributary (post-restoration only). Sampling in the tributary is scheduled to begin in 2021.

Linnton (Tributary, Confluence and Shoreline)

At the Linnton restoration site (Figure 5), pre- and post-restoration sample effort will correspond to 10 confluence quadrats and 10 shoreline quadrates. Additionally, post-restoration there will be four tributary reaches, each 50 m in length, that will be sampled starting in 2021. These tributary reaches will sample the full extent of the newly created tributary habitat at the Linnton project site.

Triangle Park (Shoreline)

We propose to determine whether larval Pacific Lamprey occupy the restoration area both prior to and after piling removal. In this unique case, shoreline sample framework is being defined as the area 30 m around the line connecting the piling structures (see Figure 6). Pre- (and post-) restoration sample effort will correspond to 21 shoreline quadrats (25% of the total number of quadrats).

Rinearson Natural Area (Tributary and Confluence)

At the Rinearson Natural Area, Rinearson Creek forks into two distributary channels near the Willamette River creating two distinct confluence habitats in the restoration site. In this case, the confluence quadrat selection process was carried out as described above at Alder Point, and duplicated at each of the two distinct confluence habitats (Figure 7). The selection process resulted in 34 total sample quadrats at the two confluence habitats. At each of the two confluence locations, the lowest numbered quadrats as ordered by the GRTS method were assigned the highest priority for sampling. Evaluation of larval lamprey occupancy in Rinearson Creek post-restoration is proposed to occur over an approximately 1,200 m long segment of creek, spanning from the confluence with the Willamette River upstream to the crossing of River Road (Milwaukie, OR; Figure 7). Sample reaches were delineated at a rate of one 50 m reach for every 50 m of stream. Thus, within the approximately 1,200 m long study area in Rinearson Creek, 24 sample reaches were delineated, of which the lowest numbered reaches, as ordered by the GRTS method, were assigned the highest priority for sampling. Because the area of interest in Rinearson Creek was longer than 400 m, sampling effort will correspond to seven, 50 m-long reaches in the creek.

PGE 13.1 (Shoreline)

To evaluate larval lamprey occupancy of PGE 13.1, a layer of 30 m x 30 m quadrats was developed and overlaid on the restoration area (shoreline polygon) at PGE 13.1 (Figure 8). Using a GRTS approach, quadrats at PGE 13.1 were delineated in a random spatially-balanced manner. The lowest 10 numbered quadrats were assigned the highest priority for sampling.

Reference Sites

Multnomah Channel (Shoreline)

The Multnomah Channel reference site contains shoreline habitat (Figure 9). The quadrat selection process was carried out as described above for shorelines at Alder Point. The length of the shoreline was modeled after that of restoration sites. The 10 lowest numbered shoreline quadrats as ordered by the GRTS method were again assigned the highest priority for sampling.

McCarthy Creek (Confluence and Shoreline)

The McCarthy Creek reference site has tributary, confluence and shoreline habitats (Figure 10). Upon visiting the site we discovered that the tributary did not contain a reasonable amount of Type I habitat and the tributary sites were removed from the sampling design. In McCarthy Creek confluence habitat within the Multnomah Channel, quadrat selection was carried out as described above for confluences at Alder Point. The 10 lowest numbered confluence quadrats as ordered by the GRTS method were again assigned the highest priority for sampling. In shoreline habitat within the mainstem Multnomah Channel, quadrat selection was carried out as described above for shoreline habitat at Alder Point. The 10 lowest numbered shoreline quadrats as ordered by the GRTS method were again assigned the highest priority for sampling.

Columbia Slough (Confluence)

The Columbia Slough reference site contains confluence habitat within the mainstem Willamette River. The confluence quadrat selection was carried out as described above for confluences at Alder Point. The 10 lowest numbered confluence quadrats as ordered by the GRTS method were again assigned the highest priority for sampling (Figure 11).

Ross Island (Shoreline)

The Ross Island reference site contains shoreline habitat. The quadrat selection process was carried out as described above for shorelines at Alder Point. The length of the shoreline was modeled after that of restoration sites. The 10 lowest numbered shoreline quadrats as ordered by the GRTS method were again assigned the highest priority for sampling (Figure 12).

Cemetery Creek (Confluence and Shoreline)

The Cemetery Creek reference site has confluence and shoreline habitats. Though there is a tributary at the site, there was not adequate Type I habitat and the sites were removed from the reference sample design. For confluence habitat within the mainstem Willamette River, quadrat selection was carried out as described above for confluences at Alder Point. The 10 lowest numbered confluence quadrats as ordered by the GRTS method were again assigned the highest priority for sampling. For shoreline habitat within the mainstem Willamette River, quadrat selection was carried out as described above for shoreline habitat at Alder Point. The 10 lowest numbered shoreline quadrats as ordered by the GRTS method were again assigned the highest priority for sampling (Figure 13).

Oswego Creek (Confluence and Tributary)

The Oswego Creek reference site contains confluence habitat within the mainstem Willamette River. The confluence quadrat selection was carried out as described above for confluences at Alder Point. The 10 lowest numbered confluence quadrats as ordered by the GRTS method were again assigned the highest priority for sampling (Figure 14). The Oswego Creek reference site also has tributary habitat. In Oswego Creek, the tributary area of interest was less than 400 m in length. The area spanned from the confluence with the Willamette River upstream approximately 370 m to a reach with significant private ownership. Because the area of interest was not more than 400 m in length, we attempted to sample all viable reaches (contiguous 50 m reaches) in Oswego Creek up to a total of 350 m (the most downstream 350 m in Oswego Creek).

Miller Creek (Tributary)

Miller Creek has tributary habitat (Figure 15). In Miller Creek, the tributary area of interest was less than 400 m in length, spanning from the confluence with the Multnomah Channel upstream approximately 350 m to a high gradient reach with significant private ownership. Because the area of interest was not more than 400 m in length, we attempted to sample all viable reaches (contiguous 50 m reaches) in Miller Creek up to a total of 350 m (the most downstream 350 m in Miller Creek).

Reach Sampling in Wadeable Water Habitats

For wadeable depth tributary (or slough) habitats, each sampling event consisted of electrofishing 50 m reaches to determine if larval lamprey were present (Silver et al. 2010). Sample reaches were accessed on foot using GPS units loaded with sample reach UTMs for navigation. When a reach could not be sampled due, for example, to dewatered conditions, excessive depth (e.g. > 2 m), or lack of access due to private property, they were eliminated and subsequent reaches were increased in priority. Once a sample reach was accessed, a 50 m segment was measured and flagged. Water temperature and conductivity were recorded in each reach. The reach was electrofished using an AbP-2 backpack electrofisher. Power output settings for the AbP-2 were adapted from Weisser and Klar (1990). Initially, the electrofisher delivered three DC pulses per second at 25% duty cycle, 125 V, with a 3:1 burst pulse train (i.e., three pulses on, one pulse off). This current is designed to stimulate burrowed larvae to enter the water column. Once a larva was observed in the water column, 30 pulses/second were occasionally applied to temporarily immobilize the larva for capture in a net. We spent relatively more time (approximately 30 seconds/m^2) within each reach electrofishing areas of preferred larval lamprey rearing habitat where depositional silt and sand substrates were dominant (henceforth Type I habitat, Slade et al. 2003). Relatively less time (approximately 5 seconds/m^2) was spent electrofishing areas with relatively large gravel, hard bedrock and boulder substrates (henceforth Type II and type III habitats, Slade et al. 2003). All larval lamprey observed were captured and placed in buckets containing stream water.

Quadrat Sampling in Deep Water Habitats

For deep water habitats, each sampling event consisted of a single drop with deepwater electrofishing equipment within the 30 x 30 m quadrat (Bergstedt and Genovese 1994; Jolley et al. 2012). Quadrats were accessed and sampled by boat, using quadrat center point in Universal Transverse Mercator (UTM) coordinates for navigation. When quadrats could not be sampled due, for example, to dewatered conditions, depth less than 0.3 m, excessive velocity, or excessive depth (>21 m) they were eliminated and subsequent quadrats were increased in priority (Table 1). The deepwater electrofisher was comprised of a modified AbP-2 electrofisher (ETS Engineering, Madison, WI) which delivered electrical stimulus to river bottom substrates at electrodes mounted to a fiberglass bell (or hood; 0.61 m^2 in area). The electrofisher delivered three pulses DC per second at 10% duty cycle, with a 2:2 pulse train (i.e., two pulses on, two pulses off). Output voltage was adjusted at each quadrat to maintain a peak voltage gradient between 0.6 and 0.8 V/cm across the electrodes. The electrofisher bell was coupled by a 76 mm vinyl suction hose to a gasoline-fueled hydraulic pump. The hydraulic pump was started approximately 5 seconds prior to shocking to purge air from the suction hose. Suction was produced by directing flow from the pump through a hydraulic eductor, which allows larvae to be collected in a mesh basket (27 x 62 x 25 cm; 2 mm wire mesh) while preventing them from passing through the pump. A 60 second pulse delivery was followed by an additional 60 seconds of pumping to further allow displaced larvae to cycle through the hose and into the collection basket. The sampling techniques are described in detail by Bergstedt and Genovese (1994) and were similar to those used in the Great Lakes region (Fodale et al. 2003) and the Willamette River (Jolley et al. 2012).

Biological Data Collection

Collected lamprey were measured for total length (TL in mm; total weight was not measured), classified according to developmental stage (i.e., larvae, juvenile, or adult), and when possible (i.e., when larvae > 60 mm TL; Goodman et al. 2009, Docker et al 2016) identified to genus (i.e., *Entosphenus* [Pacific Lamprey] or *Lampetra* [Western Brook or River Lamprey]) according to visual evaluations of caudal fin pigmentation patterns. Larvae were released near the area of capture. Physical anomalies (lesions, suspected bird strikes, tumors, etc.) were recorded for all larvae. If abnormalities were observed on a larva, the individual was euthanized and preserved for potential evaluation at a later date. In addition, observations of juveniles, adults, or suspected Pacific Lamprey nests were also recorded.

Habitat Data Collection

Tributary

Within each sample reach, water temperature (°C) and conductivity (µS/cm) were measured. The proportion (%) of Type I burrowing substrate within each reach was estimated. In general, larval lamprey habitats are classified as Type I, II, or III, and it is widely accepted that larvae appear to prefer Type I habitat the most and Type III the least (see Slade et al. 2003). Non-sediment habitat variables are presented as mean (± SE) unless otherwise noted.

Confluence and Shoreline

Concurrent to each sampling event a sediment sample was taken (when possible) from each quadrat with a Ponar bottom sampler (16.5 cm x 16.5 cm). Each sample was mixed thoroughly and one 250-500 ml subsample was transferred to containers provided by a contracted laboratory. Samples were labeled with the site number and date, placed on ice, returned to the USFWS office, and subsequently handled per the instructions provided from the contracted laboratory. Sediment samples collected at each confluence quadrat were transferred to ALS Environmental Laboratory (Kelso, WA) for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses. Water depth was measured at each quadrat are presented as mean (± SE) unless otherwise noted. Beginning in 2018, water temperature (°C) and conductivity (μS/cm) were recorded at each site on the sample day (in previous years, these data were recorded at each quadrat).

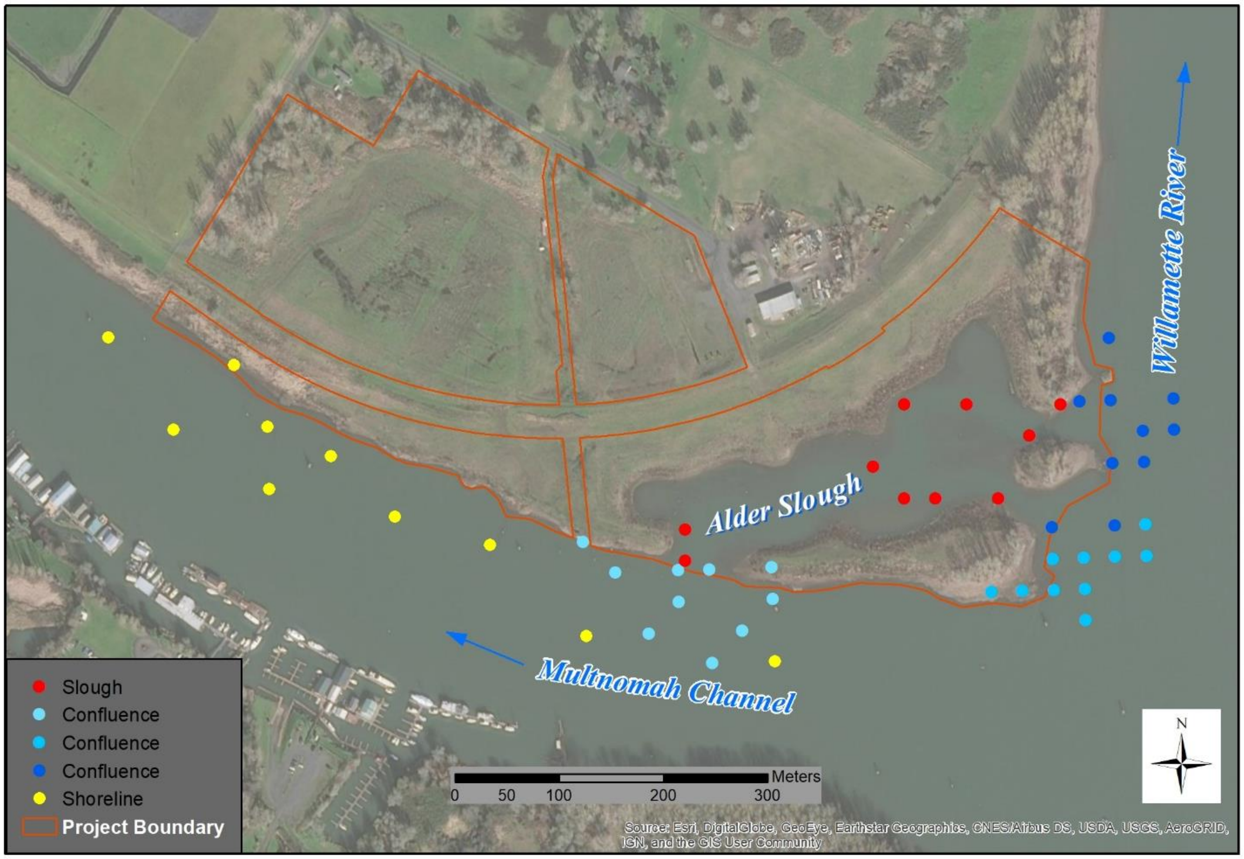

Figure 3. Alder Point restoration site sample sites. Habitats within the sites are confluence quadrats (blue points; each point represent a quadrat center point), shoreline quadrats (yellow points), and slough quadrats (red points).

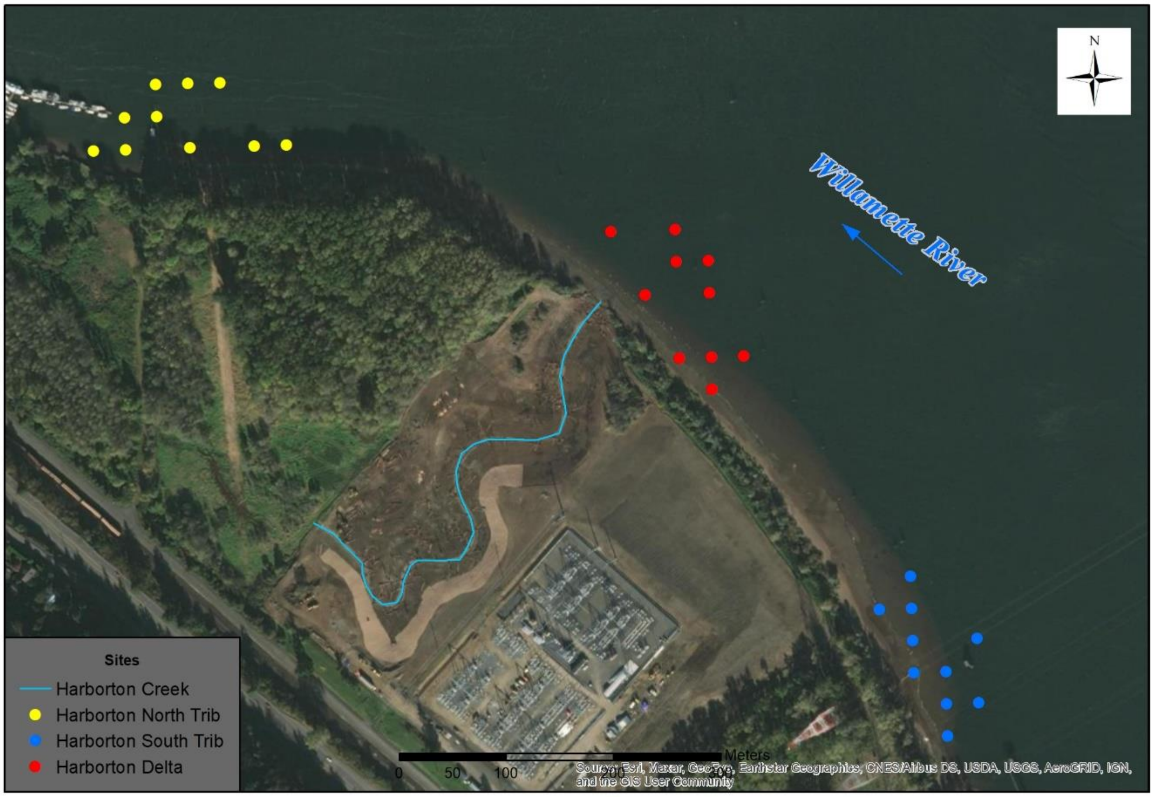

Figure 4. Harborton restoration sample sites with North Tributary quadrats (yellow points), South Tributary quadrats (blue points), and confluence quadrats (red points).

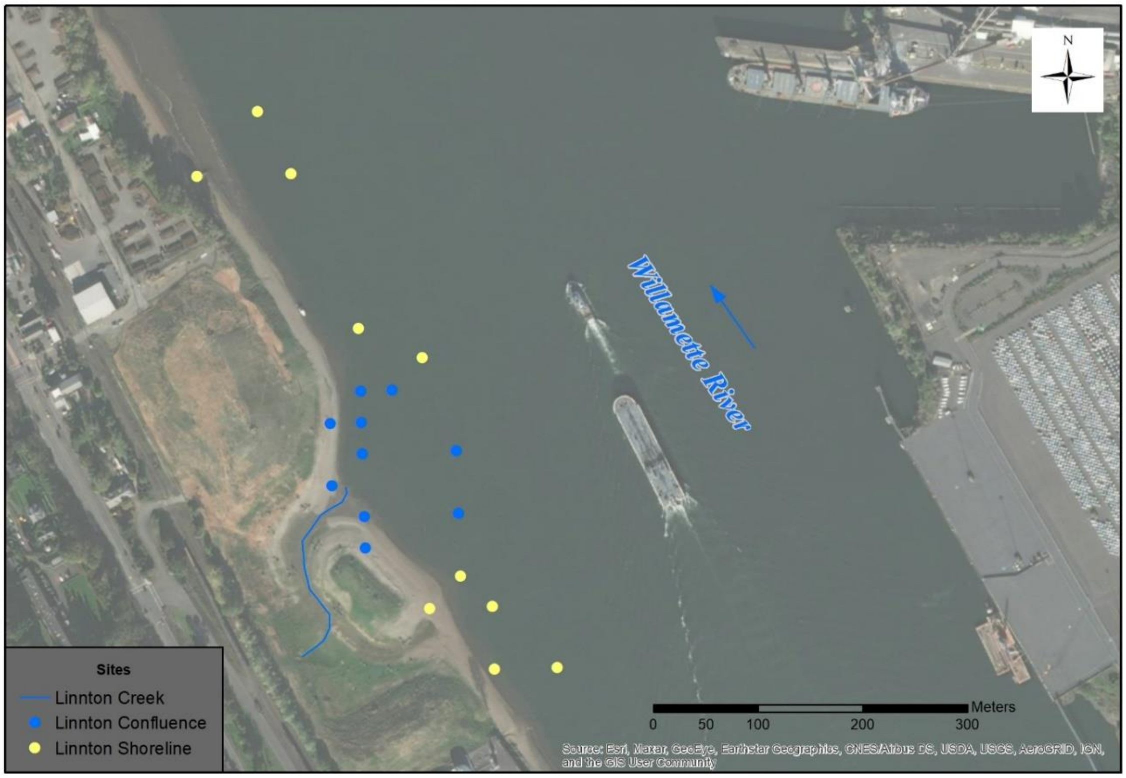

Figure 5. Linnton restoration site with shoreline quadrats (yellow points) and confluence quadrats (blue points).

Figure 6. Triangle Park restoration site with shoreline quadrats (yellow points).

Figure 7. Rinearson Natural Area restoration site with confluence quadrats (blue points) and tributary sample reaches (red points).

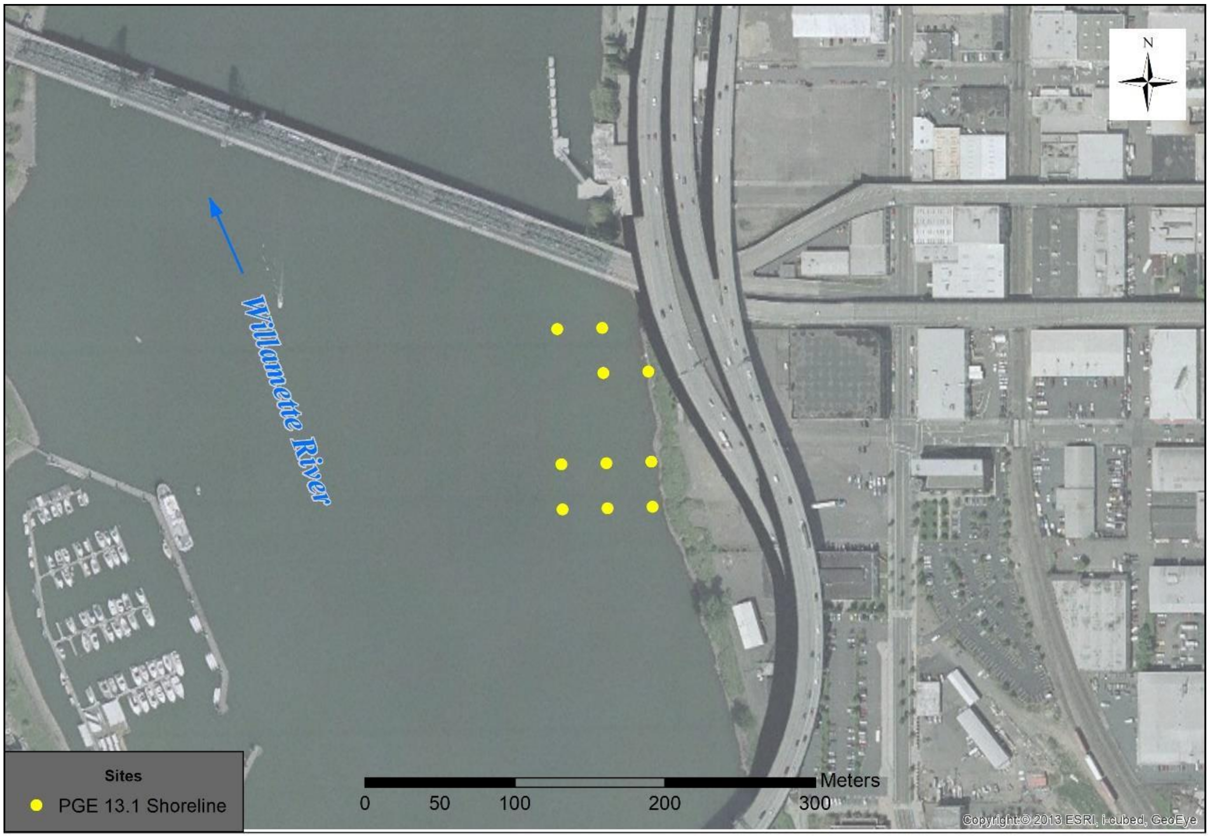

Figure 8. PGE 13.1 restoration site with shoreline quadrats (yellow points).

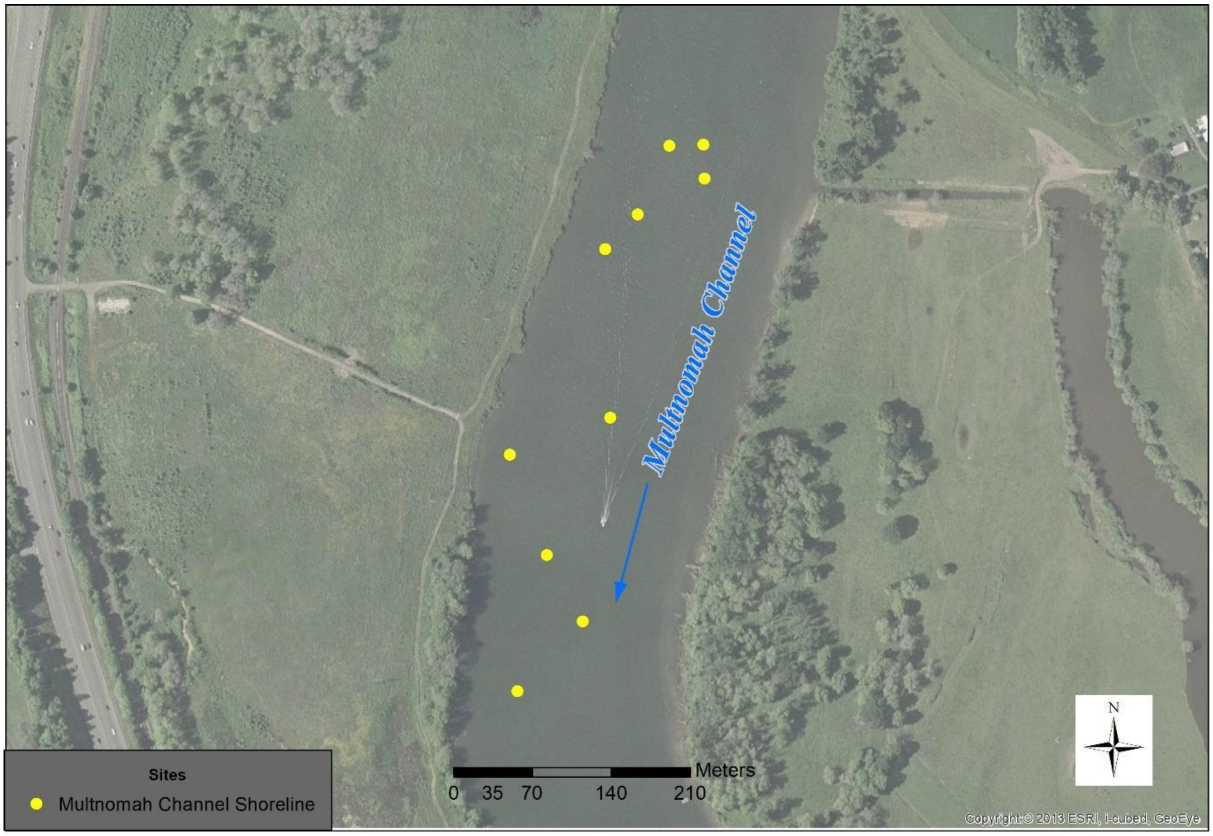

Figure 9. Multnomah Channel reference site with shoreline quadrats (yellow points).

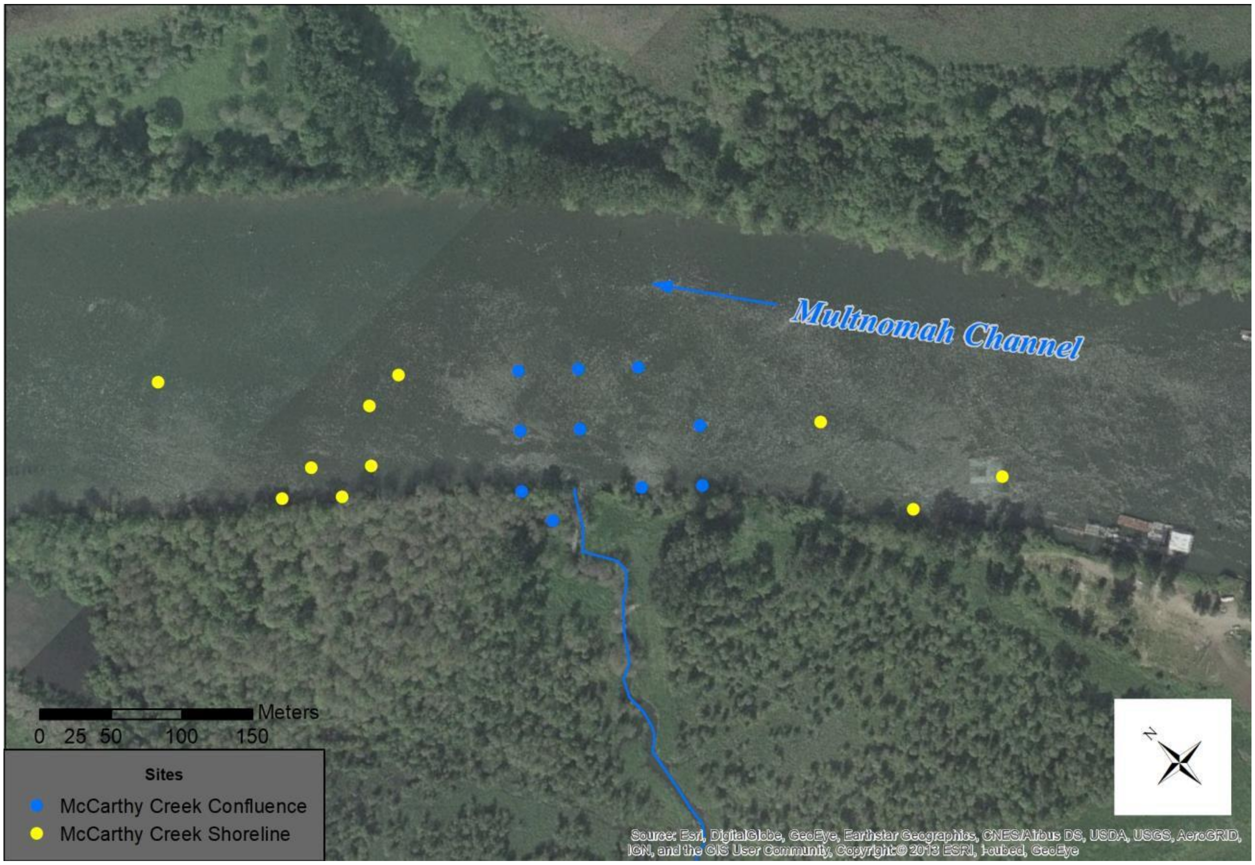

Figure 10. McCarthy Creek reference site with confluence quadrats (blue points) and shoreline quadrats (yellow points).

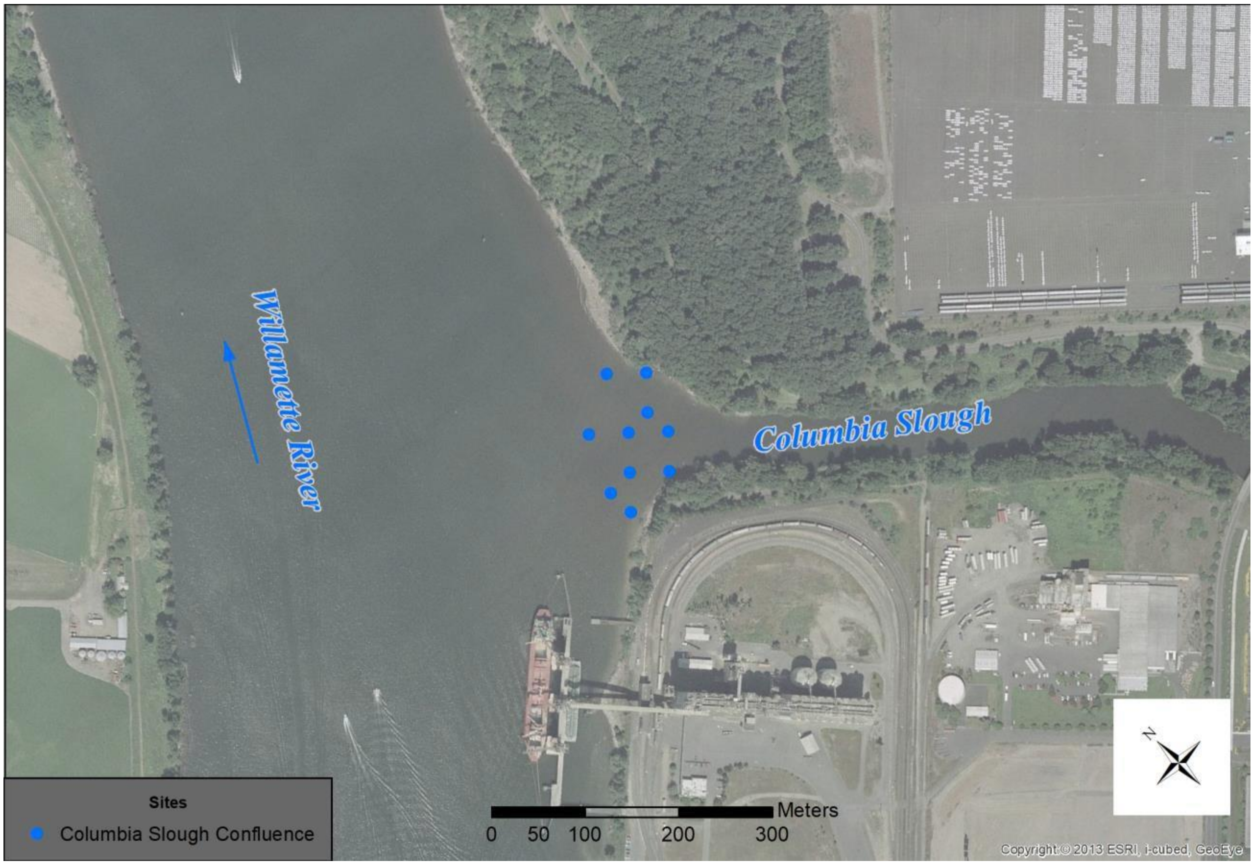

Figure 11. Columbia Slough reference site confluence quadrats (blue points).

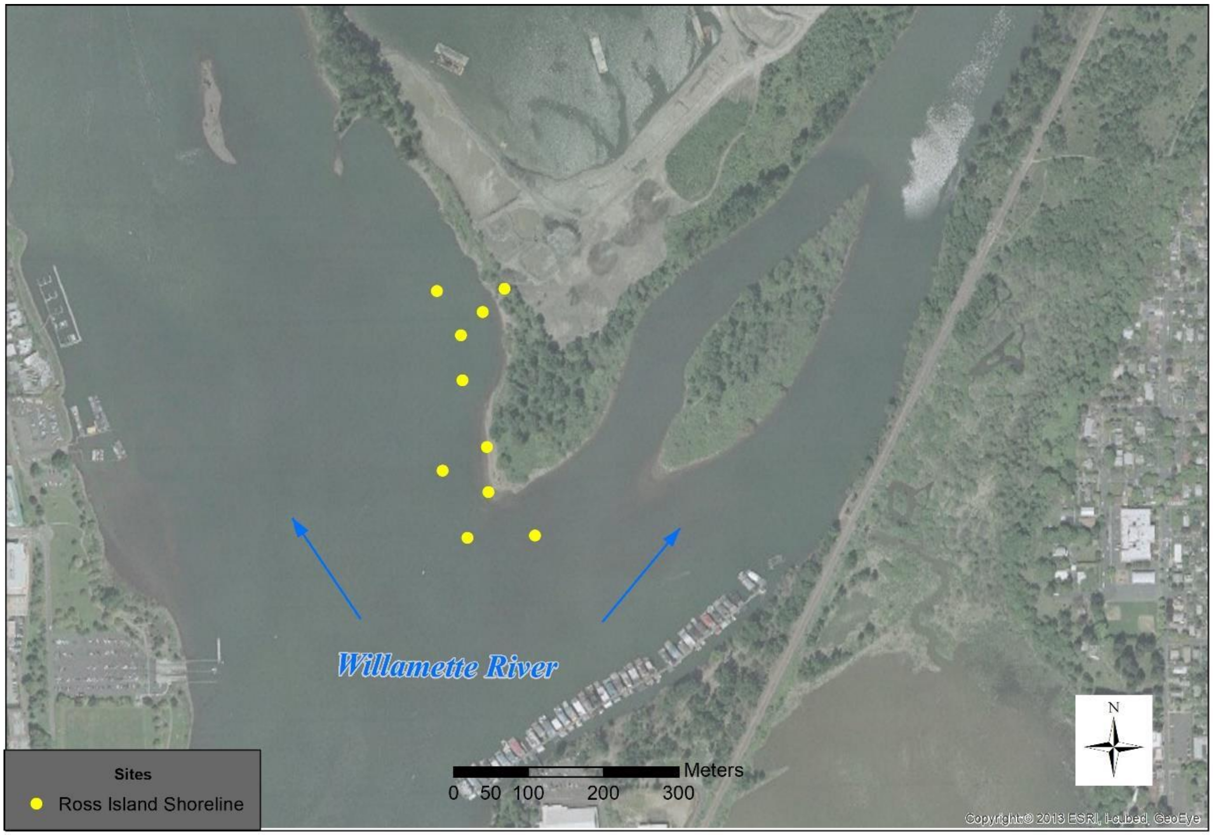

Figure 12. Ross Island reference site shoreline quadrats (yellow points).

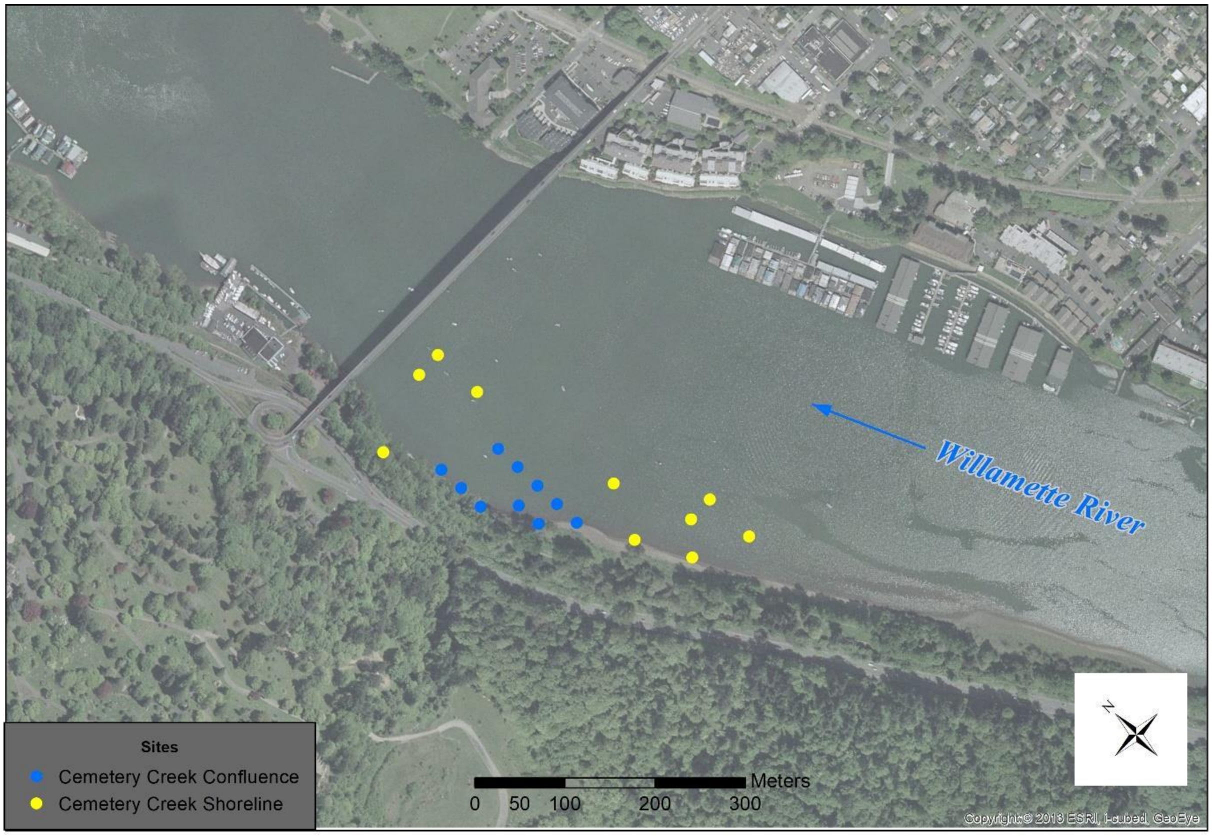

Figure 13. Cemetery Creek reference site with confluence (blue points) and shoreline (yellow points).

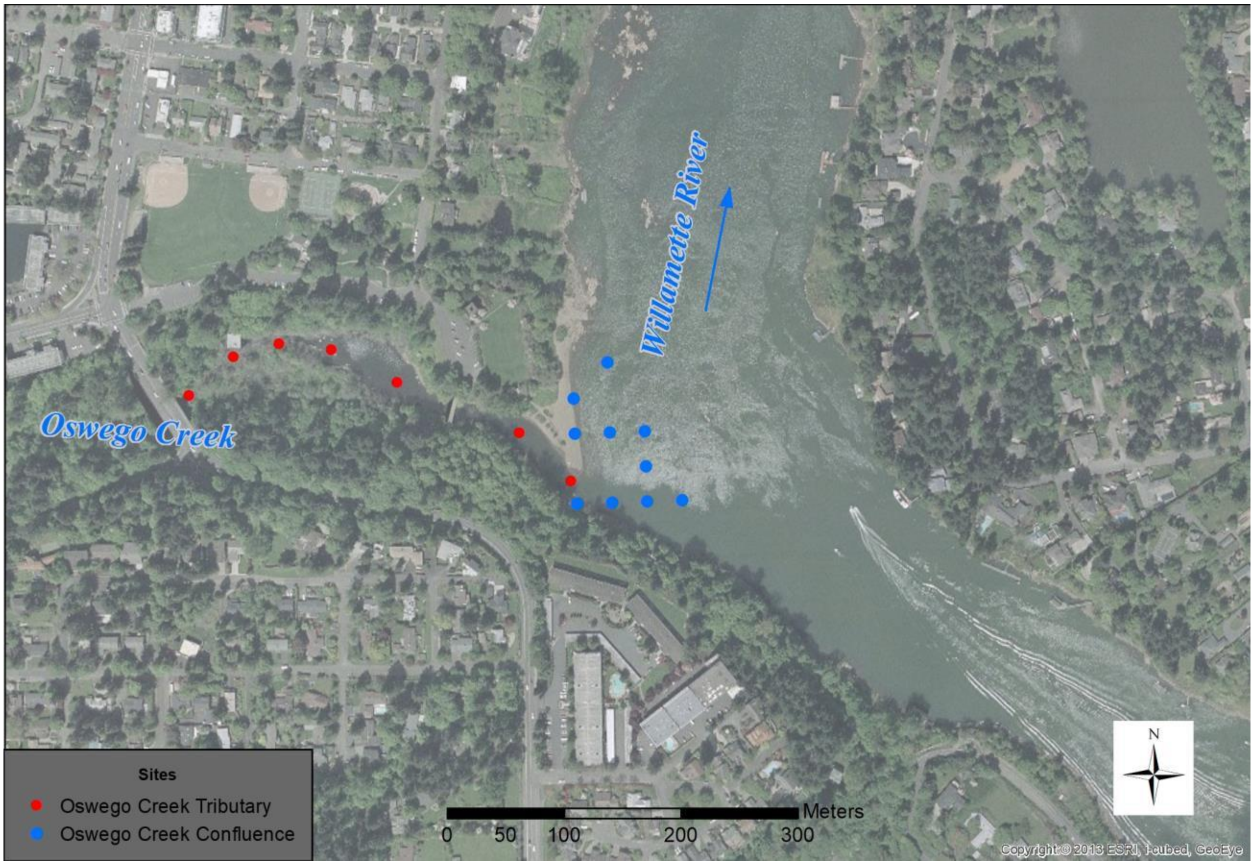

Figure 14. Oswego Creek reference site confluence quadrats (blue points) and tributary sample reaches (red).

*

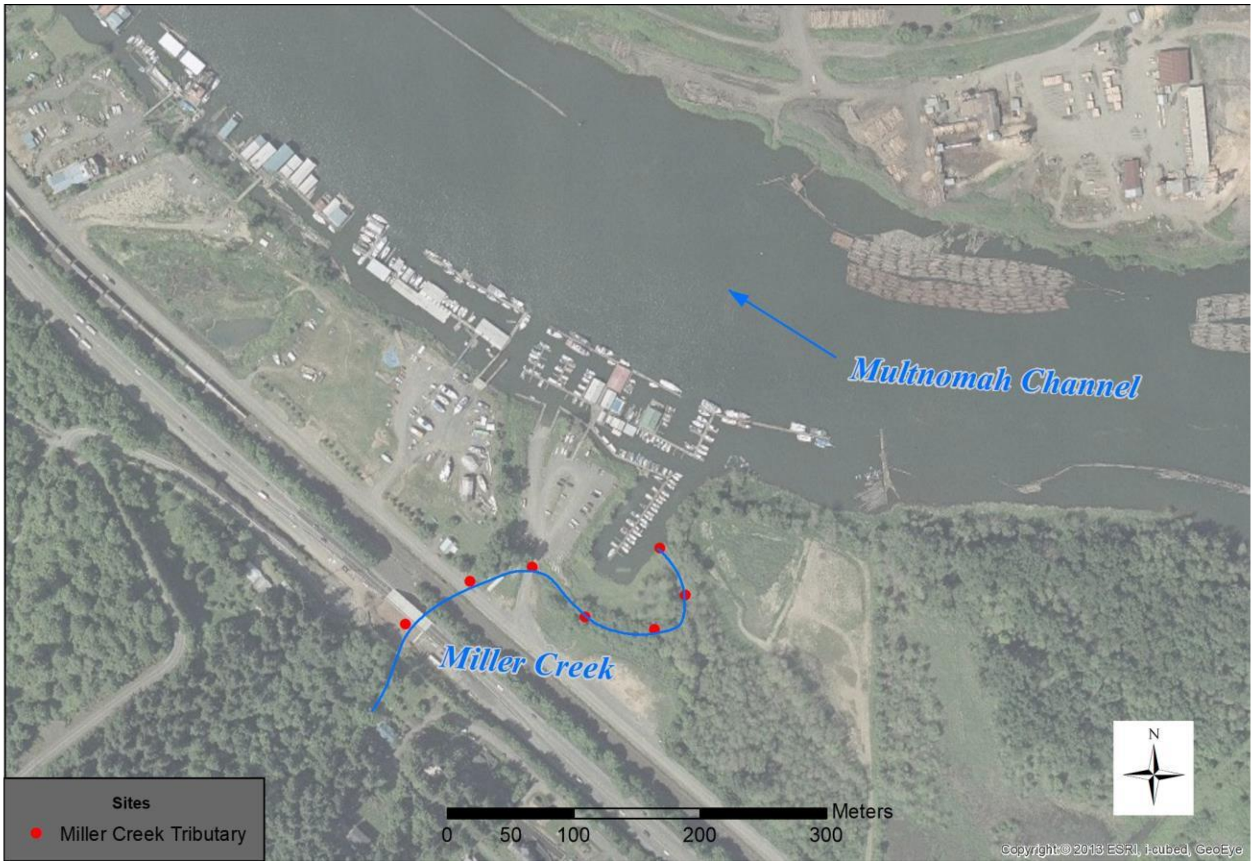

Figure 15. Miller Creek tributary sample reaches (red points).

Results

All lamprey collected at restoration sites were of the larval life stage. No detections of juveniles or evidence of adults (e.g., live adults, spawning nests) occurred. All larvae collected appeared healthy based on visual observation of external features, no abnormalities or indications of disease or poor health were observed. Lamprey identification and length measurements are summarized in Table 1 and site-specific depth, temperature, and conductivity are summarized in Table 2**.**

Restoration Sites

Alder Point Restoration Site

No larval lamprey were detected in the 30 confluence quadrats, the 10 shoreline quadrats, or 10 slough quadrats (d = 0.00, Table 1, Figure 3). At the confluence site, depth ranged from 0.3 to 10.8 m (Table 2). Water temperature was 17.1 – 19.4°C and conductivity was 67.3 - 73.8 μS/cm. Samples were collected 2 October 2020. At the shoreline site, depth ranged from 0.6 to 11.3 m. Water temperature was 17.0°C and 70.2 μS/cm. Sampling was conducted on 2 October 2020. At the slough site, depth ranged from 0.4 to 2.1 m. Water temperature was 16.9°C and 90.6 μS/cm. Sampling was conducted on 6 October 2020.

Harborton Restoration Site

This site was not sampled in 2020 (Figure 4).

Linnton Restoration Site

No lamprey were detected in the 10 confluence quadrats and 10 shorelines quadrats sampled (d = 0.00, Table 1, Figure 5). At the confluence site, depths ranged from 0.3 to 9.1 m (Table 2). Water temperature was 16.9°C and conductivity was 67 μS/cm. Samples were collected 7 October 2020. At the shoreline site, depth ranged from 0.4 to 11.1 m. Water temperature was 17.1°C and 66.5 μS/cm. Sampling was conducted on 7 October 2020.

Triangle Park Restoration Site

This site was not sampled in 2020 (Figure 6).

Rinearson Natural Area (Confluences and Tributary)

Larval lamprey (n = 3) were detected in one of 10 confluence quadrats (d = 0.10, Table 1, Figure 7). Lamprey (n = 1) were detected in one of seven tributary reaches available to sample (d = 0.14, Table 1). The maximum number of larvae occupying any individual quadrat was three. At the confluence site, species composition included Pacific Lamprey (n = 1, TL = 72 mm) and unidentifiable (less than 60 mm TL) lamprey (n = 2, TL = 29 - 55 mm). Sample depths ranged from 0.4 m to 6.0 m (Table 2). Larvae were detected at depth 0.9 m. Water temperature was 15.4°C and conductivity was 58.3 μS/cm. Sampling was conducted on 9 October 2020. At the tributary site, species composition was Pacific Lamprey (n = 1, TL = 84 mm), which was sampled at a depth of 0.1m roughly 60 m upstream from the mouth of the tributary. The depths ranged from 0.1 to 0.5 m (Table 2). Water temperature was 11.4°C and conductivity was 142.2 μS/cm. Sampling was conducted on 30 October 2020.

PGE 13.1 Restoration Site

This site was not sampled in 2020 (Figure 8).

Reference Sites

All lamprey collected at reference sites were of the larval life stage except one transforming *Lampetra spp.* sampled at Miller Creek. No other detections of juveniles or evidence of adults (e.g., live adults, spawning nests) occurred. All larvae collected appeared healthy based on visual observation of external features, with the exception of one lamprey (27 mm) at Cemetery Creek Confluence that had a kinked notochord. Otherwise, no abnormalities or indications of disease or poor health were observed.

Multnomah Channel (Shoreline)

This site was not sampled in 2020 (Figure 9).

McCarthy Creek (Confluence and Shoreline)

No lamprey were detected in the 10 confluence quadrats sampled or 10 shoreline quadrats sampled (d = 0.00, Table 1, Figure 10). Sample depths at the confluence sites ranged from 0.3 to 11.2 m and at the shoreline site depths ranged from 0.3 to 10.6 m (Table 2). At the confluence site, water temperature was 17.4°C and conductivity was 78.7 μS/cm. Sampling occurred on 30 September 2020. At the shoreline site, water temperature was 17.1°C and conductivity was 77.9 μS/cm. Sampling occurred on 6 October 2020.

Columbia Slough (Confluence)

Larval lamprey (n = 2) were detected at two of 10 confluence quadrates sampled (d = 0.20, Table 1, Figure 11). Both lamprey were too small to identify to species (n = 2, TL = 28-30 mm). Sample depths ranged from 0.1 to 3.1 m (Table 2). Lamprey were detected at 0.6 to 3.1 m depths. Water temperature was 17.8°C and conductivity was 115.6 μS/cm. Sampling occurred on 6 October 2020.

Ross Island (Shoreline)

No lamprey were detected at the 10 confluence quadrats sampled (d = 0.00, Table 1, Figure 12). Sample depths ranged from 0.6 to 11.7 m (Table 2). Water temperature was 16.3°C and conductivity was 58.9 μS/cm. Sampling occurred on 8 October 2020.

Cemetery Creek (Confluence and Shoreline)

Larval lamprey were detected in one of 10 confluence quadrats (n = 4, d=0.10) and at four of 10 shoreline quadrats sampled (n = 8, *d* = 0.40, Table 1, Figure 13). The maximum number of larvae occupying any individual quadrat was four. Species composition included unidentifiable (less than 60 mm TL) lamprey (n = 7, TL = 25-59 mm), Pacific lamprey (n=1, TL = 70 mm) and *Lampetra spp.* (n = 4, TL = 54-80 mm). One of the unidentified lamprey (TL = 27) had a kink in the notochord. This deformity has been observed in other parts of the region and is potentially not a permanent condition. For the confluence site, sample depths ranged from 0.4 to 5.8 m and all lamprey were captured at 5.8 m depth (Table 2). The temperature was 16.5°C and conductivity was 57.6µS/cm. At the shoreline site, sample depths ranged from 0.9 to 8.2 m. Larvae were detected at depths from 4.1-8.2 m. Water temperature was 16.2°C and conductivity was 56.0 μS/cm. Sampling occurred on 8 October 2020 for both sites.

Oswego Creek (Confluence and Tributary)

Larval lamprey (n = 2) were detected at two of 10 confluence quadrats sampled (*d* = 0.20; Table 1, Figure 14). Species composition included Pacific Lamprey (n = 1, TL = 82 mm) and *Lampetra spp.* (n = 1, TL = 72 mm). Sample depths ranged from 0.7 to 9.2 m (Table 2). Larvae were detected at depths 0.9 m to 3.0 m. Water temperature was 15.7°C and conductivity was 57.7 μS/cm on 9 October 2020. Larval lamprey (n = 2) were detected at two of seven tributary reaches (*d* = 0.29; Table 1). Species composition included Pacific Lamprey (n = 1, TL = 102 mm) and *Lampetra spp.* (n = 1, TL = 94 mm). Measured sample depths ranged from 0.1 – 0.9 m (Table 2). In two of the reaches, large pools were too deep to get depth measurements. Larvae were detected at depths of 0.8 m. Water temperature was 13.1°C and conductivity was 129.4 μS/cm. For the sites assessed, Type I habitat ranged from 2 to 85%. The lamprey that were sampled were detected in reaches that both had 40% Type I habitat. Sampling occurred on 30 October 2020.

Miller Creek (Tributary)

Larval lamprey (n = 34) were detected at five of six tributary reaches sampled (*d* = 0.83; Table 1, Figure 15). The maximum number of larvae collected in an individual reach was 13. Species composition included *Lampetra spp.* (n = 24, TL = 54-144 mm) and unidentifiable (less than 60 mm TL) lamprey (n = 10, TL = 20-52 mm). One *Lampetra spp*. transformer was sampled (TL = 140). Sample depths ranged from 0.17 to 0.55 m (Table 2). Larvae were detected at depths 0.17 m to 0.55 m. Water temperature was 9.0°C and conductivity was 73.7 μS/cm. One reach was not sampled due to the inability of the crew to access the water through the dense brush. Sampling occurred on 23 October 2020.

Table 1. In 2020, total number of quadrats visited, sampled, occupied by larval lamprey, and corresponding larval lamprey detection probability (*d*). Small (i.e., less than 60 mm TL) larvae cannot be accurately identified and are classified as unidentified (UNID).

Site Type	Site		Visited	Sampled	Occupied	*d*	Pacific Lamprey *N*	Pacific Lamprey TL(mm) Range	*Lampetra spp.* *N*	*Lampetra spp.* TL(mm) Range	Unidentified *N*	Unidentified TL(mm) Range	Total *N*
Restoration	Alder Point	Confluence	30	30	0	0.00	0	-	0	-	0	-	0
		Shoreline	10	10	0	0.00	0	-	0	-	0	-	0
		Slough	10	10	0	0.00	0	-	0	-	0	-	0
	Linnton	Confluence	10	10	0	0.00	0	-	0	-	0	-	0
		Shoreline	10	10	0	0.00	0	-	0	-	0	-	0
	Rinearson	Confluence	10	10	1	0.10	1	72	0	-	2	29-45	3
		Tributary	7	7	1	0.14	1	84	0	-	0	-	1
Reference	Cemetery Creek	Confluence	10	10	1	0.10	0	-	3	62-80	1	27	4
		Shoreline	10	10	4	0.40	1	70	1	54	6	25-59	8
	Columbia Slough	Confluence	10	10	2	0.20	0	-	0	-	2	28-30	2
	McCarthy Creek	Confluence	10	10	0	0.00	0	-	0	-	0	-	0
		Shoreline	10	10	0	0.00	0	-	0	-	0	-	0
	Miller Creek	Tributary	7	6	5	0.83	0	-	24	54-144	10	20-52	34
	Oswego Creek	Confluence	10	10	2	0.20	1	82	1	72	0	-	2
		Tributary	7	7	2	0.29	1	102	1	94	0	-	2
	Ross Island	Shoreline	10	10	0	0.00	0	-	0	-	0	-	0

Table 2. In 2020, habitat variables measured at restoration and reference sites. Capture depth range is the minimum and maximum depths at which lamprey were captured. Sediment collection was transferred to ALS Environmental Laboratory (Kelso, WA).

Site Type	Site		2020 Date Sampled	Capture Depth (m), range	Sample Depth (m), range	Temperature (°C)	Conductivity (µS/cm)	Sediment Collected?
Restoration	Alder Point	Confluence 1-3	6-Oct	-	0.3-10.8	17.1-19.4	67.3-73.8	Yes
		Shoreline	6-Oct	-	0.6-11.3	17.0	70.2	Yes
		Slough	6-Oct	-	0.4-2.1	16.9	90.6	Yes
	Linnton	Confluence	7-Oct	-	0.3-9.1	16.9	67.0	Yes
		Shoreline	7-Oct	-	0.4-11.1	17.1	66.5	Yes
	Rinearson	Confluence	9-Oct	0.9	0.4-6	15.4	58.3	Yes
		Tributary	30-Oct	0.1	0.1-.5	11.4	142.2	Yes
Reference	Cemetery Creek	Confluence	8-Oct	5.8	0.4-5.8	16.5	57.6	Yes
		Shoreline	8-Oct	4.1-8.2	0.9-8.2	16.2	56.0	Yes
	Columbia Slough	Confluence	6-Oct	0.6-3.1	0.1-3.1	17.8	115.6	Yes
	McCarthy Creek	Confluence	6-Oct	-	0.-11.2	17.4	78.7	Yes
		Shoreline	6-Oct	-	0.3-10.6	17.1	77.9	Yes
	Miller Creek	Tributary	23-Oct	0.17-0.55	0.17-0.55	9.0	73.7	No
	Oswego Creek	Confluence	9-Oct	0.9-3.0	0.7-9.2	15.7	57.7	No
		Tributary	3-Oct	0.8	0.1-0.9	13.1	129.4	Yes
	Ross Island	Shoreline	9-Oct	-	0.6-11.7	16.3	58.9	Yes

Table 3. Occupancy results from sampling at restoration and reference sites across all sampling years (pre and post restoration actions). Total number of quadrats visited, sampled, occupied by larval lamprey, and corresponding larval lamprey detection probability (*d*). Small (i.e., less than 60 mm TL) larvae cannot be accurately identified and are classified as unidentified (UNID).

					Quadrats						
Site Type	Site		Year	Status	Visited	Sampled	Occupied	*d*	Pacific Lamprey	*Lampetra* spp.	UNID	Total N
Restoration	Alder Point	Confluence 1-3	2016	Post Yr 1	30	30	1	0.03	0	0	1	1
			2017	Post Yr 2	30	30	1	0.03	0	0	1	1
			2018	Post Yr 3	30	30	1	0.03	0	0	1	1
			2019	Post Yr 4	30	30	2	0.07	0	1	1	2
			2020	Post Yr 5	30	30	0	0.00	0	0	0	0
		Shoreline	2014	Pre Yr 1	30	29	2	0.07	0	3	0	3
			2016	Post Yr 1	10	10	1	0.10	0	1	0	1
			2017	Post Yr 2	10	10	1	0.10	1	0	1	2
			2018	Post Yr 3	10	10	0	0.00	0	0	0	0
			2019	Post Yr 4	10	10	0	0.00	0	0	0	0
			2020	Post Yr 5	10	10	0	0.00	0	0	0	0
		Slough	2016	Post Yr 1	10	10	0	0.00	0	0	0	0
			2017	Post Yr 2	10	10	0	0.00	0	0	0	0
			2018	Post Yr 3	10	10	0	0.00	0	0	0	0
			2019	Post Yr 4	10	10	0	0.00	0	0	0	0
			2020	Post Yr 5	10	10	0	0.00	0	0	0	0
	Harborton	Confluence	2017	Pre Yr 1	10	10	1	0.10	0	0	2	2
		North Tributary	2017	Pre Yr 1	10	10	1	0.10	0	1	0	1
		South Tributary	2017	Pre Yr 1	10	10	0	0.00	0	0	0	0
	Linnton	Confluence	2017	Pre Yr 1	10	10	0	0.00	0	0	0	0
		Confluence	2020	Post Yr 1	10	10	0	0.00	0	0	0	0
		Shoreline	2017	Pre Yr 1	10	10	0	0.00	0	0	0	0
		Shoreline	2020	Post Yr 1	10	10	0	0.00	0	0	0	0

Table 3. Continued.

Site Type	Site		Year	Status	Quadrats Visited	Quadrats Sampled	Quadrats Occupied	*d*	Pacific Lamprey	*Lampetra* spp.	UNID	Total N
Restoration	Triangle	Shoreline	2017	Pre Yr 1	21	21	0	0.00	0	0	0	0
Restoration	Rinearson	Confluence	2015	Pre Yr 1	13	10	3	0.30	3	0	3	6
Restoration	Rinearson	Confluence	2019	Post Yr 1	10	10	3	0.30	1	0	3	4
Restoration	Rinearson	Confluence	2020	Post Yr 2	10	10	1	0.10	1	0	2	3
Restoration	Rinearson	Tributary	2015	Pre Yr 1	-	7	1	0.14	3	0	0	3
Restoration	Rinearson	Tributary	2019	Post Yr 1	6	4	0	0.00	0	0	0	0
Restoration	Rinearson	Tributary	2020	Post Yr 2	7	7	1	0.14	1	0	0	1
Restoration	PGE 13.1	Shoreline	2017	Pre Yr 1	10	10	0	0.00	0	0	0	0
Restoration	PGE 13.1	Shoreline	2019	Post Yr 2	10	10	0	0.00	0	0	0	0
Reference	Multnomah Channel	Shoreline	2016	-	10	10	1	0.10	0	0	1	1
Reference	Multnomah Channel	Shoreline	2017	-	10	10	0	0.00	0	0	0	0
Reference	Multnomah Channel	Shoreline	2018	-	10	10	0	0.00	0	0	0	0
Reference	Multnomah Channel	Shoreline	2019	-	10	10	0	0.00	0	0	0	0
Reference	Cemetery Creek	Tributary	2015	-	2	2	0	0.00	0	0	0	0
Reference	Cemetery Creek	Confluence	2015	-	10	10	5	0.50	2	0	6	8
Reference	Cemetery Creek	Confluence	2016	-	13	10	2	0.20	0	0	2	2
Reference	Cemetery Creek	Confluence	2017	-	10	10	6	0.60	3	0	7	10
Reference	Cemetery Creek	Confluence	2018	-	10	10	5	0.50	4	0	4	8
Reference	Cemetery Creek	Confluence	2019	-	10	10	2	0.20	0	0	4	4
Reference	Cemetery Creek	Confluence	2020	-	10	10	1	0.10	0	3	1	4
Reference	Cemetery Creek	Shoreline	2016	-	10	10	3	0.30	1	0	2	3
Reference	Cemetery Creek	Shoreline	2017	-	10	10	4	0.40	3	0	3	6
Reference	Cemetery Creek	Shoreline	2018	-	10	10	3	0.30	2	0	4	6
Reference	Cemetery Creek	Shoreline	2019	-	10	10	3	0.30	0	0	5	5
Reference	Cemetery Creek	Shoreline	2020	-	10	10	4	0.40	1	1	6	8

Table 3. Continued.

Site Type	Site		Year	Status	Quadrats Visited	Quadrats Sampled	Quadrats Occupied	*d*	Pacific Lamprey	*Lampetra* spp.	UNID	Total N
Reference	Columbia Slough	Confluence	2016	-	10	10	0	0.00	0	0	0	0
			2017	-	11	10	1	0.10	1	0	0	1
			2018	-	10	10	0	0.00	0	0	0	0
			2019	-	10	10	0	0.00	0	0	0	0
			2020	-	10	10	2	0.20	0	0	2	2
	McCarthy Creek	Tributary	2016	-	7	2	0	0.00	0	0	0	0
		Tributary	2017	-	7	2	0	0.00	0	0	0	0
		Confluence	2016	-	10	10	0	0.00	0	0	0	0
			2017	-	10	10	1	0.10	1	1	0	2
			2018	-	10	10	2	0.20	1	0	1	2
			2019	-	10	10	0	0.00	0	0	0	0
			2020	-	10	10	0	0.00	0	0	0	0
		Shoreline	2016	-	10	10	1	0.10	0	0	1	1
			2017	-	10	10	0	0.00	0	0	0	0
			2018	-	10	10	0	0.00	0	0	0	0
			2019	-	10	10	1	0.10	0	0	1	1
			2020	-	10	10	0	0.00	0	0	0	0
	Miller Creek	Tributary	2019	-	7	7	5	0.71	0	4	4	8
		Tributary	2020	-	7	6	5	0.83	0	24	10	34
	Oswego Creek	Confluence	2016	-	10	10	4	0.40	2	1	3	6
			2017	-	10	10	5	0.50	3	0	6	9
			2018	-	10	10	2	0.20	2	0	2	4
			2019	-	10	10	5	0.50	0	0	13	13
			2020	-	10	10	2	0.20	1	1	0	2
		Tributary	2019	-	7	7	1	0.14	0	0	1	1
			2020	-	7	7	2	0.29	1	1	0	2

Table 3. Continued.

Site Type	Site		Year	Status	Quadrats Visited	Quadrats Sampled	Quadrats Occupied	*d*	Pacific Lamprey	*Lampetra* spp.	UNID	Total N
	Ross Island	Shoreline	2014	-	28	26	5	0.19	0	6	0	6
			2016	-	10	10	2	0.20	2	0	0	2
			2017	-	13	10	3	0.30	5	0	1	6
			2018	-	10	10	3	0.30	3	2	1	6
			2019	-	10	10	0	0.00	0	0	0	0
			2020	-	10	10	0	0.00	0	0	0	0

Findings

Restoration actions are complete at four sites, Alder Point, Linnton, Rinearson, and PGE 13.1. Within site comparisons of pre- and post-restoration sampling show similarities in patterns of larval lamprey occupancy and rates of detection. Monitoring at the Alder Point shoreline habitat can be directly compared to the reference site at Ross Island, which is sampled concurrently. To date, lamprey were found to occupy the confluence or shoreline habitats at both sites in most years of monitoring, though there have been more zero detections at both Alder Point and Ross Island over the past few years. In the newly constructed Alder Slough, no lamprey have been detected since the habitat was constructed. It is not known whether, and after how long, larval lamprey use of this newly-created habitat may occur. It remains unclear whether Alder Slough will provide useful habitat for lamprey. Thus, to date, lamprey appear to be using the post-restoration area of Alder Point in a manner similar to pre-restoration. Likewise, changes in the shoreline habitat occupancy over the sample period appear be similar to those documented at the paired reference site, Ross Island. Over the past two years, both shoreline habitats have had zero detections of larval lamprey. Continued monitoring of larval lamprey occupancy at the Alder Point site and its paired reference site Ross Island is warranted and will provide a better understanding of larval lamprey colonization rates of newly available habitats.

Monitoring at the Rinearson site can be directly compared to the reference site habitats at Cemetery and Oswego creeks, which are sampled concurrently. Larval lamprey have generally occupied confluence and shoreline habitat at both sites both pre and post restoration. Larval lamprey occupied tributary habitat within the RNA site pre restoration, and the first larval lamprey was detected post restoration in 2020. The larval lamprey was detected 60 m upstream from the confluence with the Willamette, in the lowest downstream tributary reach. It is likely too soon after restoration to draw any conclusions about the long-term occupancy of the RNA tributary by lamprey. Tributary habitat in Oswego Creek has been occupied over the past two years since being added as a reference site.

The first year of post-project monitoring for the Linnton site occurred in 2020. The McCarthy Creek site acts as a reference location for both the shoreline and confluence habitat at the Linnton restoration site. No larval lamprey were detected in either the shoreline and confluences habitats for both the restoration and references sites. This occupancy data follows patterns documented over the sampling period, as detection rates (d = 0.00-0.20) and total number of larval lamprey captured (n = 6) are both low across the five-year sampling period at the McCarthy Creek site. There have been no larval lamprey detected (d = 0.00) at the Linnton site over the two sampling events. It is too early to make conclusions about larval lamprey use of the newly constructed shallow water habitat that the Linnton site.

Reference site monitoring is an important component of the lamprey monitoring program associated with the Portland Harbor Superfund project. Patterns of larval lamprey occupancy at reference sites will provide a baseline for evaluating changes in larval lamprey occupancy at restoration sites over time, and assessing the utility of restoration actions for larval lamprey. Monitoring at the reference sites is ongoing. After the 2017 sampling, we eliminated the wadeable portions of Cemetery Creek and McCarthy Creek from the group of reference sites (essentially, reference habitat was not available). In 2019, we assessed and added the Miller Creek tributary as a replacement for the McCarthy Creek tributary and added the Oswego Creek tributary as a replacement for Cemetery Creek tributary. Finding tributaries that are suitable as reference sites has proven to be a challenge.

Similar to the results of previous years' sampling (Jolley et al. 2015; Silver et al. 2016; Skalicky et al. 2018, Skalicky et al. 2019, Skalicky and Whitesel 2020) we observed a combination of larval Pacific Lamprey and *Lampetra* spp. in the Portland Harbor Superfund area. Mainstem habitats associated with the Alder Point, Rinearson, and Linnton restoration sites, as well as habitats at many reference sites, continue to appear suitable to and available for colonization by larvae in the mainstem Willamette River and Multnomah Channel. This was evidenced by the presence of larvae in shoreline and confluence habitats. The larvae detected at the Alder Point and Rinearson restoration sites as well as at reference sites may have originated from tributaries that enter the Willamette River upstream of the study areas (for example, the Clackamas River subbasin) and gradually dispersed downstream to their location of capture. Given that the larvae detected included *Lampetra sp.*, and that brook lamprey would not be expected to spawn in relatively large and deep rivers, it is likely they originated from out of the area. Furthermore, evidence suggesting dispersal of larval lamprey out of tributaries and into mainstem habitats has been observed previously in the mainstem Columbia River and Willamette River basins (Jolley et al. 2012; Jolley et al. 2013; Jolley et al. 2014) and may occur over extensive distances (Scribner and Jones 2002; Derosier et al. 2007). In addition to the Clackamas River, there are numerous small tributaries that enter into the Portland Harbor Superfund site, including Abernethy and Johnson creeks, where documented Pacific Lamprey spawning has occurred (Oregon Department of Fish and Wildlife. 2020). Larval lamprey from these tributaries could disperse short distances into the Portland Harbor Superfund reach and spend multiple years rearing in Willamette River. Pacific Lamprey spawning has not been documented in the Portland Harbor Superfund area. However, as observed in the lower mainstem of the Lewis River (J. Doyle, PacifiCorp, personal communication) and directly adjacent to the Portland Harbor Superfund reach at confluence of the Clackamas River and the Willamette River (B. Walczak, Oregon Department of Fish and Wildlife, personal communication), Pacific Lamprey spawning in relatively large rivers (5^{th} order, possibly larger) is plausible where suitable substrate and flow regimes occur. Thus, it is possible but unlikely that the larval Pacific Lamprey detected at restoration and reference sites originated from spawning within the Portland Harbor Superfund area.

Acknowledgements

We are grateful to those who have been involved in developing this project. We would like to specifically thank L. Fishler, and A. Houts for administrative support; J. Harris for analytical guidance; J. Kassakian for project oversight and integration.

Literature Cited

Arntzen E.V., and R.P. Mueller. 2017. Video-Based Electroshocking Platform to Identify Lamprey Ammocoete Habitat: Field Validation and New Discoveries in the Columbia River Basin. North American Journal of Fisheries Management 37(3):676-681.

Bayley, P.B., and J.T. Peterson. 2001. An approach to estimate probability of presence and richness of fish species. Transactions of the American Fisheries Society 130:620-633.

Beamish, R.J., and C.D. Levings. 1991. Abundance and freshwater migrations of the anadromous parasitic lamprey, *Lampetra tridentata*, in a tributary of the Fraser River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 48:1250-1263.

Beamish, R.J., and J.H. Youson. 1987. Life history and abundance of young adult *Lampetra ayresi* in the Fraser River and their possible impact on salmon and herring stocks in the Strait of Georgia. Canadian Journal of Fisheries and Aquatic Sciences 44:525-537.

Bergstedt, R.A., and J.H. Genovese. 1994. New technique for sampling sea lamprey larvae in deepwater habitats. North American Journal of Fisheries Management 14:449-452.

Close, D.A., M.S. Fitzpatrick, and H.W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific lamprey. Fisheries 27:19-25.

CRITFC (Columbia River Inter-Tribal Fish Commission). 2008. Tribal Pacific lamprey restoration plan for the Columbia River Basin. Formal draft available: www.critfc.org/text/lamprey/restor_plan.pdf. (February 2010).

Derosier, A. L., D. L. Jones, and K. T. Scribner. 2007. Dispersal of sea lamprey larvae during early life history: relevance for recruitment dynamics. Environmental Biology of Fish. 78: 271-284.

Docker, M.F., G.S. Silver, J.C. Jolley, and E.K. Spice. 2016. Simple genetic assay distinguishes lamprey genera *Entosphenus* and *Lampetra*: Comparison with existing genetic and morphological identification methods. North American Journal of Fisheries Management. 36(4):780-787.

Farlinger, S.P., and R.J. Beamish. 1984. Recent colonization of a major salmon-producing lake in British Columbia by the Pacific lamprey (*Lampetra tridentata*). Canadian Journal of Fisheries and Aquatic Sciences. 41:278-285.

Fodale, M.F., C.R. Bronte, R.A. Bergstedt, D.W. Cuddy, and J.V. Adams. 2003. Classification of lentic habitat for sea lamprey (*Petromyzon marinus*) larvae using a remote seabed classification device. Journal of Great Lakes Research 29 (Supplement 1):190–203.

Gadomski, D. M., and C. A. Barfoot. 1998. Diel and distributional abundance patterns of fish embryos and larvae in the lower Columbia and Deschutes rivers. Environmental Biology of Fishes 51:353-368.

Goodman, D.H., A.P. Kinzinger, S.B. Reid, M.F. Docker. 2009. Morphological diagnosis of *Entosphenus* and *Lampetra* ammocoetes (Petromyzontidae) in Washington, Oregon, and California. Pages 223-232 *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.

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 173-189 *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 pp. 173-189.

Hansen, M.J., and D.W. Hayne. 1962. Sea lamprey larvae in Ogontz Bay and Ogontz River, Michigan. Journal of Wildlife Management 26:237-247.

Harris, J.E., and J.C. Jolley. 2017. Estimation of occupancy, density, and abundance of larval lampreys in tributary river mouths upstream of dams on the Columbia River, Washington and Oregon. Canadian Journal of Fisheries and Aquatic Sciences 74: 843–852.

Jolley, J.C., G.S. Silver, and T.A. Whitesel. 2012. Occupancy and detection of larval Pacific lampreys and *Lampetra* spp. in a large river: the lower Willamette River. Transactions of the American Fisheries Society 141:305-312.

Jolley, J.C., G.S. Silver, and T.A. Whitesel. 2013. Occurrence, detection, and habitat use of larval lamprey in the lower White Salmon River and mouth: post-Condit Dam removal, 2012 Annual Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA.

Jolley, J.C., G.S. Silver, J.J. Skalicky, and T.A. Whitesel. 2014. Evaluation of larval Pacific lamprey rearing in mainstem areas of the Columbia and Snake Rivers impacted by dams. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA.

Jolley, J.C., G.S. Silver, and T.A. Whitesel. 2015. Evaluation of Portland Harbor Superfund area restoration: larval Pacific lamprey, 2014 Annual Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA. 16 pp.

Kostow, K. 2002. Oregon lampreys: natural history status and problem analysis. Oregon Department of Fish and Wildlife, Portland.

Lee, D.S., and J.G. Weise. 1989. Habitat selection of lentic larval lampreys: preliminary analysis based on research with a manned submersible. Journal of Great Lakes Research 15:156-163.

McGree, M., T.A. Whitesel, and J. Stone. 2008. Larval metamorphosis of individual Pacific lampreys reared in captivity. Transactions of the American Fisheries Society 137:1866-1878.

Moser, M.L., and D.A. Close. 2003. Assessing Pacific lamprey status in the Columbia River basin. Northwest Science 77:116-125.

Moursund, R. A., D. D. Dauble, and M. J. Langeslay. 2003. Turbine intake diversion screens: investigating effects on Pacific lamprey. Hydro Review 22:40-46.

Oregon Department of Fish and Wildlife. 2020. Summary of Winter Steelhead Spawning Surveys. Retrieved from https://odfw.forestry.oregonstate.edu/spawn/datasumm19-20.htm

National Oceanic and Atmospheric Administration (NOAA). 2017. Final Portland Harbor Programmatic EIS and Restoration Plan. Portland, Oregon.

Nursall, J. R., and D. Buchwald. 1972. Life history and distribution of the Arctic lamprey (*Lethenteron japonicum* (Martens)) of Great Slave Lake, N.W.T. Fisheries Research Board of Canada Technical Report 304.

Peterson, J.T., and J. Dunham. 2003. Combining inferences from models of capture efficiency, detectability, and suitable habitat to classify landscapes for conservation of threatened bull trout. Conservation Biology 17:1070-1077.

Renaud, C. B. 1997. Conservation status of northern hemisphere lampreys (Petromyzontidae). Journal of Applied Ichthyology 13:143-148.

Roni, P., Hanson, K., and T. Beechie. 2008. Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques. North American Journal of Fisheries Management 28:856-890

Rosenzweig, M. 2003. Win-win Ecology, How the Earth's species can survive in the midst of human enterprise. Oxford, UK: Oxford University Press.

Russell, J. E., F. W. H. Beamish, and R. J. Beamish. 1987. Lentic spawning by the Pacific lamprey, *Lampetra tridentata*. Canadian Journal of Fisheries and Aquatic Sciences 44:476-478.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Ottawa.

Scribner, K. T., and M. L. Jones. 2002. Genetic assignment of larval parentage as a means of assessing mechanisms underlying adult reproductive success and larval dispersal. Great Lakes Fishery Commission, 2002 Project Completion Report.

Silver, G.S., J.C. Jolley and T.A. Whitesel. 2010. White Salmon River Basin: Lamprey Project. National Fish and Wildlife Federation, Project #2006-0175-020, Final Programmatic Report.

Silver, G.S., J.C. Jolley, and T.A. Whitesel. 2016. Evaluation of Larval Pacific Lamprey

Occupancy in Portland Harbor Superfund Area Restoration Sites: Rinearson Natural Area, 2015 Annual Report. U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, WA. 28 pp.

Skalicky, J.J., J. Barkstedt, and T.A. Whitesel. 2018. Evaluation of Larval Pacific Lamprey Occupancy of Habitat Restoration Sites in the Portland Harbor Superfund Area; 2017 Annual Report. U.S. Fish & Wildlife Service, Columbia River Fish & Wildlife Conservation Office, Vancouver, Washington. 48 pp.

Skalicky, J.J., J. Barkstedt, and T.A. Whitesel. 2019. Evaluation of Larval Pacific Lamprey Occupancy of Habitat Restoration Sites in the Portland Harbor Superfund Area; 2018 Annual Report. U.S. Fish & Wildlife Service, Columbia River Fish & Wildlife Conservation Office, Vancouver, Washington. 47 pp.

Skalicky, J.J., and T.A. Whitesel. 2020. Evaluation of Larval Pacific Lamprey Occupancy of Habitat Restoration Sites in the Portland Harbor Superfund Area; 2019 Annual Report. U.S. Fish & Wildlife Service, Columbia River Fish & Wildlife Conservation Office, Vancouver, Washington. 52 pp.

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 larval and metamorphosed sea lampreys in Great Lakes tributaries, 1995-2001. Journal of Great Lakes Research 29 (Supplement 1): 137-151.

Stevens, D. L., Jr., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Stone, J. 2006. Observations on nest characteristics, spawning habitat, and spawning behavior of Pacific and western brook lamprey in a Washington stream. Northwestern Naturalist 87:225-232.

Stone, J., and S. Barndt. 2005. Spatial distribution and habitat use of Pacific lamprey (*Lampetra tridentata*) ammocoetes in a western Washington stream. Journal of Freshwater Ecology 20:171-185.

Sutton, T.M., and S.H. Bowen. 1994. Significance of organic detritus in the diet of larval lamprey in the Great Lakes Basin. Canadian Journal of Fisheries and Aquatic Sciences 51:2380-2387.

Torgersen, C.E., and D.A. Close. 2004. Influence of habitat heterogeneity on the distribution of larval Pacific lamprey *Lampetra tridentata* at two spatial scales. Freshwater Biology 49:614-630.

Wagner, W.C., and T.M. Stauffer. 1962. Sea lamprey larvae in lentic environments. Transactions of the American Fisheries Society 91:384-387.

Weisser, J. W. and G. T. Klar. 1990. Electric fishing for sea lampreys (*Petromyzon marinus*) in the Great Lakes region of North America. In Developments in electric fishing. Edited by I. G. Cowx. Cambridge University Press, Cambridge, UK. Pp 59-64.

White, J. L., and B. C. Harvey. 2003. Basin-scale patterns in the drift of embryonic and larval fishes and lamprey ammocoetes in two coastal rivers. Environmental Biology of Fishes 67:369-378.

Young, R. J., G.C. Christie, R.B. McDonald, D.W. Cuddy, T.J Morse, and N.R. Payne. 1996. Effects of habitat change in the St. Marys River and northern Lake Huron on sea lamprey (*Petromyzon marinus*) populations. Canadian Journal of Fisheries and Aquatic Sciences 53:99-104.

Appendix 1.

Results from sediment sampling have been provided to and can be obtained from:

Industrial Economics, Inc.
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July 2021