U.S. Fish and Wildlife Service

Occurrence, Detection, and Habitat Use of Larval Lamprey in the Lower White Salmon River and Mouth: Post-Condit Dam Removal

FY 2012 Annual Report

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Columbia River Fisheries Program Office
Vancouver, WA 98683

On the cover: *Lower White Salmon River (Skamania County), Washington just upstream of the mouth at Bonneville Reservoir showing newly deposited fine sediments from Northwestern Reservoir after the breach of Condit Dam. Photo taken in August 2012 by Jeff Jolley.*

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Abstract – Pacific lamprey *Entosphenus tridentatus* are declining in the Columbia River Basin and larval lamprey use of large, mainstem river habitats is unknown. Their use of shallow depositional areas associated with tributary inputs is equally unknown. We used a deepwater electrofisher to explore occupancy, detection, and habitat use of larval Pacific lamprey and *Lampetra* spp. in the lower reaches and mouths of the Klickitat, White Salmon, and Wind rivers, tributaries to Bonneville Reservoir and the Columbia River. We repeated similar work conducted in 2011. Specifically, sampling in 2011 in the White Salmon River and mouth took place prior to the breach of Condit Dam and subsequent release of sediments from Northwestern Reservoir. The Wind River and Klickitat River were used as reference rivers. We used a generalized randomized tessellation stratified (GRTS) approach to select sampling quadrats in a random, spatially-balanced order and used a deepwater electrofisher to collect larval lamprey. Pacific lamprey, *Lampetra* spp., and unidentified lamprey occupied all strata. We calculated reach-specific detection probabilities which ranged from 0.03 to 0.29. Detection was lowest at the White Salmon River mouth and lower Klickitat River and highest at the Wind River mouth. A newly-formed delta is now present at the White Salmon River mouth and is occupied by Pacific lamprey; this habitat did not exist prior to the breach and removal of Condit Dam. The effect of water level management in these shallow habitats on larval lamprey should be considered when conserving these important species.

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Introduction

Pacific lamprey *Entosphenus tridentatus* in the Columbia River Basin and other areas have experienced a great decline in abundance (Luzier et al. 2011). They are culturally important to Native American tribes, are ecologically important within the food web, and whose decline provides insight into the impact of human actions on ecological function (Close et al. 2002). Information is lacking on basic biology, ecology, and population dynamics required for effective conservation and management.

Pacific lampreys have a complex life history that includes multiple year larval (ammocoete), migratory juvenile, and adult marine phases (Scott and Crossman 1973). Larvae and juveniles are strongly associated with stream and river sediments. Larvae live burrowed in stream and river sediments, 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 habitat preference of larvae comes from Columbia River Basin tributary systems (Moser and Close 2003; Torgersen and Close 2004; Stone and Barndt 2005; Stone 2006) and coastal systems (Farlinger and Beamish 1984; Russell et al. 1987; Gunckel et al. 2009).

Lamprey larvae are known to occur in sediments of shallow streams but their use of larger river (i.e., >5th order [1:100,000 scale]; Torgersen and Close 2004) 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). Anecdotal observations exist regarding larval lamprey occurrence in large river habitats mainly at hydropower facilities or in downstream bypass reaches (Hammond 1979; Moursund et al. 2003; Dauble et al. 2006; CRITFC 2008), impinged on downstream screens, or through observation during dewatering events. Occurrences at hydropower facilities are generally thought to be associated with downstream migration and specific collections of presumably migrating larvae have been made in large river habitats (Beamish and Youson 1987; Beamish and Levings 1991). Sea lamprey *Petromyzon marinus* larvae have been documented in deepwater habitats in tributaries of the Great 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*b*), and in the St. Marys River, a large river that connects Lake Superior to Lake Huron (Young et al. 1996). References to other species occurring in deepwater or lacustrine habitats are scarce (American brook lamprey *Lampetra appendix*; Hansen and Hayne 1962). Previous studies of larval Pacific lamprey and *Lampetra* spp. use of mainstem river habitats (Silver et al. 2008; Jolley et al. 2012c) indicated larvae of both Pacific lamprey and *Lampetra* spp. across a wide size range occupy broad areas of the Willamette River and the Columbia River mainstem (Jolley et al. 2011a, 2011b, 2012a, 2012b).

The White Salmon River in southwest Washington originates on Mount Adams and the basin is within lands ceded to the United States by the Yakama Nation (Figure 1). Historically, the basin supported steelhead *Oncorhynchus mykiss*, coho salmon *O. kisutch*, Chinook salmon *O.tshawytscha*, coastal cutthroat trout *O. clarki*, Pacific lamprey and western brook lamprey. However, the construction of Condit Dam in the early 1900's, caused declines in anadromous fish production (Rawding 2000). All fish passage was blocked after fish ladders were destroyed in the early 1900s. Relatively little fish production occurred downstream of Condit Dam due to habitat loss and alteration of the natural flow regime (Rawding 2000).

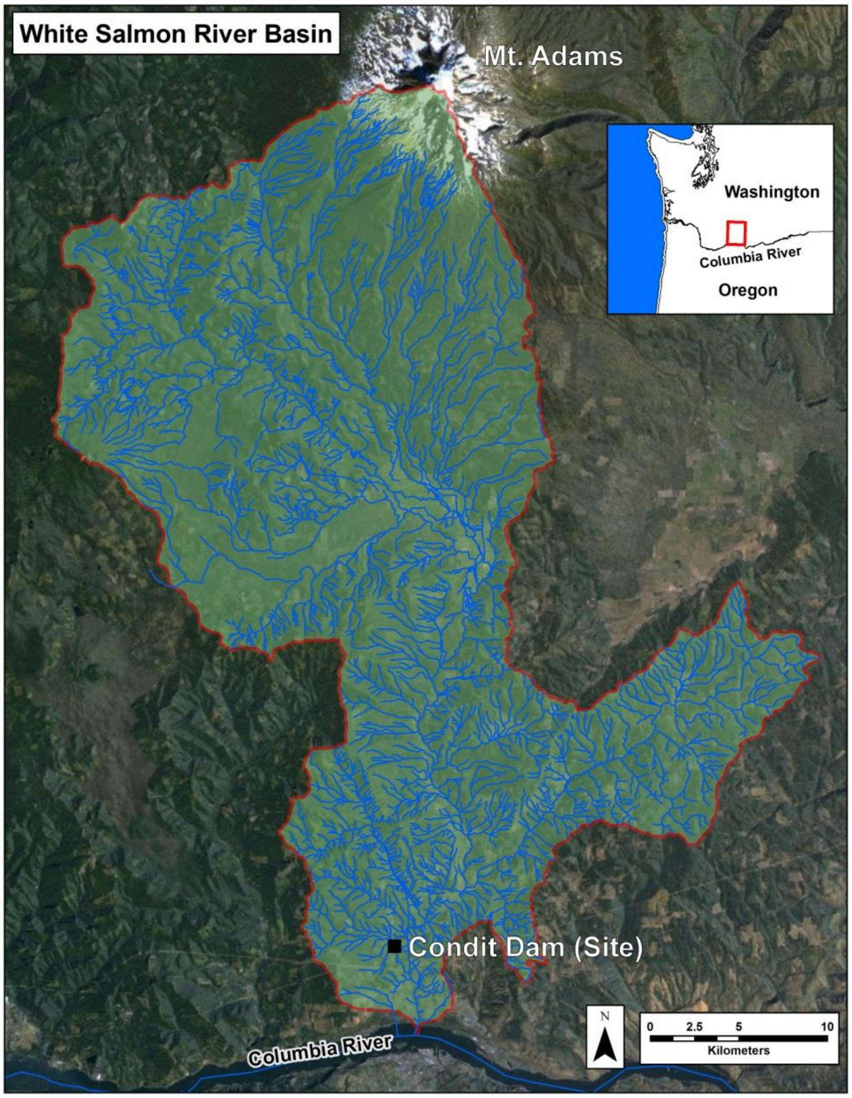

Figure 1. White Salmon River basin in Washington.

Condit Hydroelectric Project was breached in October 2011 and was completely removed by September 2012. It was owned by PacifiCorp, and included the 144-m long Condit Dam (38-m high). The dam was located 5.3 km upstream from the confluence of the White Salmon River and the Columbia River and was the only dam on the 72-km mainstem White Salmon River (Figure 1). Sediment from the impounded Northwestern Reservoir was allowed to rapidly flush downstream after the breach and continues to mobilize and move during the high winter and spring flows. The removal of Condit Dam has reconnected historic fish spawning habitat to the mainstem of the Columbia River. The U.S. Fish and Wildlife Service has partnered with the Yakama Nation, the U.S. Geological Survey, the Washington Department of Fish and Wildlife, NOAA Fisheries and PacifiCorp to assess the impact that the removal of Condit Dam may have on fish populations and aquatic habitats in the White Salmon River basin. Pacific lamprey was identified as a high priority species for restoration.

Preliminary survey data of lamprey species in the White Salmon River basin indicated that resident western brook lampreys were rare above Condit Dam, while anadromous Pacific lampreys were locally extirpated (Rawding 2000). Habitat surveys have suggested that there is suitable habitat both downstream and upstream of the dam site for spawning and rearing of anadromous fish, including lampreys. We began assessing lamprey occupancy and habitat in the White Salmon River basin in 2007. Lampreys have been previously detected in the basin; western brook lampreys were present above Condit Dam, in Northwestern Reservoir, Trout Lake Creek (Silver et al. 2010) and possibly Buck Creek (B. Allen, USGS, personal communication). Lamprey, including Pacific lamprey, have also been detected in the lower White Salmon River (Allen and Connolly 2011; Silver et al. 2010; Jolley et al. 2012b).

This work continued in 2011 (Jolley et al. 2012b) and 2012, focused on the lower White Salmon River, the reach downstream of Condit Dam to the Columbia River. This reach was the most immediately and dramatically affected by the removal of Condit Dam and release of Northwestern Reservoir sediments. In general, we documented presence or absence of larval Pacific lamprey and *Lampetra* spp. in lowest 1.4 km of the lower White Salmon River. Collectively, this work will serve as a baseline for comparison for post-Condit Dam removal studies. In 2012, our specific objectives were to:

1) Document whether larval lamprey occupied the lower White Salmon River and river mouth (within Bonneville Reservoir) after the breach and removal of Condit Dam

2) Document whether larval lamprey occupied the lower section and river mouth (within Bonneville Reservoir) of two reference rivers, the Wind River and the Klickitat River.

3) Given they were occupied, determine the probability of detecting larval lamprey in these rivers using a deepwater electrofisher.

4) Document whether migrating adult Pacific lamprey were ascending the White Salmon River

The long-term objectives of the project are to: 1) determine if anadromous lampreys return to previously unavailable spawning habitat after removal of Condit Dam; 2) determine the time for anadromous lampreys to return after dam removal and 3) determine the effects of dam removal on lamprey spawning and rearing habitats above and below the site of Condit Dam.

Methods

Study area

The White Salmon River is a 5th order (1:100,000 scale) river, flows from the south side of 3,742 m peak of Mount Adams and enters the Columbia River at Rkm 269 (Figure 1 and 2). The basin covers 1,000 km^2 and Condit Dam is 5.3 km upstream from the confluence of the White Salmon River and Columbia River. The Wind River is a 5th order river; the basin is west of the White Salmon River basin and originates in McClellan Meadows of the western Cascade Mountains. The basin covers 582 km^2 and enters the Columbia River at Rkm 249 (Figure 2).

Shipherd Falls is located 3 km from the mouth that historically blocked anadromous fish passage but a ladder was constructed in the 1950's providing fish passage (Connolly et al. 1999). The Klickitat River is a 5th order river; the basin is east of the White Salmon River basin and originates near Cispus Pass in the Goat Rocks region of the Cascade Mountains. The basin covers 3,496 km^2 and enters the Columbia River at Rkm 290 (Figure 2). It is one of longest undammed rivers in the Pacific Northwest although the gradient is steep and there are many waterfalls which may be challenges to fish passage (Sharp et al. 2000). These two rivers were chosen as reference sites to the White Salmon River and are of comparable size, function, and proximity. All rivers presumably have fine sediments originating from the Cascade Mountains that would provide adequate rearing habitats for larval lamprey.

Occupancy

We estimated occupancy of larval lamprey in the lower White Salmon, Wind, and Klickitat rivers and associated river mouths (within Bonneville Reservoir; Figure 2) by using an approach that was applied to studies of larval lamprey in the Willamette and Columbia rivers (see Jolley et al. 2011a, 2011b; 2012a, 2012b). The approach has several requirements: 1) a site- and gear-specific detection probability (assumed or estimated); 2) the probability of presence at a predetermined acceptably low level (given no detection); and 3) random identification of spatially-balanced sample sites that allow estimation of presence and refinement of detection probabilities. A reach-specific probability of detection, d_{reach}, was calculated as the proportion of quadrats (i.e., 30 m x 30 m sampling quadrat) occupied (i.e., larvae captured) by larval lamprey in the Lower Willamette River, an area known to be occupied. The posterior probability of reach 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 we knew the reach was occupied with larval lamprey, 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). Patterns of occupancy by river were compared using the Chi-square test for differences in probabilities (Conover 1999).

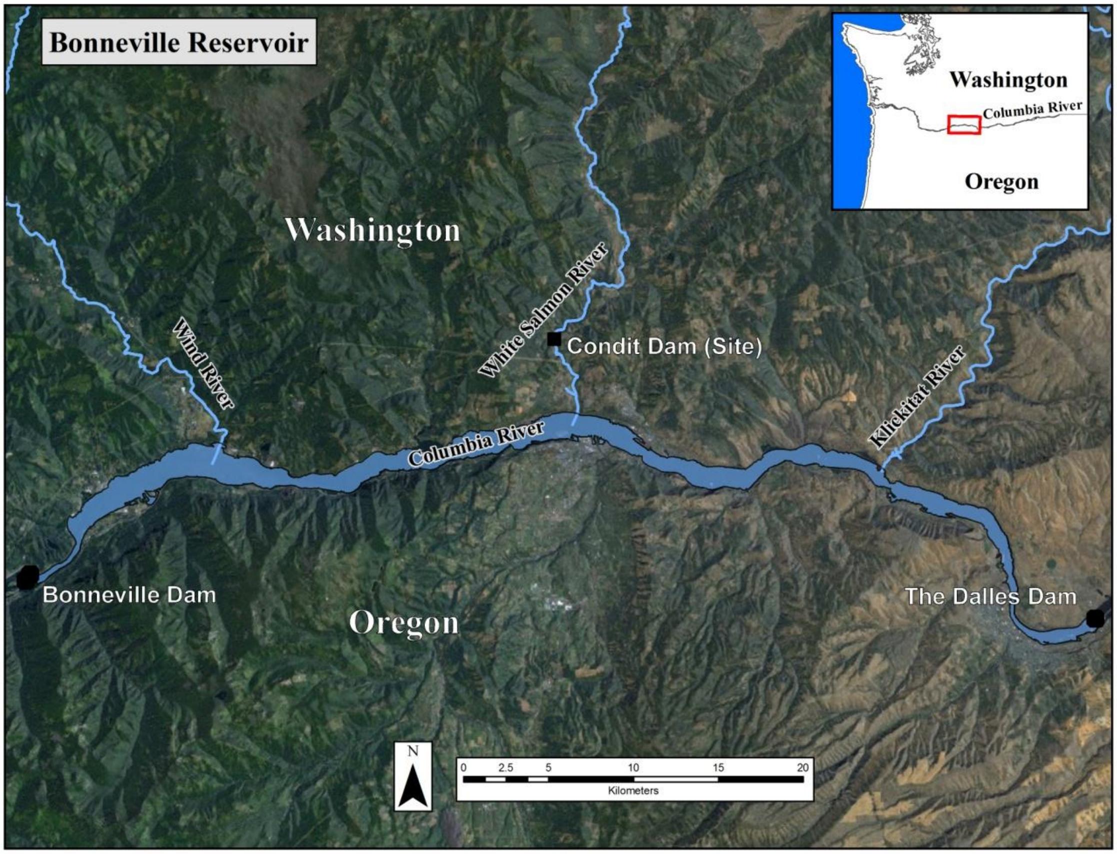

Figure 2. Bonneville Reservoir of the Columbia River and tributary inputs sampled for larval lamprey occupancy in 2012.

The lower reaches and river mouth areas of these rivers were sampled in May-September 2012 for larval lamprey occupancy. We sampled the Lower White Salmon River from the Highway 14 bridge upstream approximately 1.0 km, to where boat navigation was no longer possible. In 2011, we were able to sample the lower 1.4 km of the White Salmon River and used this distance to guide a similar sampling effort in the Klickitat River and Wind River. We attempted to repeat sampling the same quadrats as was done in 2011, ultimately we sampled upstream 1.0 km in the Klickitat River and approximately 1.25 km in the Wind River to where we could no longer navigate a boat due to shallow water (Figure 3). River mouth areas were defined as the area contained by a 0.5 km semi-circle from the point where the center of the tributary channel meets Bonneville Reservoir (Figure 4).

A sampling event consisted of using a deepwater electrofisher (Bergstedt and Genovese 1994) in a 30 m x 30 m quadrat (Jolley et al. 2012c). This quadrat size was selected based on the previous experience of sea lamprey researchers in the Great Lakes (M. Fodale, USFWS, personal communication) as their sampling approach evolved from a systematic to adaptive approach (Fodale et al. 2003*a*). A description of the complete configuration of the deepwater electrofisher is given by Bergstedt and Genovese (1994). The bell of the deepwater electrofisher was lowered from a boat to the river bottom. 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. Suction was produced by directing the flow from a pump through a hydraulic eductor, prohibiting ammocoetes from passing through the pump. Suction began approximately 5 seconds prior to shocking to purge air from the suction hose. Shocking was conducted for 60 seconds, and the suction pump remained on for an additional 60 seconds after shocking to ensure collected ammocoetes passed through the hose and emptied into a collection basket (27 x 62 x 25 cm; 2 mm wire mesh). 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*b*) and the Willamette River (Jolley et al. 2012c).

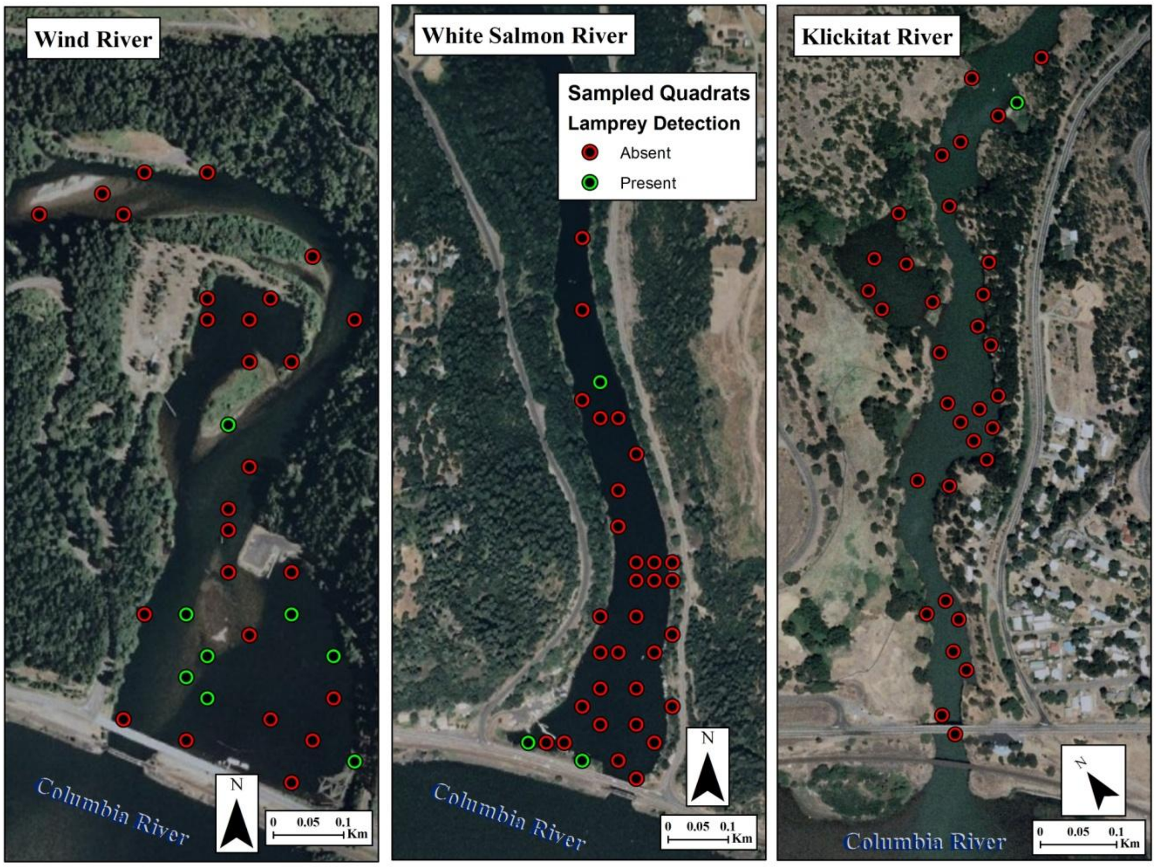

Figure 3. Lower reaches of the Wind River, White Salmon River, and Klickitat River sampled for lamprey occupancy in 2012. Symbols indicate sampling quadrats where lamprey were detected (green) or not detected (red).

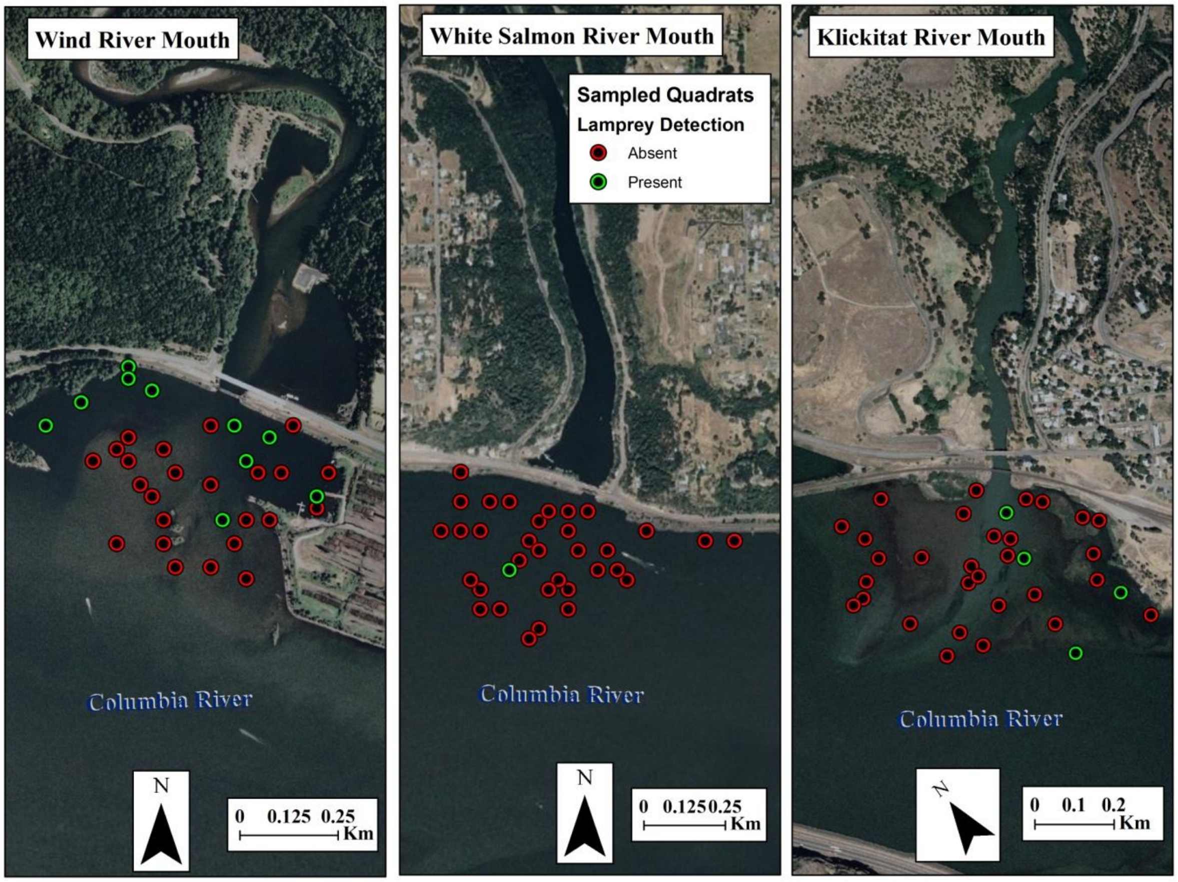

Figure 4. River mouths of the Wind River, White Salmon River, and Klickitat River sampled for lamprey occupancy in 2012. Symbols indicate sampling quadrats where lamprey were detected (green) or not detected (red).

We used a Generalized Random Tessellation Stratified (GRTS) approach to select sampling quadrats in a random, spatially-balanced order (Stevens and Olsen 2004). We developed a layer of 30 m x 30 m quadrats using ArcMap 9.3 (Environmental Systems Research Institute, Redlands, California) which was overlaid on each lower river section (Figure 5). There were 143, 205, and 253 quadrats in the lower reaches of each the Klickitat River, White Salmon River, and Wind River, respectively (Table 1). The Universal Trans Mercator (UTM) coordinates representing the center point of each quadrat were determined. The GRTS approach was applied to all quadrats to generate a random, spatially balanced sample design for these areas. This approach was used to generate an unbiased sample design that would allow the quantification of detection probabilities.

The quadrats were ordered sequentially as they were selected in the GRTS approach and the lower numbered quadrats were given highest priority for sampling. Based on previous occupancy sampling in a variety of areas, with detection rates ranging from 0.02 to 0.32 (Jolley et al. 2012a), we assumed a relatively low to moderate detection rate of 0.07 (given an area was occupied). At this detection rate, a minimal sampling effort of 17 quadrats was necessary to achieve 80% certainty of lamprey absence when they are not detected (see Jolley et al. 2012c).

To be conservative, we doubled that sampling rate to 34 quadrats. The GRTS approach allows increasing the sample effort, while maintaining a random and spatially-balanced design, when warranted (i.e., low detection). Quadrats that were not feasible due to dewatered conditions or excessive velocity (Table 1) were eliminated from the sample and all subsequent quadrats were increased in priority.

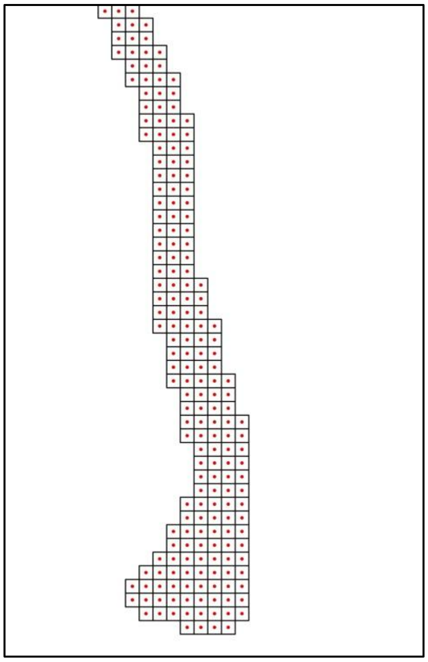

Figure 5. A schematic showing a hypothetical section of a river divided into 30 m x 30 m quadrats and associated UTM center points.

Collected lampreys were anesthetized in a solution of tricaine methanesulfonate (MS-222), identified as Pacific lamprey or *Lampetra* spp. according to caudal pigmentation (Goodman et al. 2009), and classified according to developmental stage (i.e., larvae, juvenile, or adult). Lampreys were measured (TL in mm), placed in a recovery bucket of fresh river water, and released after resuming active swimming behavior. Length-frequency histograms were constructed for each species to describe size structure.

Concurrent to each sampling event a sediment sample was taken from the river bottom by using a Ponar bottom sampler (16.5 cm x 16.5 cm). A 500 mL sample was labeled, placed on ice, and returned to the lab. Samples were oven-dried for 12 hours at 100°C to remove all water. Sediment size was characterized by weighing the component portions of the sample that collected on a set of sieves (opening sizes: 37.5 mm, 19 mm, 9.5 mm, 1 mm, 0.5 mm, and remainder less than 0.5 mm). Percent organic content of replicate samples was determined using loss-on-ignition methods (Heiri et al. 2001) by combusting organic material at 500-550° C for six hours.

Adult Pacific lampreys were also targeted for capture in the White Salmon River using pot traps (Luzier et al. 2006). The traps varied in dimensions and were 92 cm x 20 cm or 92 cm x 25 cm PVC pipe with a funnel on one end, an internal funnel and a one inch thick round wood hatch; funnel openings measured 5 cm in diameter. Traps were opportunistically fished in the mainstem White Salmon River at the Spring Creek National Fish Hatchery acclimation raceways site.

Results

We visited 34 to 39 quadrats in each lower river and river mouth area and ultimately sampled 34 or 35 quadrats in each lower river and river mouth. The feasibility of being able to sample a given quadrat ranged from 87% to 100% (Table 1). Some quadrats were not sampled because they were not feasible (dewatered conditions or excessive velocity). Larval lampreys occupied all rivers. Pacific lamprey and unidentified lamprey larvae occupied the lower Klickitat River (d=0.03) and mouth (d=0.12, Table 1). *Lampetra* spp. and unidentified lamprey occupied the lower White Salmon River (d = 0.09) and Pacific lamprey occupied the White Salmon River mouth (d=0.03). Pacific lamprey, *Lampetra* spp., and unidentified lamprey occupied the lower Wind River (d = 0.24, Table 1) and mouth (d=0.29). Detection probabilities differed among reaches (Fisher's Exact Test, *P*<0.05). Specifically, detection probabilities were greater at the Wind River mouth than those at the White Salmon River mouth or Lower Klickitat River (*P*=0.03).

Table 1. Total number of quadrats delineated, visited, sampled, and occupied and species present at three rivers in 2012. Unidentified larval lamprey are noted as "Unid".

	Quadrats								
Reach	Total	Visited	Sampled	Occupied	*d*	Pacific lamprey	*Lampetra* spp.	Unid	Total
Lower Klickitat River	143	35	34	1	0.029	1	0	0	1
Klickitat River mouth	359	34	34	4	0.118	3	0	2	5
Lower White Salmon River	205	39	34	3	0.088	0	4	0	4
White Salmon River mouth	423	39	35	1	0.029	1	0	0	1
Lower Wind River	253	34	34	8	0.235	4	10	1	15
Wind River mouth	353	36	34	10	0.294	6	15	16	37

Lamprey larvae ranged in size from <20 mm (typically those escaped through the mesh in the collection basket) to 136 mm. No differences in total length were detected by species or reach (two-way ANOVA, *P*>0.05) although sample sizes were small and this comparison was not powerful. Depths sampled ranged from 0.3 to 19.5 m and larvae were detected in depths ranging from 0.3 to 6.4 m. The total number of larvae occupying any individual quadrat ranged from 0 to 9.

Mean percent organic content ranged from 1.4 to 8.9% and was significantly higher in the Lower Wind River and Wind River mouth than the other reaches (ANOVA, *F*=7.36, df=5, *P*<0.0001; Table 2). Fine sediments were present in all river reaches although the Lower White Salmon River, White Salmon River mouth, and Lower Wind River had a higher percentage of larger-sized substrate (ANOVA, *P*<0.05; Figure 6). Large cobble/boulder substrate (too large for the dredge) was detected at 8 sites (24%) at the Lower Wind River and at the White Salmon River at 1 site (3%) and at 8 sites (23%) at the White Salmon River mouth (likely bedrock). Larval lamprey only occupied quadrats dominated by the three smallest substrate size categories.

Larval lampreys were also observed in the White Salmon River in supplemental efforts to this sample design. During reconnaissance efforts, larval western brook lampreys were detected with a backpack electrofisher on the mainstem White Salmon River at the Spring Creek National Fish Hatchery acclimation ponds. No adult lampreys were captured in the pot traps which were fished from 6/26/12 to 10/31/12 and checked weekly.

Table 2. Mean percent organic content in sediment in river reaches and mouths in 2012.

Reach	Mean percent organic content	Number	Standard error
Klickitat mouth	1.4	34	0.2
Lower Klickitat	2.7	34	0.5
Lower Wind	8.9	26	1.4
Lower White Salmon	2.5	33	0.3
Wind mouth	8.5	34	2.4
White Salmon mouth	3.2	25	0.6

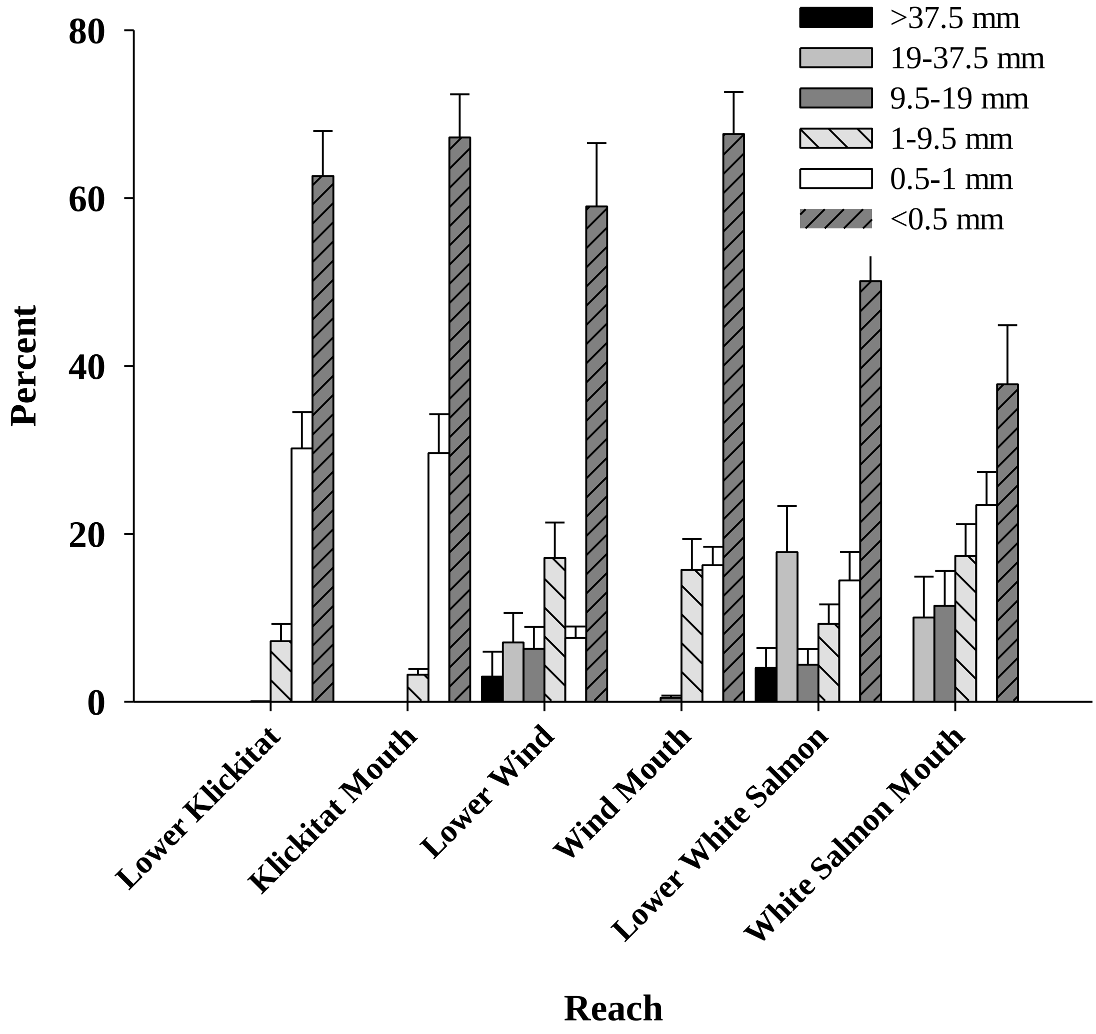

Figure 6. Mean percent of sediment in different size categories (mm) in river reaches in 2012. Large cobble and bedrock categories not included. Bars denote standard errors.

Conclusions

Larval Pacific lampreys occupied all reaches surveyed except the Lower White Salmon River (although *Lampetra* spp. were present). Our findings are similar to those found in the previous year (Jolley et al. 2012a; 2012b). We found remarkably similar detection rates to those found in 2011 in the Lower Wind River and Wind River mouth. In 2011, the detection rate in the Lower Wind River and Wind River mouth was 0.32 and 0.29, respectively compared to 0.23 and 0.29 in 2012 In the Klickitat River mouth we did not detect any larval lamprey in 2011, whereas in 2012 larvae were detected at 4 quadrats. Conversely, in the lower Klickitat River in 2011 larvae were detected at 9 quadrats versus only 1 quadrat in 2012.

In 2012, the Lower White Salmon River was markedly different in terms of channel structure and stream substrate, largely due to the breach and removal of Condit Dam and release of impounded sediments from Northwestern Lake. In 2012, there was larger cobble and gravel upstream from the mouth that transitions to fine sediment downstream than there was in 2011. The channel now cuts through east side of the canyon at the mouth. There is much fine sediment that is redistributing and this area has been in a constant state of flux since the dam breach. In the lower White Salmon river the larval lamprey detection rate was lower in 2012 versus 2011, likely due to the changes in sediment composition as well as the unstable condition of the newly deposited sediments. Conversely, in 2011 no lampreys were detected in the White Salmon river mouth, while in 2012 one Pacific lamprey larva was detected in this area. In 2011, the mouth area was deep, swift and scoured, and suitable substrates for larvae were scarce. Due to the sediment influx after the removal of Condit Dam, a newly formed delta of fine sediments in now present at the White Salmon River mouth. Although the source of the larva detected in the mouth area is unknown (i.e., whether the larva was from the White Salmon River itself, or was moving downstream within the Columbia River mainstem), this area now provides potential rearing or burrowing habitat that was previously unavailable. Discussions are underway to conduct dredging activities to remove sediments to reconnect the tribal in-lieu fishing access site to the White Salmon River. The consequences of dredging to larval lamprey rearing in this area are unknown and should be considered. Regardless, sediments will no doubt continue to redistribute in the seasons to come.

We failed to detect any adult lamprey through our trapping efforts. Although pot traps may be effective at capturing adult lamprey, the capture efficiency is likely very low (<8%; Le et al. 2004). In addition our trapping configuration, location, and effort may not have been sufficient to detect adult lamprey. Currently conditions are likely suitable for adult Pacific lamprey upstream passage to Husum Falls, at a minimum, where adult steelhead have been observed since the removal of the dam. A concurrent study using acoustic tagging last detected an adult Pacific lamprey at a receiver at the White Salmon River mouth. Although these adults may have then entered the White Salmon River for spawning (C. Caudill, University of Idaho, personal communication), their ultimate fate is unclear. Future adult trapping efforts should consider locations where trap efficiency may be maximized (e.g., confined channels, use of traps fished in parallel across the stream channel, in tandem with any future salmonid weir operation).

Our findings are similar to those of studies conducted in the Great Lakes, where larval sea lamprey and American brook lamprey *Lampetra appendix* have been found in lentic areas (Hansen and Hayne 1962), deepwater tributaries (Bergstedt and Genovese 1994; Fodale et al. 2003*b*) and large rivers (Young et al. 1996). This work also corroborates our earlier findings that Pacific and western brook lampreys inhabit relatively deep, mainstem areas of the Willamette and Columbia rivers (Jolley et al. 2011a, 2012c,). In addition, the larvae we collected likely represented multiple age classes. Small larvae likely recruited to these areas relatively recently. It is unknown if these larvae actively migrated downstream from headwater tributaries, were passively washed out of upstream habitats, or hatched in the mouths of these tributary rivers. Deepwater river spawning of lamprey has not been documented although lentic spawning has been observed (Russell et al. 1987). The reservoirs created by dams on the Columbia River may produce habitats that historically didn't exist or were likely less abundant prior to dam construction. For example, the lowermost portions of the tributaries studied are affected by Bonneville Reservoir, resulting in impounded areas of slower velocity, deep water, and increased fine sediments. The higher abundance and/or detection rates of larvae in these lower river habitats relative to the mainstem Columbia River may be due to a 'wash in' effect, where larvae migrate into the lower portions of tributaries from Bonneville Reservoir. Thus, larval lamprey may use these areas at a disproportionally higher rate than pre-dam construction. Alternatively, high detection rates of larval lampreys in lower river reaches and tributary mouths compared to other areas in our mainstem lamprey research to date (Jolley et al. 2012a), may be due to increased local population size relative to other areas (Royle and Nichols 2003), enhanced rearing conditions in these areas, and/or tributaries serving as source populations for larvae in the mainstem. Both the Wind River and Klickitat River are known to have populations of larval lamprey although information is scarce (Connolly et al. 1999; P. Luke, Yakama Nation Fisheries, personal communication). Understanding the source of the larval lampreys inhabiting these areas would be extremely valuable. Identifying discrete populations may allow monitoring larval dynamics, spatially and temporally.

Relatively high larval lamprey occupancy rates coupled with different levels of occupancy (i.e., n>1 individual detected) introduce the ability to incorporate multi-state occupancy models which are an extension of standard occupancy models (MacKenzie et al. 2006; Nichols et al. 2007). These models can be particularly useful to model habitat effects on occupancy. Future work might couple thorough measures of habitat variables to be used as co-variates to the detection probability models. Overall, lamprey larvae of multiple sizes and species occupied the lower reaches of tributaries to Bonneville Reservoir; we provide empirical evidence for this. These areas should not be overlooked as relevant to the conservation and management of these imperiled species. This topic has been largely ignored and further research and monitoring is needed to address larger uncertainties in population trends, recruitment, and mortality. Formation of a new river delta at the mouth of the White Salmon River will be a dynamic process and will be monitored along with the Lower White Salmon River as part of a concurrent and related project.

Relationship to the Fisheries Program Strategic Plan

Implementation of this project demonstrates application of the Pacific Region's 2009-2013 Fisheries Program Strategic Plan. The following National goals (NG) and Regional objectives (RO) have been addressed by this project:

NG1 Open, interactive communication between the Fisheries Program and its partners.

RO1.1 Develop and maintain relationships with partners throughout the Pacific Region. *We participated, coordinated, and cooperated with the White Salmon River Working Group (a partnership of federal, state, tribal, and NGOs) throughout this project.*

NG2 America's streams, lakes, estuaries, and wetlands are functional ecosystems that support self-sustaining communities of fish and other aquatic resources.

RO2.1 Facilitate management of aquatic habitats on national and regional scales by working with Tribes, States, partners and other stakeholders. *We regularly coordinated and communicated with the Columbia River Inter-Tribal Fish Commission and Yakama Nation throughout this project regarding potential management issues.*

RO2.4 Expand opportunities to connect people with nature, engage citizen scientists and volunteers, and temporarily employ youth in the aquatic habitat conservation and monitoring programs and activities we lead or support. *We employed two undergraduate STEP students to conduct field work on this project.*

NG3 Self-sustaining populations of native fish and other aquatic resources that maintain species diversity, provide recreational opportunities for the American public, and meet the needs of tribal communities.

RO3.3 Support the research and fish culture needed to prevent listing or to recover native species listed or proposed for listing under ESA. *This research provides important information on the ecology of Pacific lamprey that will be useful in conserving this important trust species.*

NG8 Assistance is provided to Tribes that results in the management, protection, and conservation of their treaty-reserved or statutorily defined trust natural resources, which help Tribes develop their own capabilities.

RO8.1 Recognize and promote the Service's distinct obligations toward Tribes. *Pacific lampreys are a trust species and research into the conservation of ecologically and culturally tribal species fulfills this obligation.*

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