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

2017 Annual Report

Joseph J. Skalicky, Judith M. Barkstedt and Timothy A. Whitesel

U.S. Fish & Wildlife Service
Columbia River Fish & Wildlife Conservation Office
Vancouver, Washington 98683

On the cover: *Photograph of the Triangle Park restoration site within the Willamette River, detailing pilings scheduled for removal. (Photo by J. Skalicky).*

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authored by

Joseph J. Skalicky
Judith Barkstedt
Timothy A. Whitesel

U.S. Fish & Wildlife Service
Columbia River Fish & Wildlife Conservation Office
1211 SE Cardinal Court, Suite 100
Vancouver, Washington 98683

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Joseph J. Skalicky, Judith Barkstedt, and Timothy A. Whitesel

U.S. Fish & Wildlife Service
Columbia River Fish & Wildlife Conservation Office
1211 SE Cardinal Court, Suite 100
Vancouver, Washington 98683

Abstract – Habitat restoration actions focused on 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 the restoration, in part, relative to larval Pacific lamprey. Determining the effects of restoration actions on Pacific lamprey requires evaluation of lamprey occurrence before and after project implementations. Here we report on occupancy, detection, and habitat use of larval Pacific lamprey and *Lampetra* spp. in shoreline, confluence, and slough habitats at five restoration sites: Alder Point, Harborton, Linnton, Triangle Park and RM 13.1. Although pre-restoration sampling has been done, the Rinearson restoration site was not sampled in 2017 because restoration was not complete. We likewise evaluated lamprey occupancy at six reference sites in the lower Willamette River and Multnomah Channel (Multnomah Channel, McCarthy Creek, Columbia Slough, Ross Island, Cemetery Creek, and Oswego Creek). A generalized random tessellation-stratified approach was used to delineate 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 sloughs and streams. Quadrats were sampled using a deepwater electrofisher with a fiberglass bell positioned on the river bottom that delivers an electrical pulse coupled with a suction pump to collect larvae in a mesh basket at the water surface. Reaches were sampled using a backpack electrofishing unit. Across all restoration sites, a total of six larval lamprey were captured and quadrat-specific detection rates (d) ranged from 0.0 to 0.2. Lamprey occupied the Alder Point and Harborton restoration sites but were not detected at the Linnton, Triangle Park, and RM 13.1 restoration sites. At the Alder Point restoration site, a total of three larval lamprey were detected at one of thirty confluence quadrats (d = 0.03) and two of ten shoreline quadrats (d = 0.2). No lamprey were detected in any of the ten quadrats in the newly constructed Alder Slough. Quadrat-specific detection probability at Alder Point, post restoration (d = 0.04 and 0.06 in 2016 and 2017, respectively) has been similar to that pre restoration in 2014 (d = 0.07). At the Harborton restoration site, larval lamprey (n = 3) were detected in one of ten north tributary quadrats (d = 0.1), one of ten confluence quadrats (d = 0.1) and zero of the south tributary quadrats (d = 0.1). At the six reference sites, larvae were detected in all but Multnomah Channel. A total of 34 larval lamprey were captured and quadrat-specific detection rates ranged from 0.1 to 0.6. This information will be used as part of a long-term evaluation of the effects of habitat restoration on occupancy and distribution of larval lamprey in the lower Willamette River, and monitoring changes in occupancy over time.

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Table of Contents

List of Tables

List of Figures

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 (ammocoete), migratory juvenile (macrophthalmia), and adult marine phase (Scott and Crossman 1973). Larvae and juveniles 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). Larvae metamorphose into juveniles from July to December (McGree et al. 2008) and major migrations are made downstream to the Pacific Ocean in the spring and fall (Beamish and Levings 1991). The sympatric western brook lamprey *Lampetra richardsoni* does not have a major migratory or marine life stage although adults may locally migrate upstream 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 (<5^{th} order [1:100,000 scale]; Torgersen and Close 2004) but their use of larger river habitats in relatively deeper areas is less known. Downstream movement of larvae, whether passive or active, occurs year-round (Nursall and Buchwald 1972; Gadomski and Barfoot 1998; White and Harvey 2003). Sea lamprey *Petromyzon marinus* ammocoetes 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 ammocoetes have been made in large river habitats in British Columbia which are thought to be representative of ammocoetes 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; Jolley et al. 2013, Jolley et al. 2014)

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 mitigate for past environmental damage being identified through the Natural Resource Damage Assessment (NRDA) process, this area is subject to various restoration activities as well as assessments of the effectiveness of any restoration. Presently, aquatic restoration projects are focused on restoring juvenile Chinook salmon *Oncorhynchus tshawytscha* habitat. It is unclear whether any of the restoration activities will provide additional benefits to other co-occurring species including larval and juvenile Pacific lamprey that may likewise occur in these areas. However, these activities 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 restoration, in part, relative to larval Pacific lamprey.

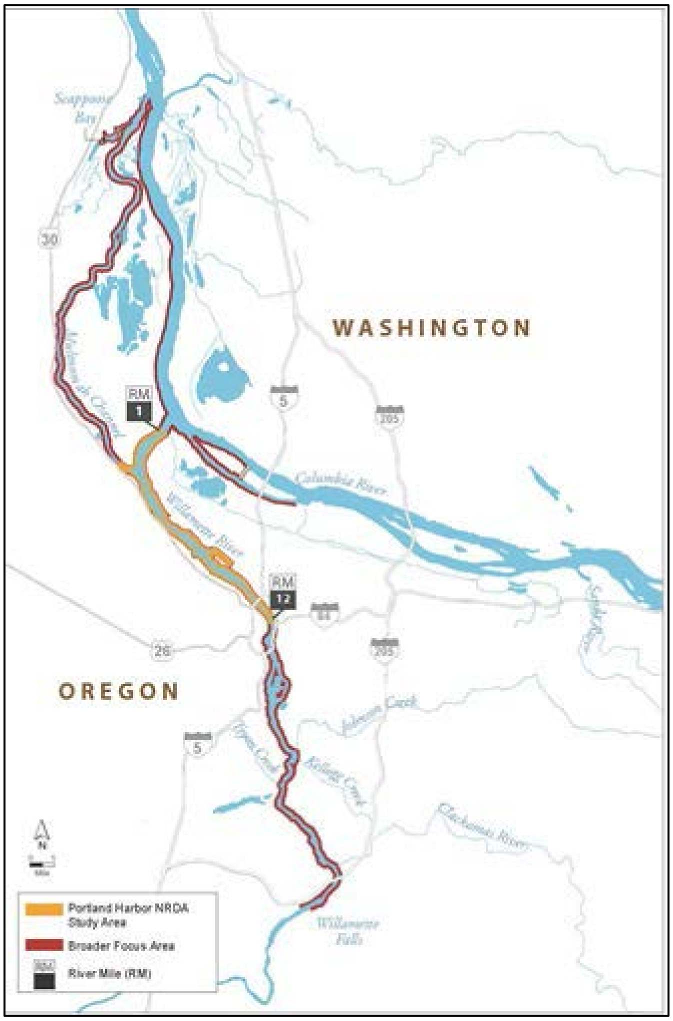

Figure 1. Portland Harbor Superfund study area (orange outline) and the broader focus area (red outline) on the lower Willamette River.

A lamprey monitoring plan (LMP) for 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 restoration actions 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 lamprey restoration projects. Since lamprey biology and life history are different from other aquatic biota, the overlap between the LMP and the general restoration monitoring and stewardship plan is not extensive. The LMP differs from the general restoration 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 restoration monitoring and stewardship. Biologists recommended monitoring lamprey for 20 years after the completion of a restoration project, with the goal of capturing data for 1 to 2 complete generations. Pre-implementation monitoring will be conducted to the extent practical at each restoration site. Lampreys are expected to colonize habitats rapidly. Therefore, monitoring will be conducted on a yearly basis for the first five years, 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.

In 2017, we continued post-habitat restoration monitoring of larval lamprey occupancy, distribution, and habitat use in or near Alder Point and began pre-habitat restoration monitoring at Harborton, Linnton, Triangle Park and RM 13.1. Understanding larval lamprey usage of habitats in and adjacent to restoration sites is critical to gauging the effectiveness of restoration activities. At present, little specific information is available on whether lampreys colonize restored habitats, which life stages may use these habitats, or how quickly and for how long they use these habitats. A before-after control-impact (BACI) approach will be used to evaluate the effectiveness of restoration activities, as that allows us to make inferences about whether changes in lamprey occupancy observed at the restoration site are the result of the restoration actions. Thus, we propose to determine whether larval Pacific lamprey occupy restoration sites and reference sites both prior to and after restoration actions. Our specific objectives for this phase of NRDA restoration 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 restoration 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). Slough habitat (henceforth Alder Slough) was constructed through the restoration site, connecting the Willamette River and Multnomah Channel. Unlike the typical confluence habitat associated with restoration 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 at the site (i.e., levee removal) occurred along both the Willamette River and Multnomah Channel. Larval lamprey are known to occur in the mainstem of the Willamette River in this region (Jolley et al. 2012), and have the potential to occur in restored areas within confluence and shoreline habitats in the mainstem Willamette River and Multnomah Channel as well as within Alder Slough. Pre-restoration sampling was conducted at shoreline habitat in Multnomah Channel and the Willamette River mainstem in fall 2014 (Jolley et al. 2015). Post-restoration monitoring consists of sampling for larval lamprey in shoreline habitats in the mainstem Willamette River and Multnomah Channel, as well as newly created confluence habitats in Multnomah Channel and the Willamette River and newly created slough habitat (Alder Slough) within the restoration site (Figure 3).

Harborton Restoration Site

The Harborton restoration 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 good quality off-channel habitat, floodplain function, and habitat connectivity between the river and Forest Park. The banks of these wetlands are natural beach with some vegetation on the edges. The shoreline appears to transition to shallow in-water habitat along the site. Currently the site has slough or tributary habitat as well as a confluence habitat and associated shoreline (Figure 4). Larval lamprey are known to occur in nearby areas of the mainstem Willamette River (Jolley et al. 2012b), and have access to and the potential to occur in or occupy the tributary/slough, confluence, and shoreline habitats of the proposed restoration site. However, it is unknown whether lamprey currently occur in or occupy the tributary/slough, confluence, or shoreline habitats at this site. Proposed actions include improvements to the tributary/slough habitat. Pre- and post-restoration monitoring is required to understand the effects of the restoration. In the case of the Harborton site, this proposal includes monitoring tributary/slough habitat (since this habitat is currently believed to be inaccessible to fish, monitoring would be post restoration only) and the confluence habitat (pre and post restoration).

Linnton Restoration Site

The Linnton restoration site is located on the southwest side of the Willamette River at river km 7.5 just upstream of Sauvie Island (Figure 2). It is an industrial property that contains an inactive plywood company. Currently the site has slough or tributary habitat as well as a confluence habitat and associated shoreline (Linnton Creek, Figure 5). However, pre-restoration monitoring is not required to understand the effectiveness of the tributary improvement. The slough or tributary habitat runs through a pipe, underground and is not accessible to fish. Lampreys are not believed to occupy or have access to the underground tributary habitat being proposed for restoration. Pre-restoration monitoring is required to understand the effects of restoration on the shoreline and confluence habitats. In the case of the Linnton site, this proposal includes monitoring newly exposed tributary/slough habitat (since this habitat is currently believed to be inaccessible to fish) monitoring would be post restoration only, as well as the confluence and shoreline habitat (pre and post restoration).

Triangle Park

Triangle Park 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 habitat in the Triangle Park site (Figure 6). Larval lamprey are known to occur in the mainstem of the Willamette River (Jolley et al. 2012b) and do have access to as well as the potential to exist in or occupy the shoreline habitat being proposed for restoration. Pre-restoration monitoring is required to understand whether larvae occupy the habitat where the pilings can be found. Proposed actions include removal of the pilings in the shoreline habitat. Post-restoration monitoring would be required to understand the impact of piling removal. In the case of Triangle Park, this would include monitoring shoreline habitat.

RM 13.1

RM 13.1 is located on the east side of the Willamette River at river km 21.1. Portland General Electric (PGE) has proposed an action to improve habitat on the east bank of the Willamette River at this site (Figure 2). The site has shoreline habitat with associated city effluents. Larval lamprey are known to occur in the mainstem of the Willamette River near this general area (Jolley et al. 2012b) as well as have access to and the potential to occur in or occupy the shoreline habitat being proposed for restoration. However, it is unknown whether lamprey currently occur in or occupy shoreline habitats of the specific restoration site (Figure 7). Pre and post restoration monitoring is required to understand the effects of the restoration on larval lamprey occupancy of the restoration site.

Rinearson Natural Area

Rinearson Creek flows through the Rinearson Natural Area restoration site (Clackamas County, OR) and enters the Willamette River from the east, just downstream of the mouth of the Clackamas River (river km 39; Figure 2). Currently the site has tributary or slough habitat that drains into the Willamette River, as well as associated confluence habitat in the mainstem Willamette River (Figure 8). Larval lamprey are known to occur in the mainstem of the Willamette River in this region (Jolley et al. 2012), and have access to and the potential to occur in proposed restoration areas in Rinearson Creek and confluence habitats in the mainstem Willamette River. Pre restoration sampling was conducted at confluence habitat in the Willamette River mainstem as well as wadeable depth tributary habitat in Rinearson Creek in spring 2015 (Silver et al. 2016). Post restoration monitoring would consist of sampling for larval lamprey in tributary reaches in Rinearson Creek as well as confluence habitats in the mainstem Willamette River. Since the restoration was not complete, Rinearson Natural Area was not sampled in 2017.

Reference Sites

Six reference sites were identified throughout the lower Willamette River and Multnomah Channel (Figure 2). Reference sites were selected in locations that contained confluence, shoreline, or slough habitats and in sites not proposed for habitat restoration in the immediate future. The confluence, shoreline, or slough habitats at the reference sites are similar to those at restoration sites following habitat restoration. Larval lamprey are known to occur in the mainstem of the Willamette River and Multnomah Channel in the vicinity of the reference sites (Jolley et al. 2012), and have access to and the potential to occur in confluence and shoreline habitats at the reference sites.

Multnomah Channel Shoreline

The Multnomah Channel reference site is located just downstream of the McCarthy Creek reference site (near river km 24; Figure 2). The Multnomah Channel reference site contains shoreline habitat similar to that of restored shorelines at restoration sites. Larval lamprey have access to and the potential to occur in Multnomah Channel (Figure 9).

McCarthy Creek Tributary, Confluence, and Shoreline

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 has tributary or slough habitat that drains into the Multnomah Channel, as well as confluence and shoreline habitats in Multnomah Channel (Figure 10). Larval lamprey have access to and the potential to occur in McCarthy Creek, as well as confluence and shoreline habitats in Multnomah Channel.

Columbia Slough Confluence

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 and is similar to confluence habitat at restoration sites (Figure 11. Larval lamprey are known to occur in the mainstem of the Willamette River in this region (Jolley et al. 2012), and have access to and the potential to occur in confluence habitats at this site.

Ross Island Shoreline

The Ross Island reference site, located just upstream of the Ross Island Bridge near downtown Portland (near river km 24; Figure 2), contains shoreline habitat similar to that of restored shorelines at restoration sites (Figure 12). The Ross Island reference site was also sampled prior to restoration at Alder Point and was sampled during the same season (summer 2014) as pre-restoration sampling at Alder Point.

Cemetery Creek Tributary, Confluence, and Shoreline

Cemetery Creek enters the Willamette River from the west, upstream of Ross Island (near river km 27; Figure 2). The Cemetery Creek reference site has tributary or slough habitat that drains into the Willamette River, as well as confluence and shoreline habitats in the mainstem

Willamette River (Figure 13). Larval lamprey are known to occur in the mainstem of the Willamette River in this region (Jolley et al. 2012), and have access to and the potential to occur in Cemetery Creek, as well as confluence and shoreline habitats in the mainstem Willamette River. During pre-restoration sampling (2015), Cemetery Creek served as a reference site to the Rinearson Natural Area, and was selected in part because it is similar in size and located in proximity to the Rinearson Natural Area restoration site. However, the selection of the tributary as a reference site was discontinued because of a lack of viable habitat (<10% Type I habitat).

Oswego Creek Confluence

Oswego Creek enters the Willamette River from the west near the town of Lake Oswego (near river km 34; Figure 2). Confluence habitat occurs in the mainstem Willamette River associated with the mouth of Oswego Creek and is similar to confluence habitat at restoration sites (Figure 14). Larval lamprey are known to occur in the mainstem of the Willamette River in this region (Jolley et al. 2012), and have access to and the potential to occur in confluence habitats at this site.

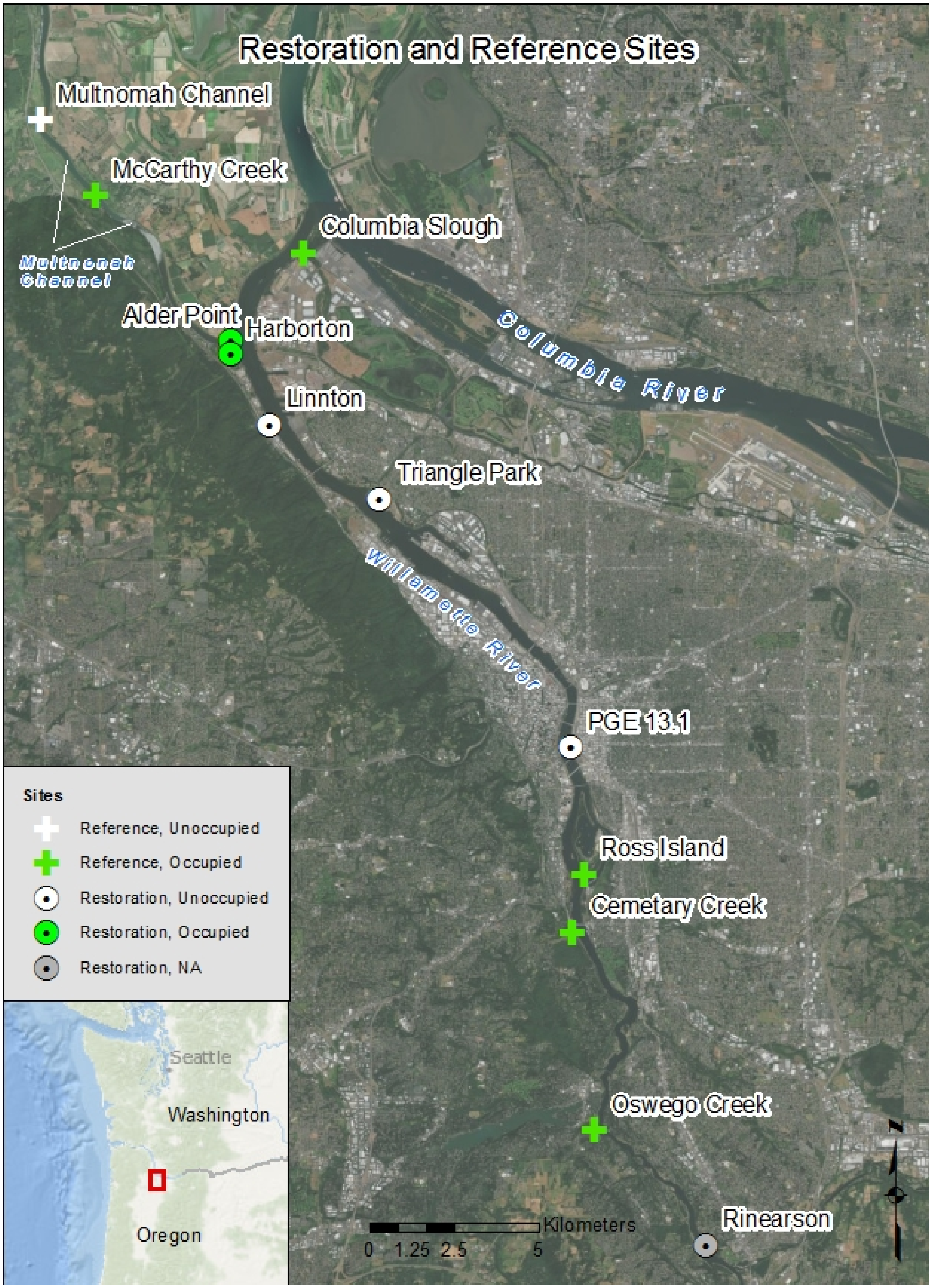

Figure 2. Locations of the restoration (circles) and reference sites (crosses) sampled in 2017. Occupied sites are green. Rinearson Creek was not sampled in 2017.

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; USFWS unpublished data). 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:

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

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($\sim F$), 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). Patterns of occupancy by area were compared using the Fisher's Exact test for differences in detection probabilities. Significance levels were set at $\alpha = 0.05$.

Confluence and Shoreline Habitat 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 proposed to use a sampling effort (number of sample quadrats) that we estimate would allow for at least 80% certainty that larval lampreys do not occupy at least 20% of a confluence or shoreline habitat when they are 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.

Wadeable Tributary Sample Framework

Evaluation of larval lamprey occupancy of wadeable depth tributary habitats will be conducted at restoration sites pre- and post-restoration. For each tributary habitat longer than 400 m, we will develop a layer of 50 m-long sample reaches for subsampling. The GRTS approach will again be 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 proposed to use 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 are 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 is less than 400 m in length, we sampled all reaches (contiguous 50 m reaches). If the area of interest is 400 m or longer, we sampled seven reaches.

Restoration Sites

Alder Point Restoration Site: Confluence, Shoreline, and Slough

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 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 (Figure 3), 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. 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 Restoration Site

At the Harborton restoration site, sample effort consisted of 10 confluence quadrats in each of three confluence habitats (30 total quadrats, to be done pre and post restoration). We anticipate the sample effort will correspond to 6-8, 50 m tributary reaches in each of two tributaries (post restoration only).

Linnton Restoration Site

At the Linnton restoration site, we anticipate the sample effort will correspond to 6-8, 50 m tributary reaches (post restoration only). Pre (and post) restoration sample effort consisted of 10 confluence quadrats and 10 shoreline quadrats.

Triangle Park Restoration Site

We propose to determine whether larval Pacific lamprey occupy the restoration area both prior to and after piling removal. The Triangle Park restoration site has shoreline habitat that contains aquatic pilings. In this case, shoreline sample framework is being defined as the area 30 m around the line connecting the piling structures (see Figure 6). Sites from this area were selected and sampled to determine occupancy. For this shoreline habitat, sampled 21 quadrats or 25% of the total number of quadrats.

RM 13.1 Restoration Site

We used a sampling effort (number of sample quadrats) that, in the case they are not detected, we estimate would allow us to be at least 80% certain that larval lamprey do not occupy a sample area (20% occurrence) (see Bayley and Peterson 2001, Peterson and Dunham 2003). The amount of effort is based, in part, on estimates from reach-specific (see Silver et al. 2010) and quadrat-specific (see Jolley et al. 2012b) probabilities of detection generated from previous work. Sample effort is also dependent, in part, on total area. For this mainstem habitat, we sampled 10 quadrats.

Rinearson Natural Area Restoration Site: Confluence, Tributary

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 8). 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. Due to ongoing restoration, Rinearson Natural area was not sampled in 2017.

Evaluation of larval lamprey occupancy in Rinearson Creek post restoration is proposed to occur over an approximately 1200 m long segment of creek, spanning from the confluence with the Willamette River upstream to the crossing of River Road (Milwaukie, OR; Figure 8). Because the area of interest in Rinearson Creek was longer than 400 m, we proposed subsampling seven 50 m-long GRTS reaches in the creek. Sample reaches were delineated at a rate of one 50 m reach for every 50 m of stream. Thus, within the approximately 1200 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. Due to ongoing restoration, Rinearson Natural area was not sampled in 2017.

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: Tributary, Confluence, and Shoreline

The McCarthy Creek reference site has tributary, confluence and shoreline habitats. Evaluation of larval lamprey occupancy in McCarthy Creek occurred over an approximately 1,350 m long segment of creek, spanning from the confluence with the Multnomah Channel upstream to the crossing of Highway 30 (near Burlington, OR). Because the area of interest in McCarthy Creek was longer than 400 m, we visited seven 50 m-long GRTS reaches in the creek. Sample reaches were delineated at a rate of one 50 m reach for every 50 m of stream. Thus, within the approximately 1,350 m long study area in, 27 sample reaches were delineated, of which the lowest numbered seven reaches as ordered by the GRTS method were assigned the highest priority for sampling (Figure 10).

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 (Figure 10).

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: Tributary, Confluence, and Shoreline

The Cemetery Creek reference site has tributary, confluence and shoreline habitats. In Cemetery Creek, the tributary area of interest was less than 400 m in length, spanning from the confluence with the Willamette River upstream approximately 300 m to a reach of very high gradient. Because the viable sample area of interest was less than 400 m in length, we sampled all viable reaches (contiguous 50 m reaches) in Cemetery Creek up to a total of 350 m. In 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. In 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

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).

Quadrat Sampling

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 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).

Wadeable Tributary Sampling

For wadeable depth tributary habitats, each sampling event consisted of electrofishing 50 m reaches for larval lamprey (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 ammocoetes to enter the water column. Once a larva was observed in the water column, 30 pulses/second were applied to temporarily immobilize the larva for capture in a net. We spent relatively more time 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 was spent electrofishing areas with hard bedrock and boulder substrates. All larval lamprey observed were captured and placed in buckets containing stream water.

Biological Data Collection

Collected lamprey were anesthetized in a solution of buffered tricaine methanesulfonate (MS-222), 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., larvae > 60 mm TL; Goodman et al. 2009) identified to genus (i.e., *Entosphenus* [Pacific Lamprey] or *Lampetra* [Western Brook or River Lamprey]) according to visual evaluations of caudal fin pigmentation patterns. Caudal fin tissue samples were also collected for potential future assignment of genus genetically (Spice et al. 2011; Docker et al. 2016). Tissue samples are archived at the Columbia River Fish & Wildlife Conservation Office (CRFWCO) pending funding availability for genetic identification. Upon resuming active swimming behavior, 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

Confluence and Shoreline Habitats

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 approximately two, 250-500 ml subsamples were transferred to containers provided by a contracted laboratory. Samples were labeled with the site number, replicate 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) within 1 week of collection for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses.

Water temperature (°C), conductivity (μS/cm) and water depth were also measured at each quadrat and are presented as mean (± SE) unless otherwise noted.

Wadeable Tributary Habitats

Sediment samples were collected from each 50 m sample reach. Samples were mixed thoroughly and approximately two, 250-500 ml subsamples were transferred to containers provided by a contracted laboratory. Each sample was labeled with the reach number, replicate number and date, placed on ice, returned to the USFWS office, and subsequently handled per the instructions provided from the contracted laboratory.

Within each sample reach, water temperature (°C) and conductivity (µS/cm) were measured, and visibility was qualitatively ranked as good, fair, or poor. The proportion (%) of Type 1 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.

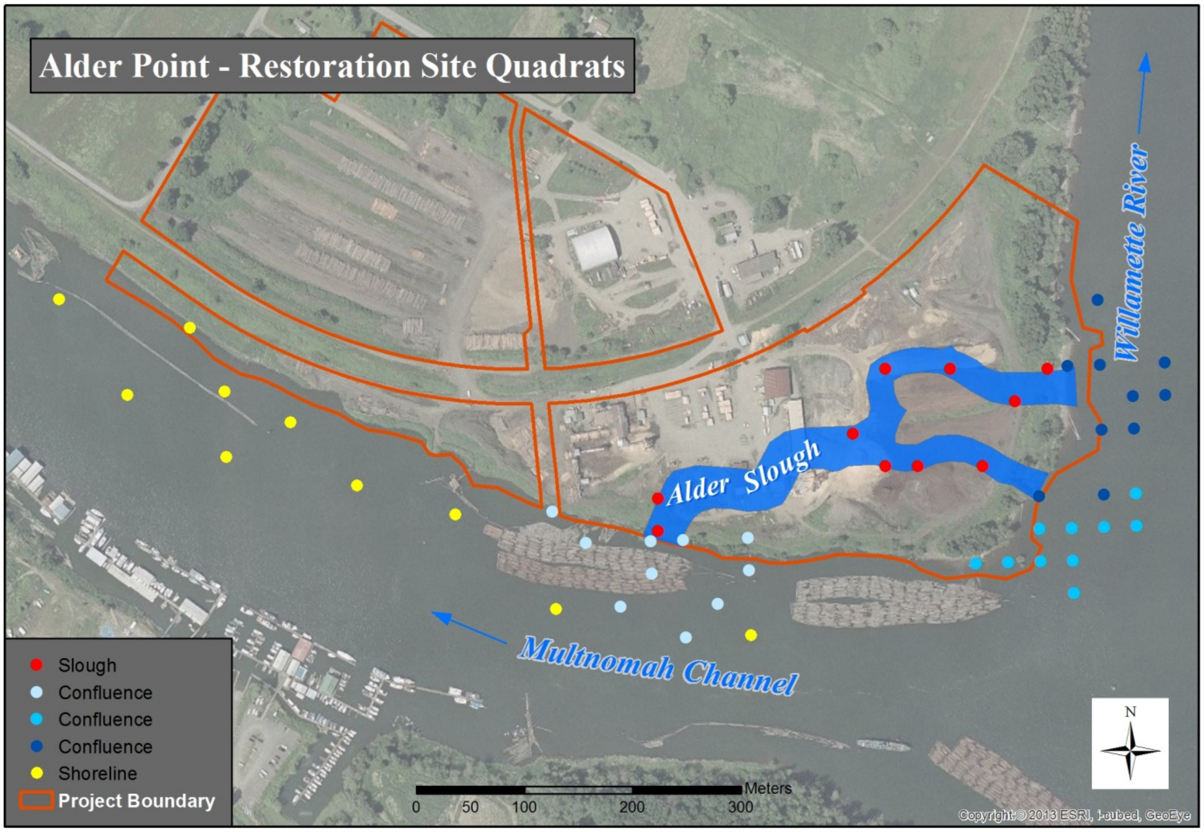

Figure 3. Alder Point restoration site 2017 sample sites. Habitats within the sites are confluence quadrats (blue points; each point represent a quadrat center point), shoreline quadrats (yellow points), and slough quadrats (red points).

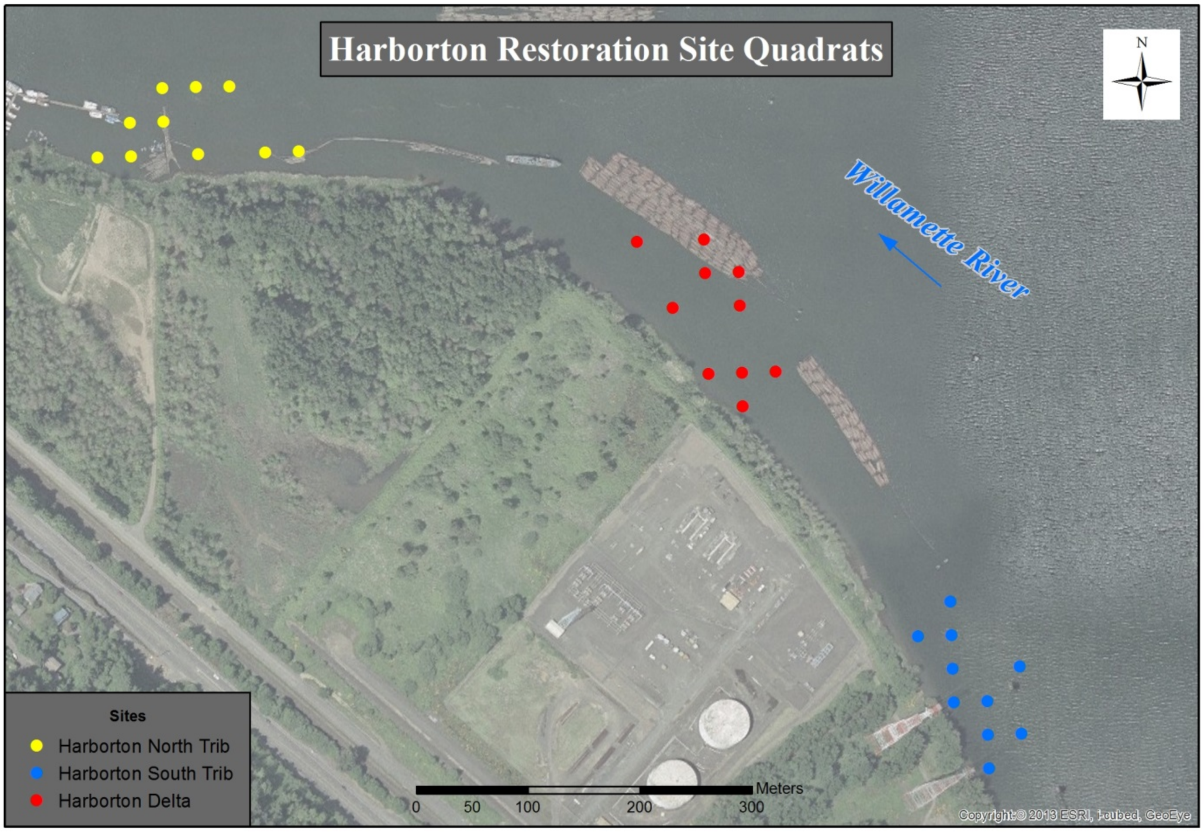

Figure 4. Harborton restoration site. North Tributary quadrats (yellow points), South Tributary quadrats (blue points), and confluence quadrats (red points) were sampled in 2017.

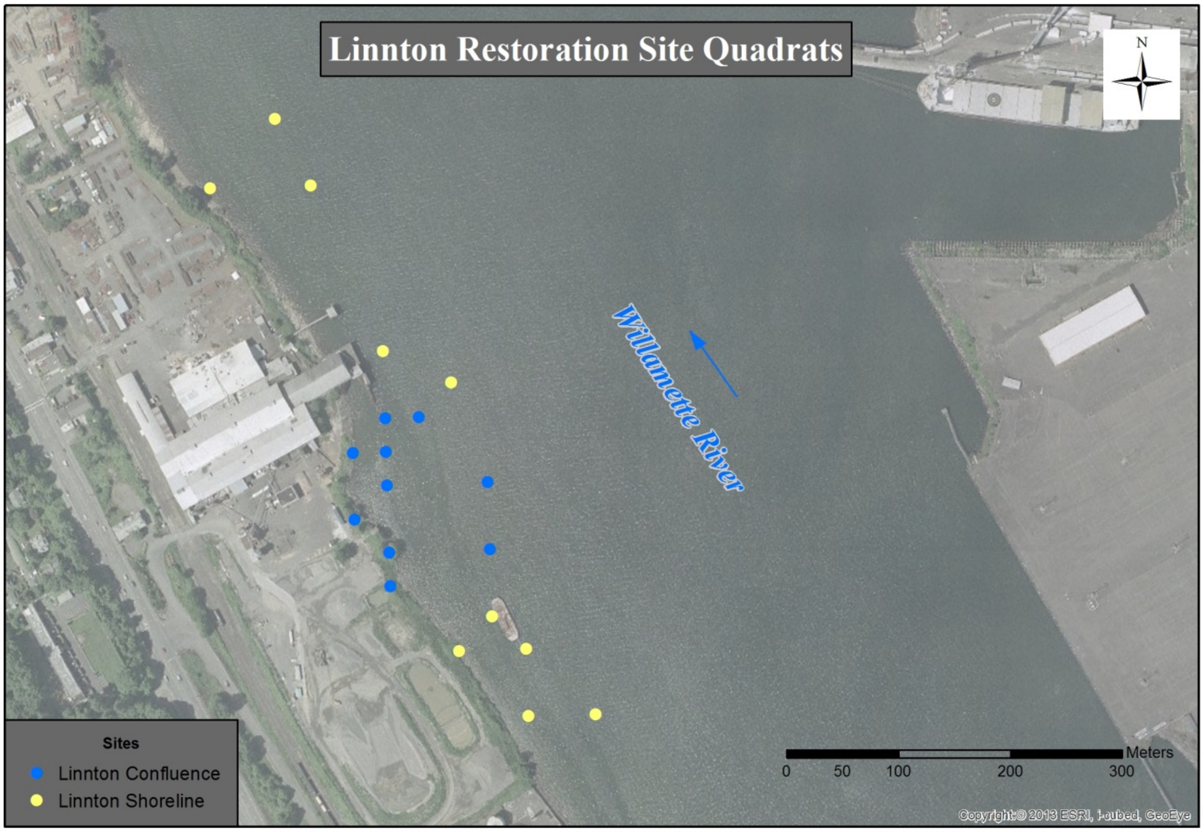

Figure 5. Linnton restoration site. Shoreline quadrats (yellow points) and confluence quadrats (blue points) were sampled in 2017.

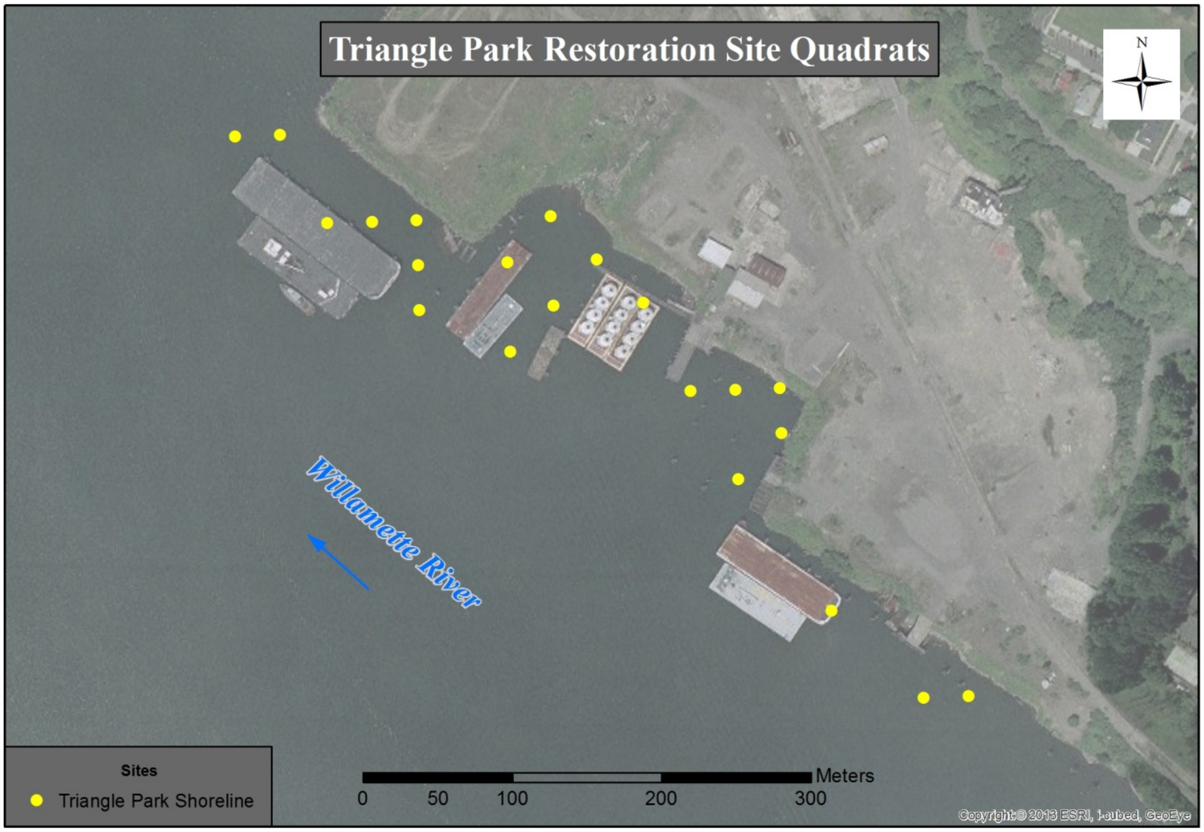

Figure 6. Triangle Park restoration site shoreline quadrats (yellow points) sampled in 2017.

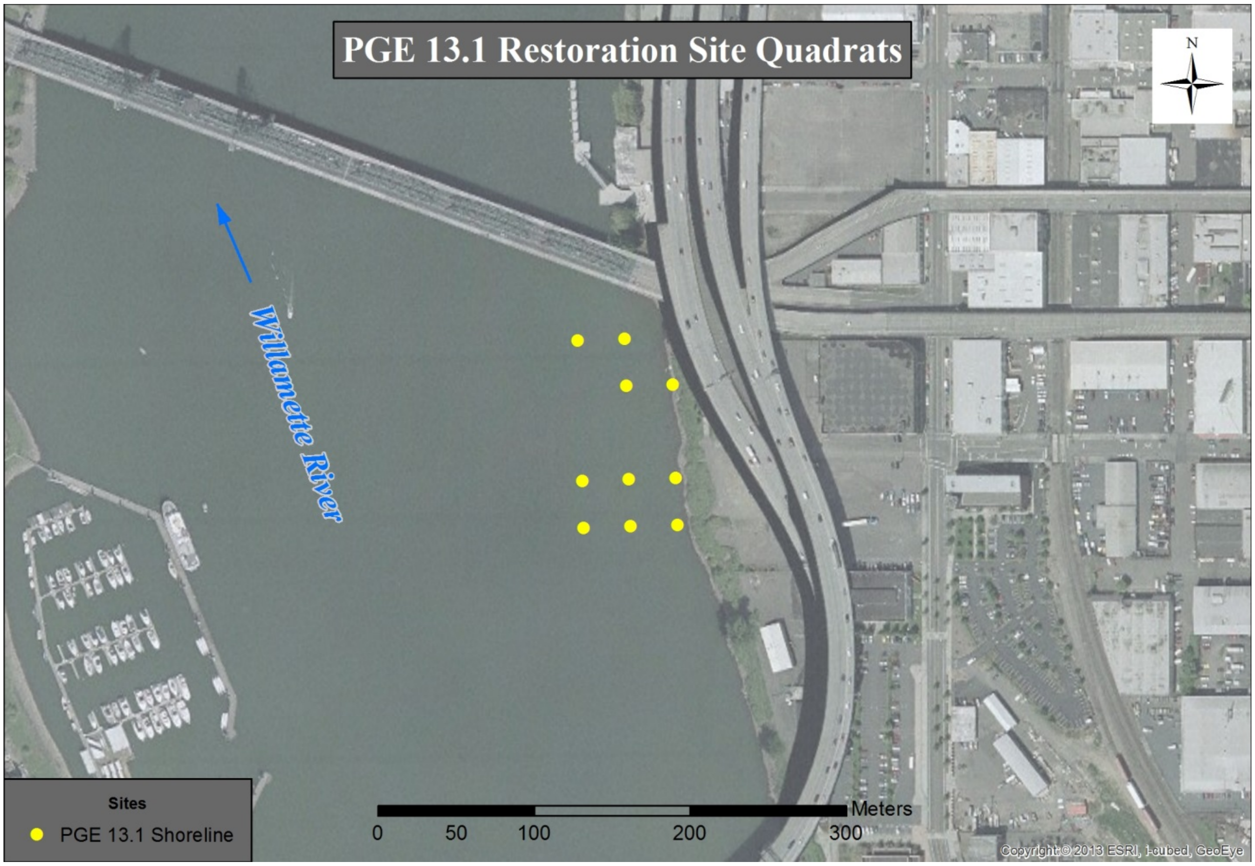

Figure 7. RM 13.1 restoration site shoreline quadrats (yellow points) sampled in 2017.

Figure 8. Rinearson Natural Area restoration site. Confluence quadrats (blue points) and tributary sample reaches (red points) are shown, however, no sampling occurred in 2017.

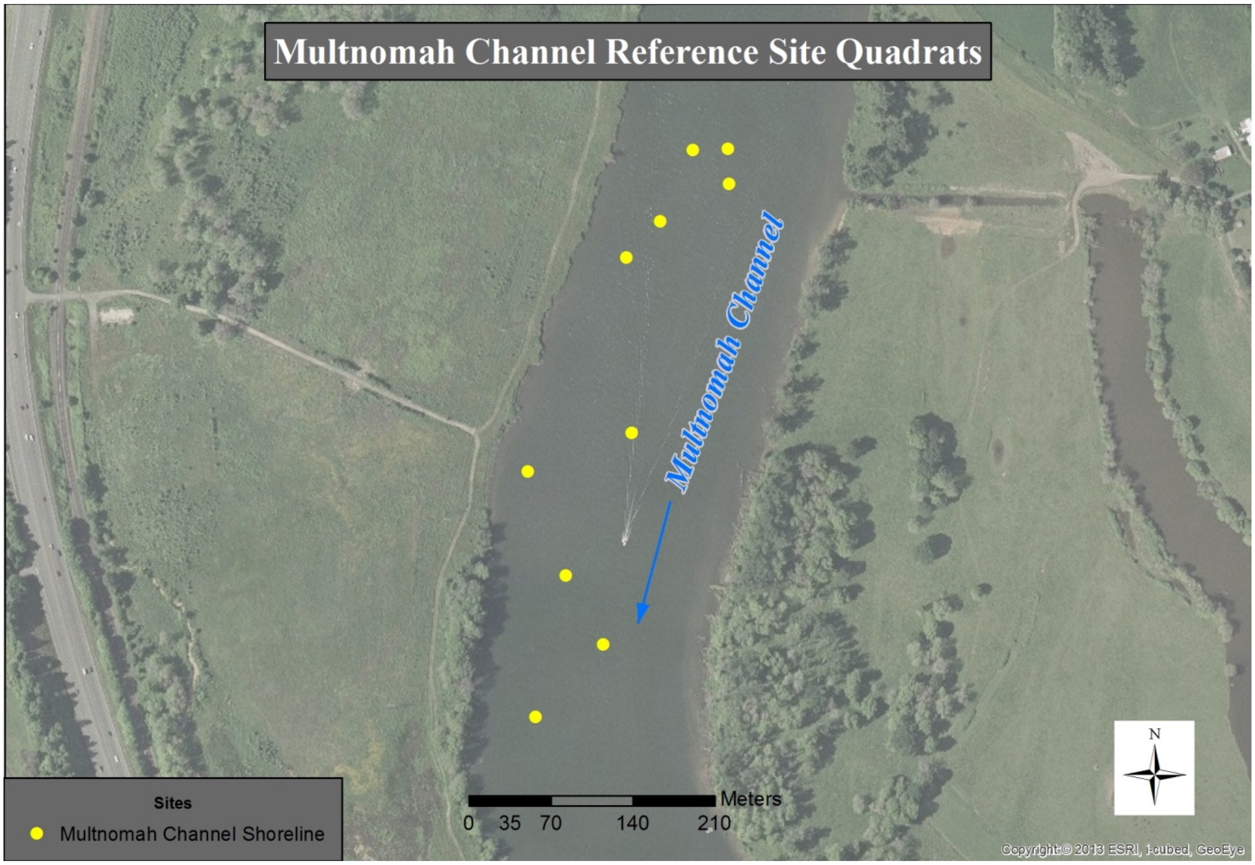

Figure 9. Multnomah Channel reference site shoreline quadrats (yellow points) sampled in 2017.

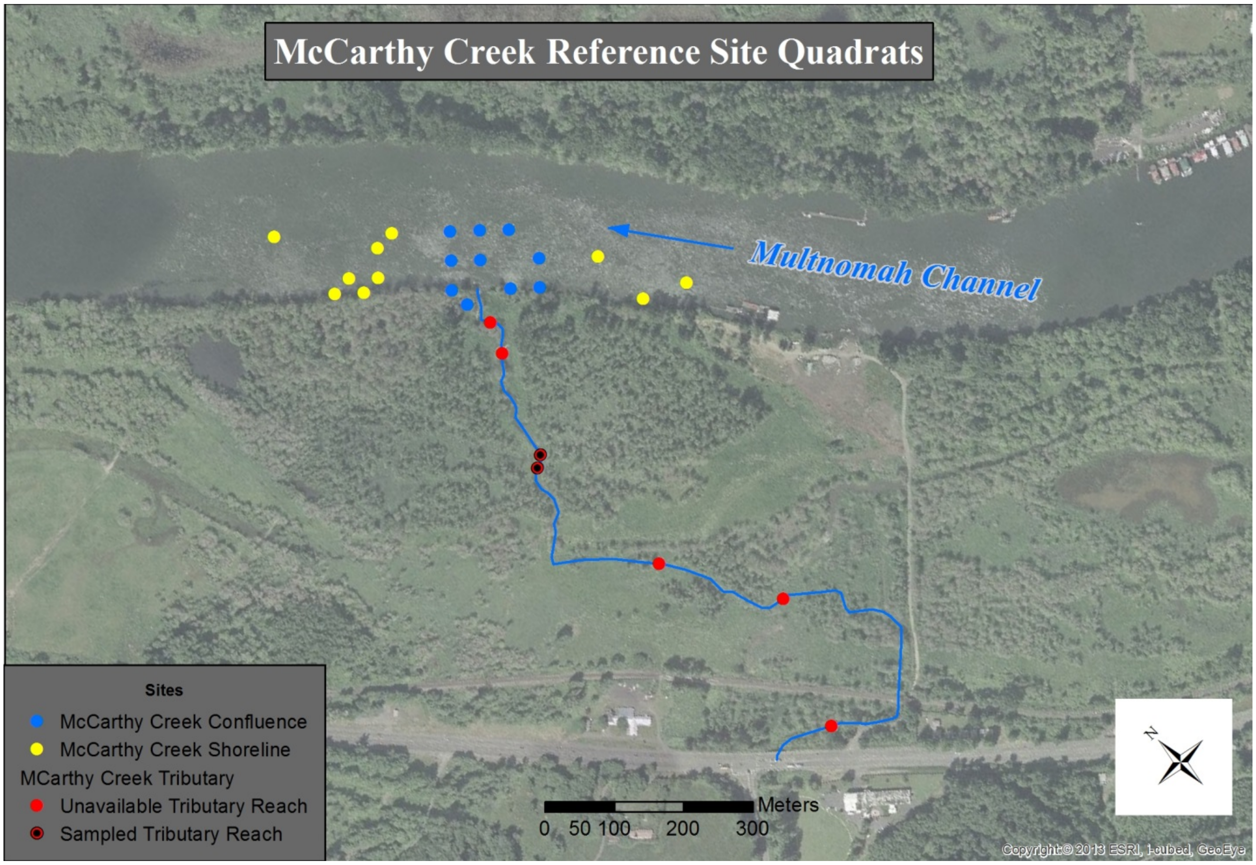

Figure 10. McCarthy Creek reference site. Confluence quadrats (blue points), shoreline quadrats (yellow points), and tributary quadrats (red points) sampled in 2017.

Figure 11. Columbia Slough reference site confluence quadrats (blue points) were sampled in 2017.

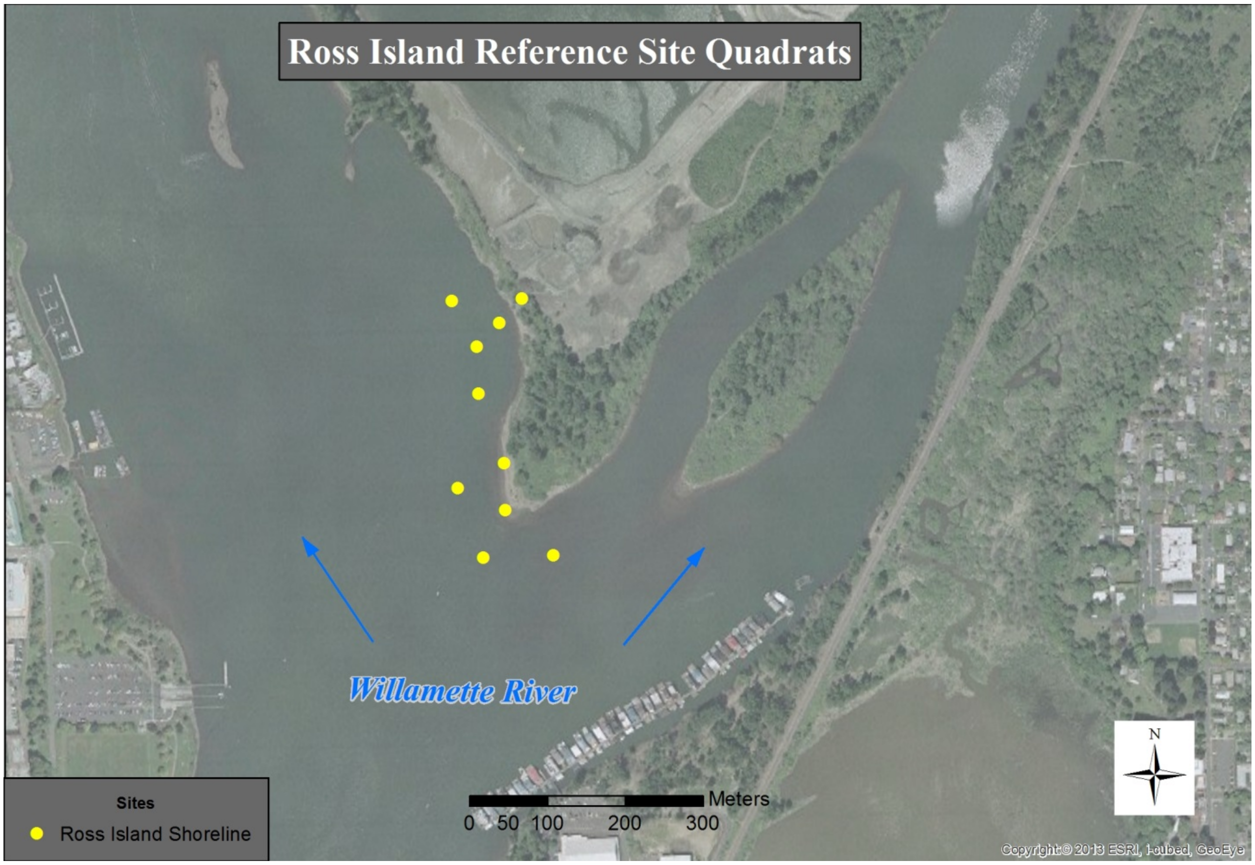

Figure 12. Ross Island reference site shoreline quadrats (yellow points) were sampled in 2017.

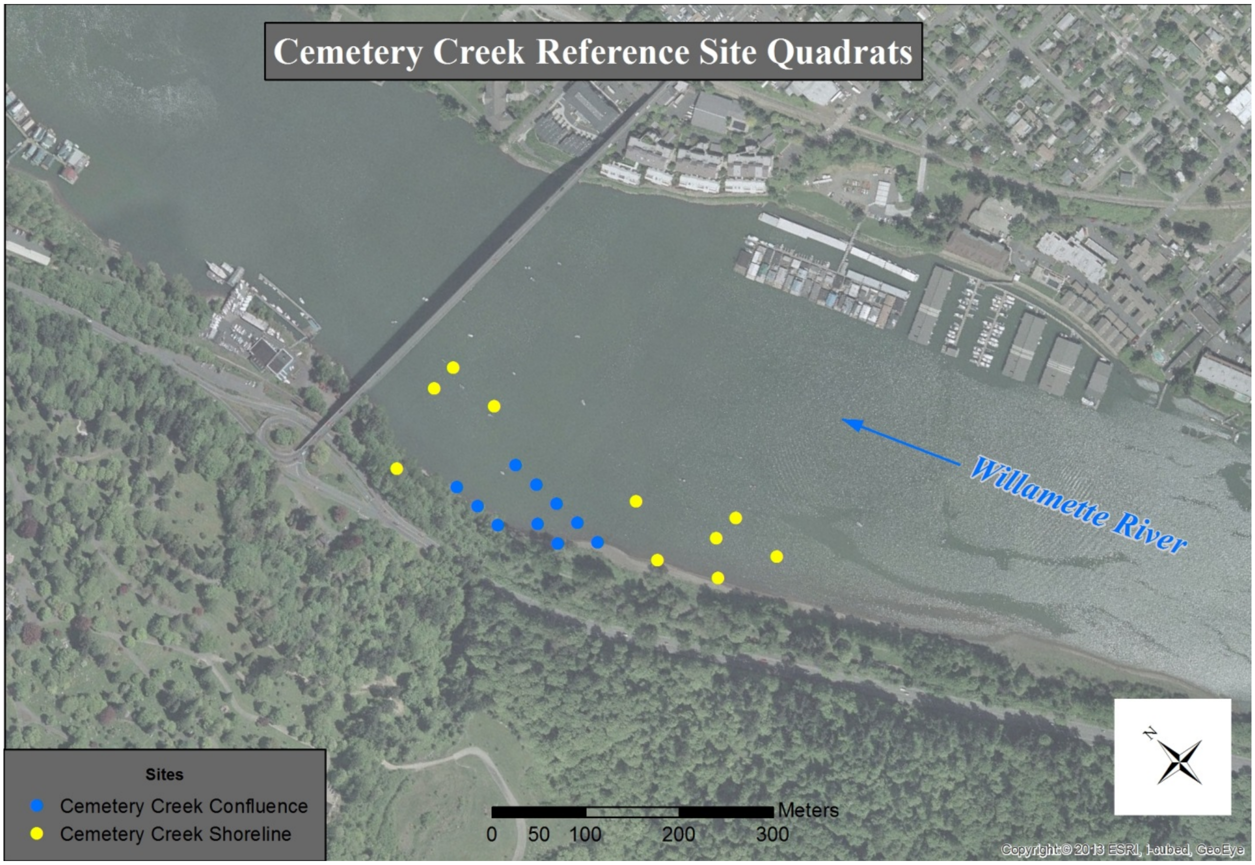

Figure 13. Cemetery Creek reference site. Confluence (blue points) and shoreline (yellow points) were sampled in 2017. No tributary sampling was conducted in Cemetery Creek in 2017 due to a lack of viable habitat.

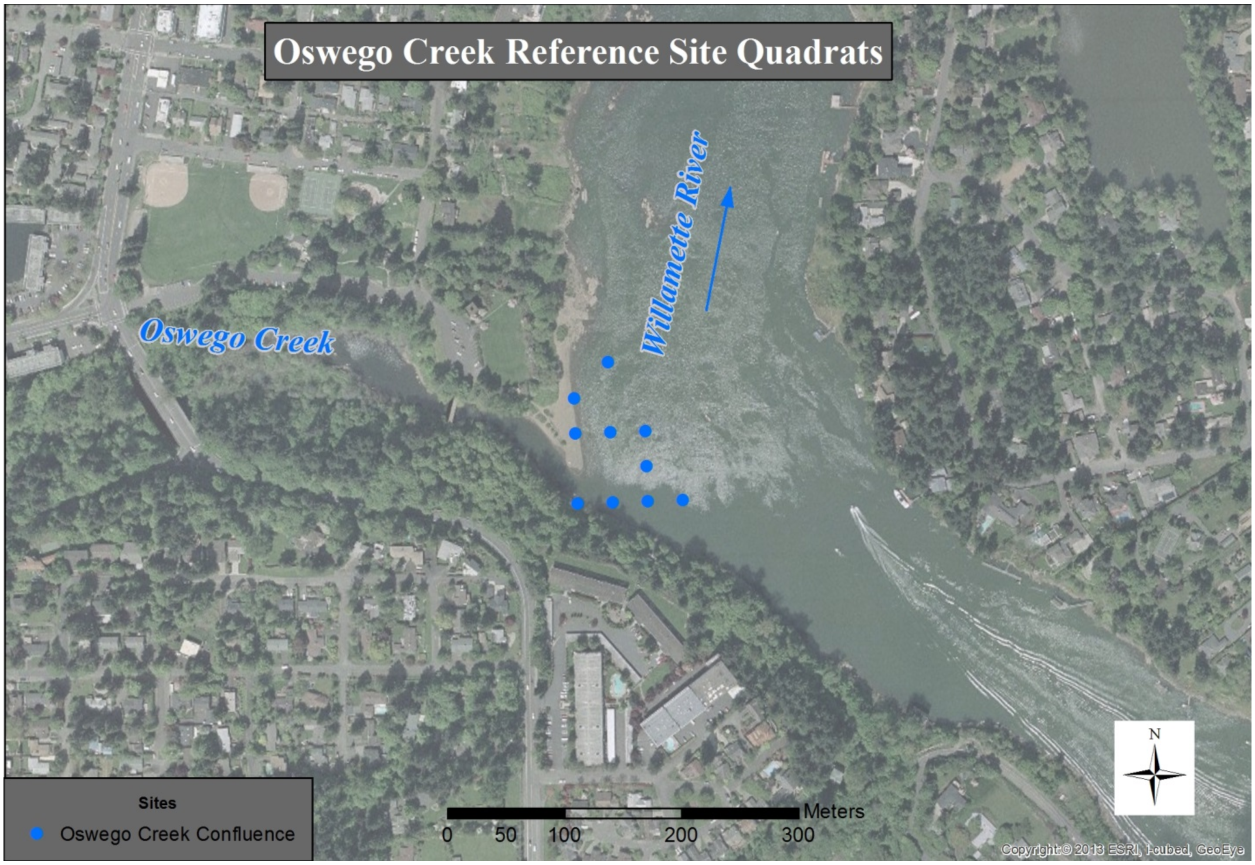

Figure 14. Oswego Creek reference site shoreline quadrates (blue points) sampled in 2017.

Results

All lamprey collected at restoration sites were of the larval life stage, no detections of juveniles or evidence of adults (i.e., spawning nests) occurred and no suitable spawning substrates were observed. 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 are site-specific depth, temperature, and conductivity are summarized in Table 2**.**

Restoration Sites

Alder Point Restoration Site

Larval lamprey (n = 3) were detected in 1 of 30 confluence quadrats (*d* = 0.03; Table 1, Figure 3), and 2 of 10 shoreline quadrats (*d* = 0.2). No lampreys were detected in 10 quadrats sampled in the newly constructed Alder Slough. The maximum number of larvae occupying any individual quadrat was one. Species composition included Pacific Lamprey (n = 1, TL = 73 mm) and unidentifiable (less than 60 mm TL) lamprey (n = 2, TL = 31 mm, 33 mm).

Sample depths ranged from 0.3 m to 11.04 m, and larvae were detected at depths from 0.3 m to 3.0 m (Table 2). Water temperature ranged from 16.0°C to 19.1°C and conductivity ranged from 100.4 μS/cm 142.8 μS/cm. Sediment samples collected at each confluence quadrat were transferred to ALS Environmental Laboratory (Kelso, WA) in October 2017 for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses.

Harborton Restoration Site

Larval lamprey (n = 3) were detected in 1 of 10 confluence quadrats (*d* = 0.1; Table 1; Figure 4), and 1 of 10 north tributary quadrats (*d* = 0.1). No lamprey were detected in 10 quadrats sampled in the south tributary. The maximum number of larvae occupying any individual quadrat was two. Species were comprised of *Lampetra spp.* (n = 1, TL = 73 mm) and unidentifiable lamprey (n = 2, TL = 49 mm, 56 mm).

Sample depths ranged from 0.61 m to 9.51 m, and larvae were detected at depths from 1.9 m to 2.1 m (Table 2). Water temperature ranged from 9.3°C to 9.8°C and conductivity ranged from 70.5 μS/cm to 73.9 μS/cm. Sediment samples collected at each confluence quadrat were transferred to ALS Environmental Laboratory (Kelso, WA) in November 2017 for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses.

Linnton Restoration Site

No lamprey were detected in any of the 10 confluence quadrats or 10 shoreline quadrats sampled at Linnton (Table 1; Figure 5).

Sample depths ranged from 0.3 m to 10.7 m (Table 2). Water temperature ranged from 21.5°C to 28.6°C and conductivity ranged from 88.4 μS/cm to 96.3 μS/cm. Sediment samples collected at each confluence quadrat were transferred to ALS Environmental Laboratory (Kelso, WA) in September 2017 for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses.

Triangle Park Restoration Site

No lamprey were detected in any of the 21 shoreline quadrats sampled at Triangle Park (Table 1; Figure 6).

Sample depths ranged from 0.90 m to 9.21 m (Table 2). Water temperature ranged from 15.1°C to 16.0°C and conductivity ranged from 91.2 μS/cm to 96.5 μS/cm. Sediment samples collected at each confluence quadrat were transferred to ALS Environmental Laboratory (Kelso, WA) in October 2017 for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses.

RM 13.1 Restoration Site

No lamprey were detected in any of the 10 shoreline quadrats sampled at RM 13.1 (Table 1, Figure 7).

Sample depths ranged from 0.46 m to 7.04 m (Table 2). Water temperature ranged from 22.1°C to 22.2°C and conductivity ranged from 87.7 μS/cm to 88.4 μS/cm. Sediment samples were not collected at RM 13.1.

Rinearson Natural Area

No sampling occurred at the Rinearson Natural Area restoration site in 2017, as restoration actions were not complete (Figure 8). Sampling is scheduled to occur in 2018 pending completion of restoration actions.

Reference Sites

All lamprey collected at reference sites were of the larval life stage, no detections of juveniles or evidence of adults (i.e., 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.

Multnomah Channel: Shoreline

No lamprey were detected in any of the 10 quadrats sampled at Multnomah Channel (Table 1; Figure 9).

Sample depths ranged from 3.8 m to 10.7 m (Table 2). Water temperature ranged from 23.5°C to 24.1°C and conductivity ranged from 120.8 μS/cm and 153.2 μS/cm.

McCarthy Creek: Tributary, Confluence and Shoreline

We sampled two of seven, 50 m tributary reaches visited in McCarthy Creek (Table 1; Figure 11). The remaining five reaches could not be sampled due to either dewatered conditions or water and mud in excess of wadeable depth. In the two reaches sampled, 99% of the habitat was estimated to be Type I and no larval lamprey were detected.

Within the mainstem reaches, larval lamprey (n = 2) were detected at 1 of 10 confluence quadrats sampled (*d* = 0.1) and 0 of 10 shoreline quadrats (Table 1, Figure 11). Species were comprised of Pacific Lamprey (n = 1, TL = 69 mm) and *Lampetra spp.* (n = 1, TL = 155 mm).

Sample depths in the confluence and shoreline ranged from 1.0 m to 10.2 m, and larvae were detected at a depth of 0.6 m (Table 2). Water temperature ranged from 21.6°C to 21.9°C and conductivity ranged from 97.5μS/cm to 109.4 μS/cm. Water temperature in the tributary was 8.9°C and conductivity was 215 μS/cm.

Columbia Slough: Confluence

Larval lamprey (n = 1) were detected at 1 of 10 confluence quadrats sampled (*d* = 0.1) and was identified as a Pacific Lamprey (TL = 71; Table 1, Figure 12).

Sample depths ranged from 0.3 m to 4.3 m and the larvae was collected at 0.7 m (Table 2). Water temperature ranged from 23.1°C to 25.5°C and conductivity ranged from 159.2 9μS/cm to 199.89μS/cm.

Ross Island: Shoreline

Larval lamprey (n = 6) were detected at 3 of 10 quadrats sampled (*d* = 0.3; Table 1, Figure 13). The maximum number of larvae occupying any individual quadrat was three. Of the six larval lamprey collected at Ross Island, five were identified as Pacific lamprey (range TL = 57 mm to 97 mm), while one was too small to accurately identify visually (TL = 47 mm).

Sample depths ranged from 0.3 m to 8.23 m, and larvae were detected at depths from 0.3 m to 7.32 m (Table 2). Water temperature ranged from 18.2°C to 19.3°C and conductivity ranged from 84.4 μS/cm to 90.3 μS/cm. Sediment samples collected at each confluence quadrat were transferred to ALS Environmental Laboratory (Kelso, WA) in September 2017 for quantification of parameters such as grain size, grain type, and organic content. See Appendix 1 for information on sediment analyses.

Cemetery Creek: Confluence and Shoreline

No sampling was conducted in Cemetery Creek tributary habitat in 2017 (as in 2016) due to lack of viable habitat (< 10% was Type I habitat).

Larval lamprey (n = 16) were detected at 6 of 10 confluence quadrats sampled (*d* = 0.6), and 4 of 10 shoreline quadrats (*d* = 0.4; Table 1 Figure 14). The maximum number of larvae occupying any individual quadrat was two. Of the 16 larvae collected at Cemetery Creek, six were identified morphologically as a Pacific Lamprey (TL range = 58-83 mm), and ten were too small to accurately identify visually (TL range = 21-48 mm).

Sample depths ranged from 0.2 m to 8.1 m, and larvae were detected at depths from 0.2 m to 5.0 m (Table 2). Water temperature ranged from 21.2°C to 22.1°C and conductivity ranged from 80.6μS/cm to 83.1 μS/cm.

Oswego Creek: Confluence

Larval lamprey (n = 9) were detected at 5 of 10 confluence quadrats sampled (*d* = 0.5; Table 1; Figure 15). The maximum number of larvae occupying any individual quadrat was three. Species were comprised of Pacific Lamprey (n = 3) and unidentifiable lamprey (n = 6).

Of the nine larval lampreys collected at Oswego Creek confluence, three were identified morphologically as a Pacific lamprey (TL = 59 mm, TL = 63 mm, and TL = 74 mm) and six were too small to identify visually (range TL = 26-33 mm; Figure 12). The maximum number of larvae occupying any individual quadrat was three.

Sample depths ranged from 0.5 m to 7.5 m, and larvae were detected at depths from 0.8 m to 4.9 m (Table 2). Water temperature ranged from 17.6°C 18.6°C and conductivity ranged from 82.3 μS/cm to 143.2 μS/cm.

Table 1. 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 (i.e., UNID).

	Site		Quadrats				Pacific Lamprey		*Lampetra spp.*		UNID		
			Visited	Sampled	Occupied	*d*	*N*	TL (mm) Range	*N*	TL (mm)	*N*	TL (mm) Range	Total *N*
Restoration	Alder Point	Confluence	30	30	1	0.03	0	-	0	-	1	33	1
		Shoreline	10	10	2	0.2	1	73	0	-	1	31	2
		Slough	10	10	0	0	0	-	0	-	0	-	0
	Harborton	Confluence	10	10	1	0.1	0	-	0	-	2	49, 56	2
		North Trib.	10	10	1	0.1	0	-	1	73	0	-	1
		South Trib.	10	10	0	0	0	-	0	-	0	-	0
	Linnton	Confluence	10	10	0	0	0	-	0	-	0	-	0
		Shoreline	10	10	0	0	0	-	0	-	0	-	0
	Triangle Park	Shoreline	21	21	0	0	0	-	0	-	0	-	0
	RM 13.1	Shoreline	10	10	0	0	0	-	0	-	0	-	0
Reference	Multnomah Channel	Shoreline	10	10	0	0	0	-	0	-	0	-	0
	McCarthy Creek	Confluence	10	10	1	0.1	1	69	1	155	0	-	2
		Shoreline	10	10	0	0	0	-	0	-	0	-	0
		Tributary	7	2	0	0	0	-	0	-	0	-	0
	Columbia Slough	Confluence	11	10	1	0.1	1	71	0	-	0	-	1
	Ross Island	Shoreline	13	10	3	0.3	5	57-97	0	-	1	-	6
	Cemetery Creek	Confluence	10	10	6	0.6	3	76-83	0	-	7	21-52	10
		Shoreline	10	10	4	0.4	3	58-81	0	-	3	21-48	6
	Oswego Creek	Confluence	10	10	5	0.5	3	59-74	0	-	6	26-33	9

Table 2. Habitat variables measured at restoration and reference sites sampled in 2017. 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	2017 Date Sampled	Capture Depth (m) range	Depth (m) mean ± SE	Temperature (°C) Mean ± SE	Conductivity (µS/cm) Mean ± SE	Sediment Collected?
Restoration	**Alder**	27-28 Sept	0.3-3.0	2.6 ± 0.4	17.4 ± 0.1	122.2 ± 1.9	Y
	Harborton	16-17 Nov	1.9-2.1	3.0 ± 0.4	9.6 ± 0.0	71.1 ± 0.1	Y
	Linnton	29-Aug		4.2 ± 0.8	22.5 ± 0.6	92.4 ± 0.5	Y
	Triangle	25-Sep		4.5 ± 0.5	15.8 ± 0.0	92.9 ± 0.4	Y
	PGE RM 13.1	20-Jul		5.0 ± 0.7	22.1 ± 0.0	88.0 ± 0.1	N
Reference	**Multnomah Channel**	15-Aug		8.2 ± 0.6	23.7 ± 0.1	139.3 ± 3.8	N
	McCarthy Creek	31-Aug	0.6	5.2 ± 0.7	21.7 ± 0.0	102.0 ± 1.2	Y
	McCarthy Creek Tributary	7-Nov		-	8.9	215.0	N
	Columbia Slough	15-Aug					Y
	Ross Island	19-Sep	0.3-7.3	2.3 ± 1.0	18.5 ± 0.1	85.7 ± 0.6	Y
	Cemetery Creek	17-Aug	0.2-5.0	2.6 ± 0.6	21.5 ± 0.1	81.9 ± 0.2	N
	Oswego Creek	19-Sep	0.8-4.9	2.9 ± 0.8	17.9 ± 0.1	92.4 ± 6.1	Y

Table 3. Occupancy results from pre- and post-restoration sampling at restoration and reference sites across all sampling years. Total number of quadrats visited, sampled, occupied by larval lamprey, and corresponding larval lamprey detection probability (*d*).

Site Type	Site Status	Sample Year	Site	Sample Area	Quadrats Visited	Quadrats Sampled	Quadrats Occupied	Quadrats *d*	Pacific Lamprey	*Lampetra* spp.	UNID	Total *N*
Restoration	Pre Yr 1	2014	**Alder Point**	Shoreline	30	29	2	0.07	0	3	0	3
		2015	**Rinearson**	Confluence	13	10	3	0.3	3	0	3	6
				Tributary		7	1	0.14	3	0	0	3
	Post Yr 1	2016	**Alder Point**	Confluence	30	30	1	0.03	0	0	1	1
				Shoreline	10	10	1	0.1	0	1	0	1
				Slough	10	10	0	0	0	0	0	0
	Post Yr 2	2017	**Alder Point**	Confluence	30	30	1	0.03	0	0	1	1
				Shoreline	10	10	2	0.2	1	0	1	2
				Slough	10	10	0	0	0	0	0	0
	Pre Yr 1		**Harborton**	Confluence	10	10	1	0.1	0	0	2	2
				North Trib.	10	10	1	0.1	0	1	0	1
				South Trib.	10	10	0	0	0	0	0	0
			Linnton	Confluence	10	10	0	0	0	0	0	0
				Shoreline	10	10	0	0	0	0	0	0
			Triangle Park	Shoreline	21	21	0	0	0	0	0	0
			PGE RM 13.1	Shoreline	10	10	0	0	0	0	0	0
Reference		2014	**Ross Island**	Shoreline	28	26	5	0.19	0	6	0	6
		2015	**Cemetary Creek**	Confluence	10	10	5	0.5	2	0	6	8
				Tributary	2	2	0	0	0	0	0	0
		2016	**Multnomah Channel**	Shoreline	10	10	1	0.1	0	0	1	1
			McCarthy Creek	Confluence	10	10	0	0	0	0	0	0
				Shoreline	10	10	1	0.1	0	0	1	1
				Tributary	7	2	0	0	0	0	0	0
			Columbia Slough	Confluence	10	10	0	0	0	0	0	0
			Ross Island	Shoreline	10	10	2	0.2	2	0	0	2
			Cemetery Creek	Confluence	13	10	2	0.2	0	0	2	2
				Shoreline	10	10	3	0.3	1	0	2	3
			Oswego Creek	Confluence	10	10	4	0.4	2	1	3	6
		2017	**Multnomah Channel**	Shoreline	10	10	0	0	0	0	0	0
			McCarthy Creek	Confluence	10	10	1	0.1	1	1	0	2
				Shoreline	10	10	0	0	0	0	0	0
				Tributary	7	2	0	0	0	0	0	0
			Columbia Slough	Confluence	11	10	1	0.1	1	0	0	1
			Ross Island	Shoreline	13	10	3	0.3	5	0	1	6
			Cemetery Creek	Confluence	10	10	6	0.6	3	0	7	10
				Shoreline	10	10	4	0.4	3	0	3	6
			Oswego Creek	Confluence	10	10	5	0.5	3	0	6	9

Findings

In 2017, we found that larval lamprey occupied few restoration sites, prior to restoration actions, as compared to reference sites where lamprey occupied the majority of sites. Lamprey occupied Alder Point and Harborton sites, however no lamprey occupied Linnton, Triangle Park, or RM 13.1 sites. Five (of six) reference sites were occupied (McCarthy Creek, Columbia Slough, Ross Island, Cemetery Creek, and Oswego Creek) but no lamprey occupied Multnomah Channel.

Restoration actions are complete at one site, Alder Point and pre and post monitoring can be compared to the reference site Ross Island, which is sampled concurrently. Within site comparisons of pre and post-restoration sampling show similarities in patterns of larval lamprey occupancy and rates of detection. In the newly constructed Alder Slough, no lamprey were detected in 2016 or 2017. It is not known whether, and after how long larval lamprey colonization of this newly-created habitat may occur. Continued monitoring of larval lamprey occupancy of Alder Slough and its paired reference site Ross Island is warranted and will provide a better understanding of larval lamprey colonization rates of newly available habitats.

Reference site monitoring is an important component of the lamprey monitoring program associated with the Portland Harbor Superfund restoration. 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 six reference sites (including Ross Island which was sampled in 2016 and 2017) is ongoing. The initial selection of reference sites included habitats that were, to the greatest extent possible, similar to those of proposed restoration sites (including confluence, shoreline and wadeble slough or tributary habitats). Many small, wadeable sized tributaries (1^{st} and 2^{nd} order) of the lower Willamette River have been identified for possible restoration. Consequently, we included as reference sites two tributary streams in the lower Willamette River and Multnomah Channel; Cemetery Creek and McCarthy Creek. Confluence habitats in the mainstem Willamette River and Multnomah Channel at each tributary were also selected. It was presumed that the two reference tributaries were potentially suitable for Pacific lamprey occurrence. However, after closer inspection and multiple attempted sampling events at these tributaries (2014, 2016, and 2017), they were found to have marginal value as reference sites. Cemetery Creek has a barrier culvert at a railroad crossing less than 100 m from its confluence with the Willamette River. McCarthy Creek below Highway 30 was found to be mostly dewatered during the sampling period, as the stream appears to be diverted from its natural channel. In an effort to maximize the utility of future reference site sampling, we propose to eliminate the wadeable portions of Cemetery Creek and McCarthy Creek from the group of reference sites. As such, the 10 confluence quadrats in the mainstem Willamette River and Multnomah Channel associated with each of these tributaries would also be eliminated, reducing the total number of mainstem sample quadrats at the six reference sites from 80 to 60. However, to best understand the impact of some of the restoration, including wadeable reference sites remains important. Thus, an effort to identify alternate reference tributaries in the lower Willamette River is ongoing. Finding suitable alternative streams has proven to be a challenge. If suitable tributaries are not identified, the wadeable depth reference tributary sampling may be eliminated from future sampling efforts or we may propose to monitor wadeable tributaries outside the specific Superfund area.

Similar to the results of previous years' sampling (Jolley et al. 2015; Silver et al. 2016) we observed a combination of larval Pacific Lamprey and *Lampetra* spp. in the lower Willamette Mainstem habitats associated with the Alder Point restoration continue to appear suitable to and available for colonization by larvae moving downstream in the mainstem Willamette River and Multnomah channel. This was evidenced by the presence of larvae in shoreline and confluence habitats. The newly created sloughs did not appear to have been colonized by larval lamprey. It remains unclear whether they 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. The larvae detected at the Alder Point restoration site 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 basin) and gradually dispersed downstream to their location of capture. Within the Superfund site, no known spawning areas have been identified in the mainstem Willamette River or Multnomah Channel, although mainstem spawning may be plausible in areas where suitable substrates and flow regimes occur. 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). Future sampling of shoreline, confluence, and slough habitats at Alder Point are planned and will be useful for monitoring spatial and temporal changes in occupancy including possible colonization within newly created habitats in Alder Slough.

This report details findings at the Alder Point restoration site in years one and two following habitat restoration. According to the initial lamprey monitoring plan, post-restoration monitoring will occur annually at restoration sites through the initial five years post-restoration. Thus, we anticipate continuous monitoring of Alder Point in calendar years 2018 through 2020. Post-restoration monitoring at Rinearson Natural Area is anticipated to begin in calendar year 2018 (assuming restoration is finalized) and likewise occur annually over the initial five years post-restoration. Annual sampling of reference sites is also expected to continue in conjunction with restoration site monitoring. The results of 2018 restoration and reference site sampling, along with potential pre-restoration monitoring at newly proposed restoration sites will be summarized in a report in spring of 2019.

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Literature Cited

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.

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.

Meeuwig, M.H. and J.M. Bayer. 2005. Morphology and aging precision of statoliths from larvae of Columbia River Basin lampreys. North American Journal of Fisheries Management 25:38-48.

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.

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.

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.

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.

Spice, E. K., T. A. Whitesel, C. T. McFarlane, and M. F. Docker. 2011. Characterization of 12 microsatellite loci for the Pacific lamprey, *Entosphenus tridentatus* (Petromyzontidae), and cross-amplification in five other lamprey species. Genetics and Molecular Research 10(4):3246–3250.

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.
ATTN: Jennifer Kassakian
2067 Massachusetts Ave.
Cambridge, MA 02140

U.S. Fish and Wildlife Service
Columbia River Fish and Wildlife Conservation Office
1211 SE Cardinal Court, Suite 100
Vancouver, WA 98683

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