U.S. Fish and Wildlife Service

Evaluation of Larval Pacific Lamprey Rearing in Mainstem Areas of the Columbia and Snake Rivers Impacted by Dams
Study Code: LMP-P-11-2

FY 2013 Annual Final Report

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Columbia River Fisheries Program Office
Vancouver, WA 98683

On the cover: *The Dalles Pool on the Columbia River and deepwater electrofishing bell. Photo taken in October 2013 by Jeff Jolley.*

The correct citation for this report is:

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. 27 pp.

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Study funded by

U.S. Army Corps of Engineers

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Final
December 19, 2014

Disclaimers

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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 understudied. Information on their use of shallow depositional areas associated with tributary inputs in the mainstem and non-tributary shallow water areas is equally lacking. We used a unique deepwater electrofisher to explore occupancy, detection, and habitat use of larval Pacific lamprey and *Lampetra* spp. in Bonneville and The Dalles pools and associated river mouths of the Hood, Klickitat, Little White Salmon, White Salmon, Wind, and Deschutes rivers, as well as shallow-water pool margins in the Bonneville Pool. We used a generalized randomized tessellation stratified (GRTS) approach to select sampling quadrats in a random, spatially-balanced order. Hydrodynamic modeling techniques were used to delineate the shallow water strata in Bonneville Pool. Pacific lamprey and *Lampetra* spp. occupied all strata. We calculated reach-specific detection probabilities which ranged from 0.00 to 0.18. Detection was lowest in the The Dalles Pool and highest at the mouth of the Wind River in the Bonneville Pool. Detection rates were relatively high in tributary mouth areas indicating the importance of this habitat for larval rearing. A newly-formed delta is now present at the White Salmon River mouth (Bonneville Pool) 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 and potential stranding 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 their 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. In 2003, the Pacific lamprey was petitioned for listing under the Endangered Species Act, and Oregon and Idaho list Pacific lamprey as a species of concern. Managers lack critical information about the life history and basic biology of Pacific lamprey that is necessary to develop effective conservation strategies. Knowledge of Pacific lamprey status (e.g., occupancy and abundance) and knowledge of biology and ecology of Pacific lamprey were deemed important data gaps by the Columbia Basin Pacific Lamprey Technical Workgroup (CBLTWG 2005). Furthermore, determining the effects of FCRPS water management operations on Pacific lamprey larvae rearing in mainstem Columbia and Snake Rivers was deemed a top study objective by Columbia Basin researchers at a recent series of workshops hosted by the U.S. Army Corps of Engineers (Juvenile and Larval Lamprey Passage Workshop, Facilitator's Summary, 2012).

Pacific lampreys have a complex life history that includes 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 for multiple years (i.e., 2-7) 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 with some beginning migration in the 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 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). The numerous hydroelectric dams on the Columbia River have transformed this river into a series of low velocity pools. 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 lampreys 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).

Patterns of occupancy, abundance, and habitat use by larval Pacific lamprey in pools created by and influenced by dams, and associated tailwater areas have been largely unexplored. The significance of mainstem larval rearing and passage through hydroprojects may be paramount to the conservation of Pacific lamprey. Information from the proposed study can be used to help inform how pool and tailwater levels might be regulated to minimize negative impacts to lamprey populations. Understanding if and how larval lampreys use mainstem habitats is essential to the conservation of this species.

We investigated and documented larval lamprey occupancy and habitat use in two pools of the Columbia River. We examined occupancy in strata nested within pools that may be particularly vulnerable to changing water conditions due to dam operations (shallow, tributary mouths). Fish and invertebrates can be influenced by flow regimes, tailwater levels, and other abiotic conditions related to dam operation (Scheidegger and Bain 1995; Clarkson and Childs

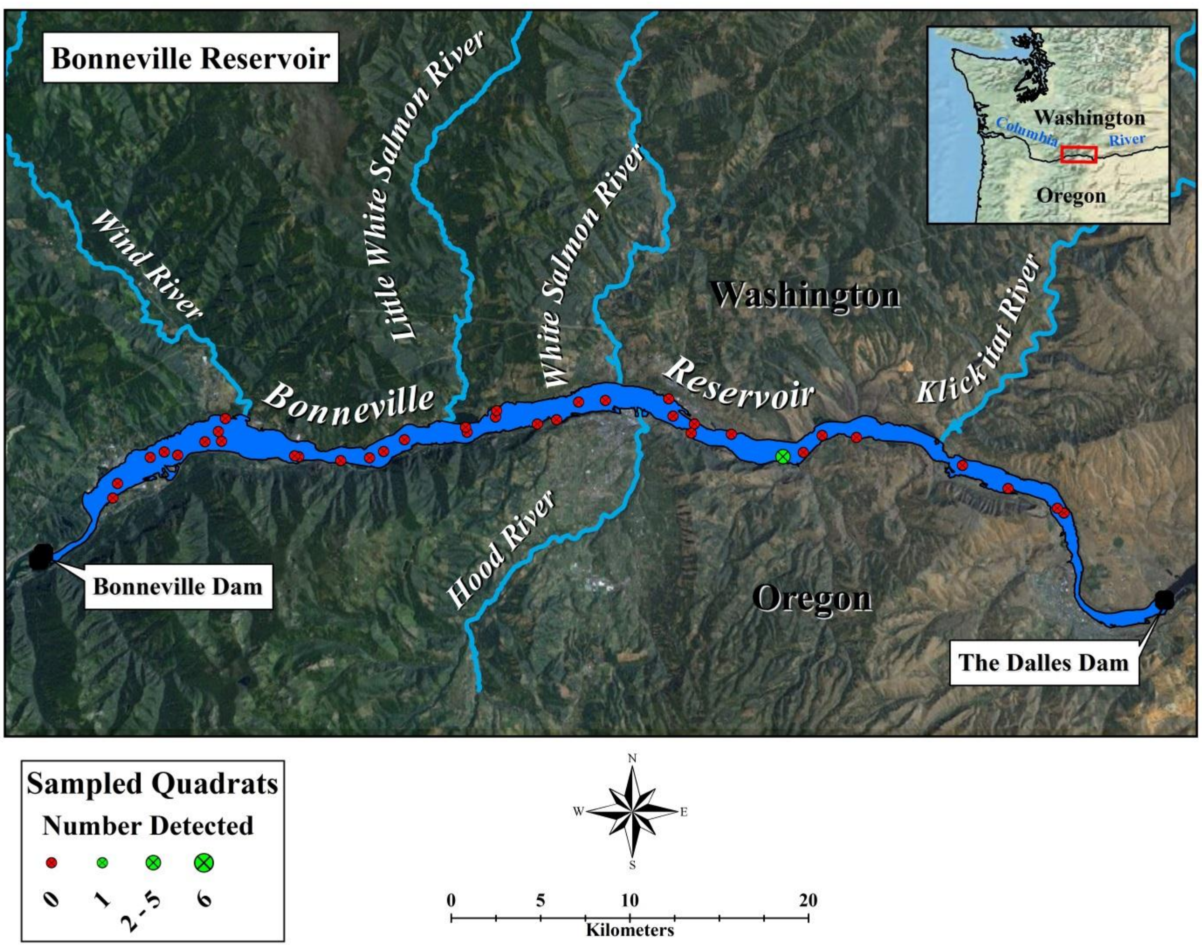

Figure 1. Bonneville Pool sampling quadrats in 2013.

2000; Vinson 2001) and larval Pacific lamprey have been specifically mentioned as susceptible to stranding by dam operations (Peterson 2009). Obtaining the information on how larval lampreys use the areas above and below dams is critical to understanding the importance of these areas for contribution to the population and long term population viability. At present, little specific information is available on how many larvae use these areas, when and how long they use these areas, and whether they tend to be found in specific habitats. This life-history information can be used to help inform how pool and tailwater levels are regulated and, in turn, help to minimize any negative impact to lamprey populations.

Our objectives were 1) evaluate whether pools are occupied by larvae, 2) evaluate strata-specific larval occupancy of pools (e.g., shallow areas potentially subject to dewatering, relatively deeper areas, river mouth areas), and 3) evaluate the size of larvae rearing in the pools. The long-term objectives of the project are to: 1) determine if occupancy and detection of larval lamprey decline with distance upstream and increasing number of migratory obstructions, 2) identify habitats that may be positively related to larval lamprey detection, and 3) determine effect of pool and water management operations on larval lamprey.

Methods

Bonneville Pool is impounded by Bonneville Dam (Rkm 234) and is bounded on the upstream end by The Dalles Dam (RKm 314). The pool is 75 km long and 7,632-ha at full pool (22.6 m above sea level). Bonneville Pool was sampled from 4 November 2013 to 18 November 2013, from The Bonneville Dam to The Dalles Dam (Figure 1).

Five major tributary mouths (4th - 6th order at the 1:100,000 scale) of the Bonneville Pool were sampled. 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 in Washington. 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 Little White Salmon River is a 4th order river and originates in the Monte Cristo Range of the Cascade Mountains in Washington. The basin covers 347 km^2, flows into Drano Lake, an impounded arm of the Columbia River which enters the mainstem Columbia River at Rkm 262. The White Salmon River is a 5th order river, flows from the south side of 3,742 m peak of Mount Adams in Washington and enters the Columbia River at Rkm 269. 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 Hood River is a 5th order river and originates on the north slope of Mount Hood in the Cascade Mountains in Oregon. The basin covers 880 km^2 and enters the Columbia River at Rkm 273. The Klickitat River is a 5th order river; the basin in east of the White Salmon River basin and originates near Cispus Pass in the Goat Rocks region of the Cascade Mountains in Washington. The basin covers 3,496 km^2 and enters the Columbia River at Rkm 290. 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). All rivers presumably have fine sediments originating from the Cascade Mountains that would provide adequate rearing habitats for larval lamprey. The tributary mouths were sampled from 14 August 2013 to 19 November 2013 (Figure 2).

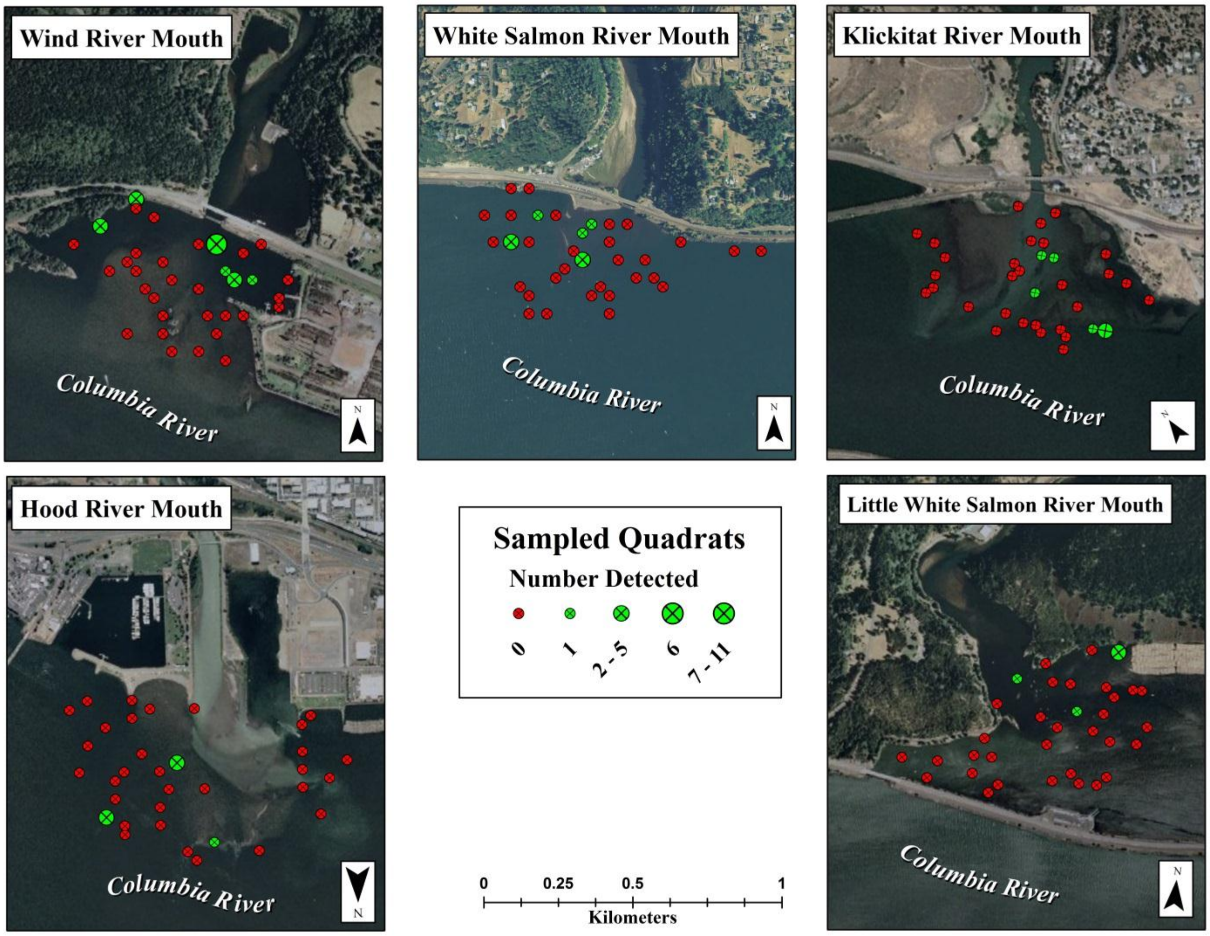

Figure 2. Tributary mouths within Bonneville Pool sampling sites in 2013.

The Dalles Pool (Lake Celilo) is impounded by The Dalles Dam (RKm 309) and John Day Dam (RKm 348) is the next upstream hydropower project. The pool is 39 km long, 3,805-ha at full pool and is 48.8 m above sea level (Figure 3). The Deschutes River is a 6th order stream and is the only significant tributary input of The Dalles Pool entering at RKm 330 (Figure 4). The pool was sampled on 20 November 2013 and 21 November 2013 and The Deschutes River mouth was sampled 7 August and 8 August 2013. The Deschutes River flows from the Lava Lake in the central Oregon Cascade Range and has a basin covering 27,200 km^2. There is a shallow depositional area at the mouth with presumably appropriate silty/sandy substrates suitable for larval lamprey rearing. Sampling occurred in summer and early fall when water velocities were the lowest and most conducive to sampling.

Near-shore, non-tributary shallow water areas were also identified for Bonneville Pool. We estimated depth most susceptible to dewatering due to normal hydrosystem operation by using a preexisting, calibrated hydrodynamic model of Bonneville Pool (Hatten and Batt 2010). The original model was only run for a Bonneville Pool tailwater elevation approximating full pool, so we adjusted the tailwater elevations and inflows to produce a low pool and high pool scenario more typical of normative operational ranges (Figure 5). The difference between these two strata is a polygon of relatively shallow water areas (shallow-water strata) within which lamprey have the highest probability of being vulnerable to stranding. Modeled strata were imported into a GIS and shorelines were extracted and uploaded to GPS for field sampling. The estimated shallow-water strata had an area of 56 ha which was 6.8% of the total pool area (Figure 6).

We estimated occupancy of larval lamprey in Bonneville and The Dalles pools, tributary mouths, and shallow-water strata by adapting an approach that was applied to studies of larval lamprey in the Willamette and Columbia rivers (Jolley et al. 2012c, 2013a; 2013b). 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:

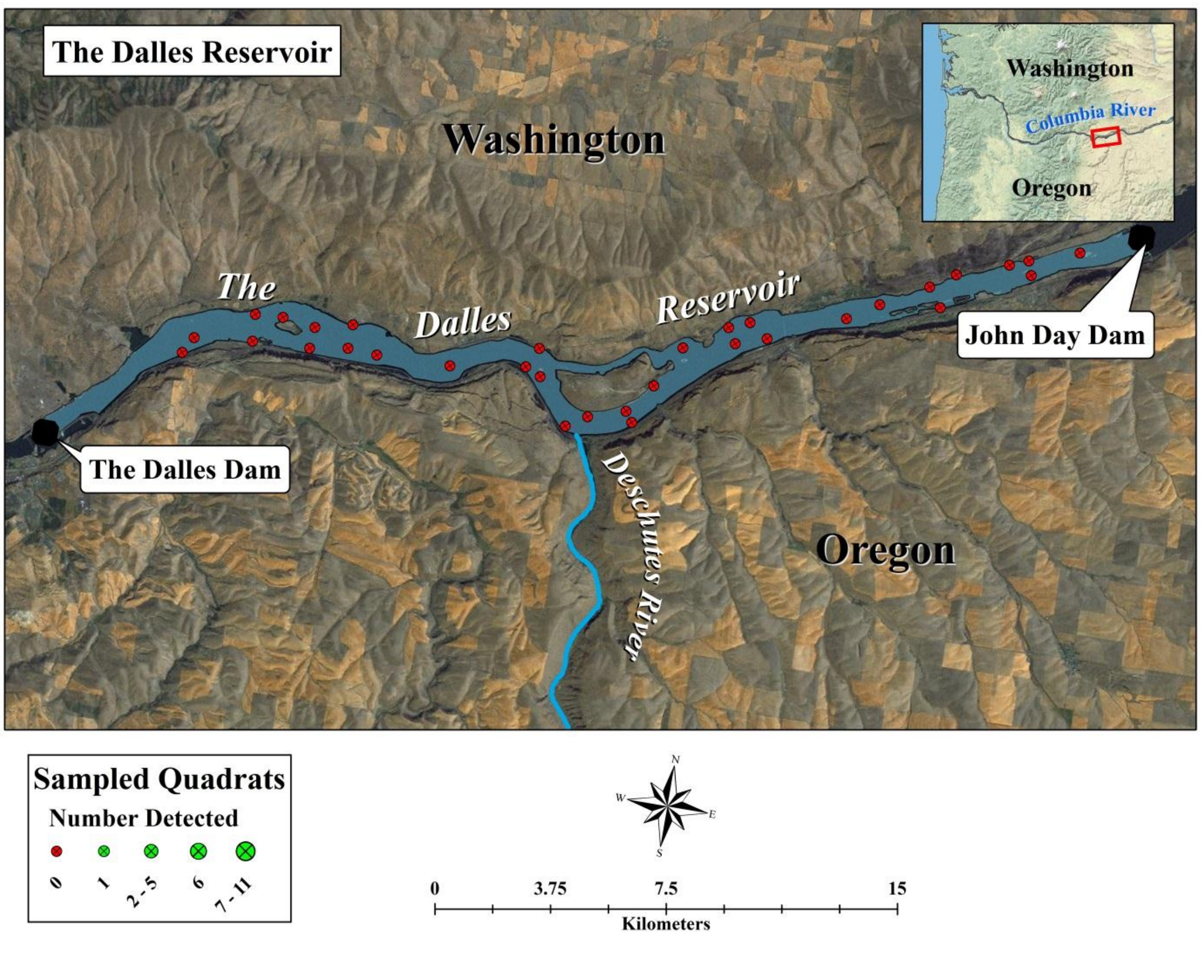

Figure 3. The Dalles Pool sampling quadrats in 2013.

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

where P(*F*) is the prior probability of larval lamprey presence. Although 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(~*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).

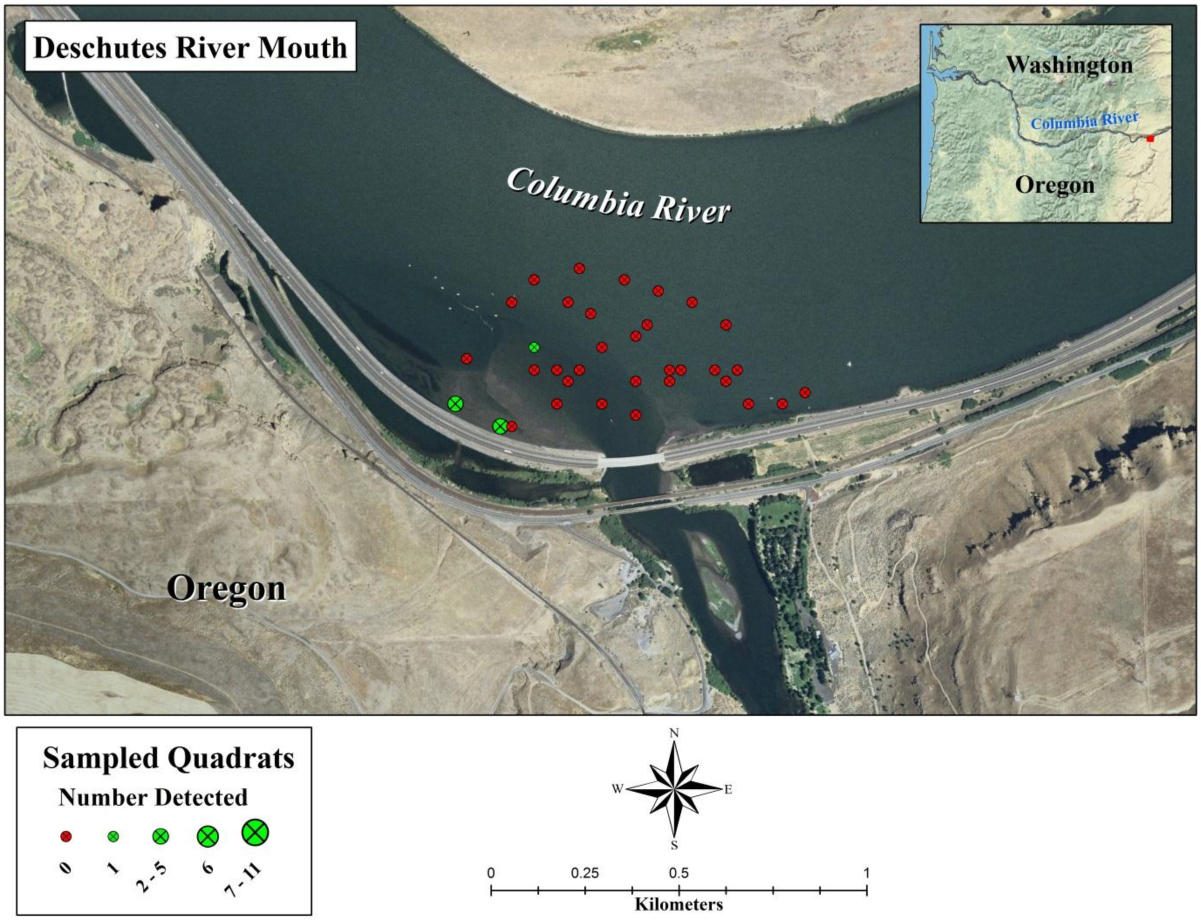

Figure 4. The Deschutes River mouth within The Dalles Pool sampling sites in 2013.

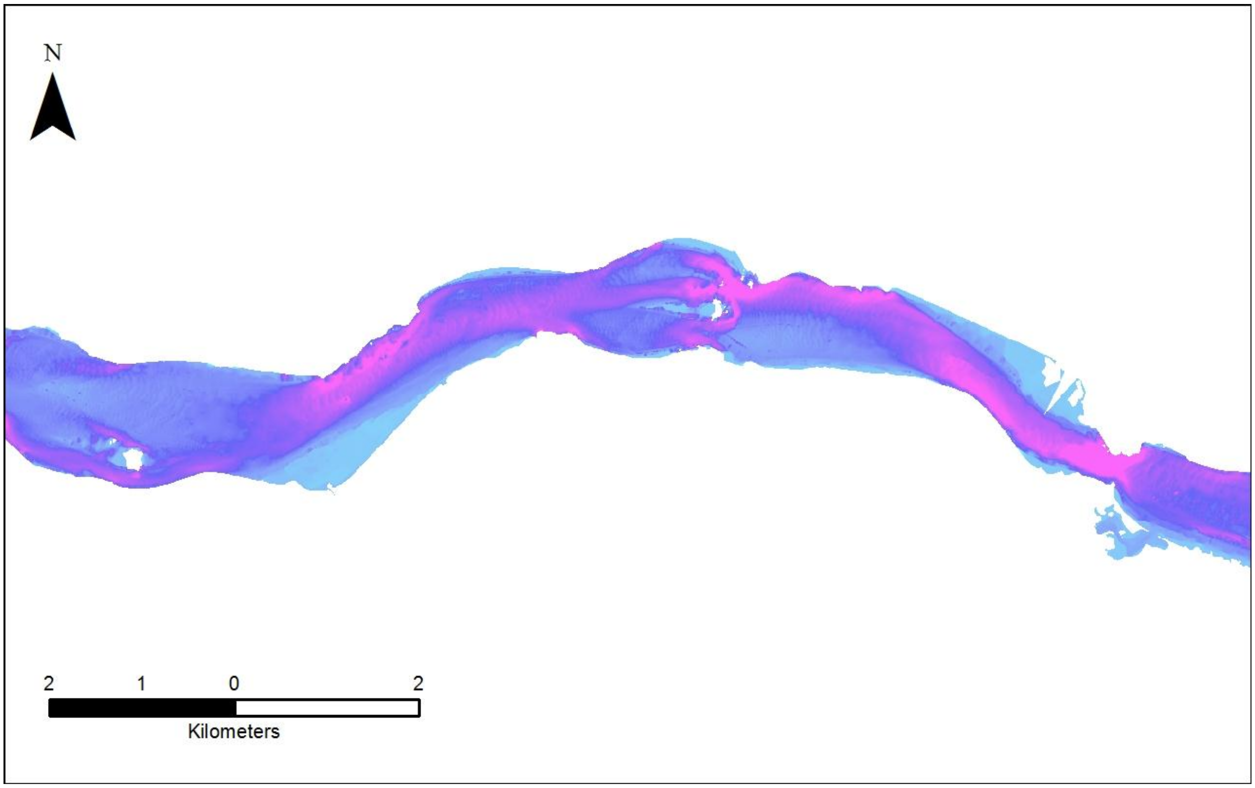

Figure 5.

A sampling event consisted of using a deepwater electrofisher (Bergstedt and Genovese 1994) in a 30 m x 30 m quadrat. 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 (0.61 cm^2) 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 larvae 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 larvae 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).

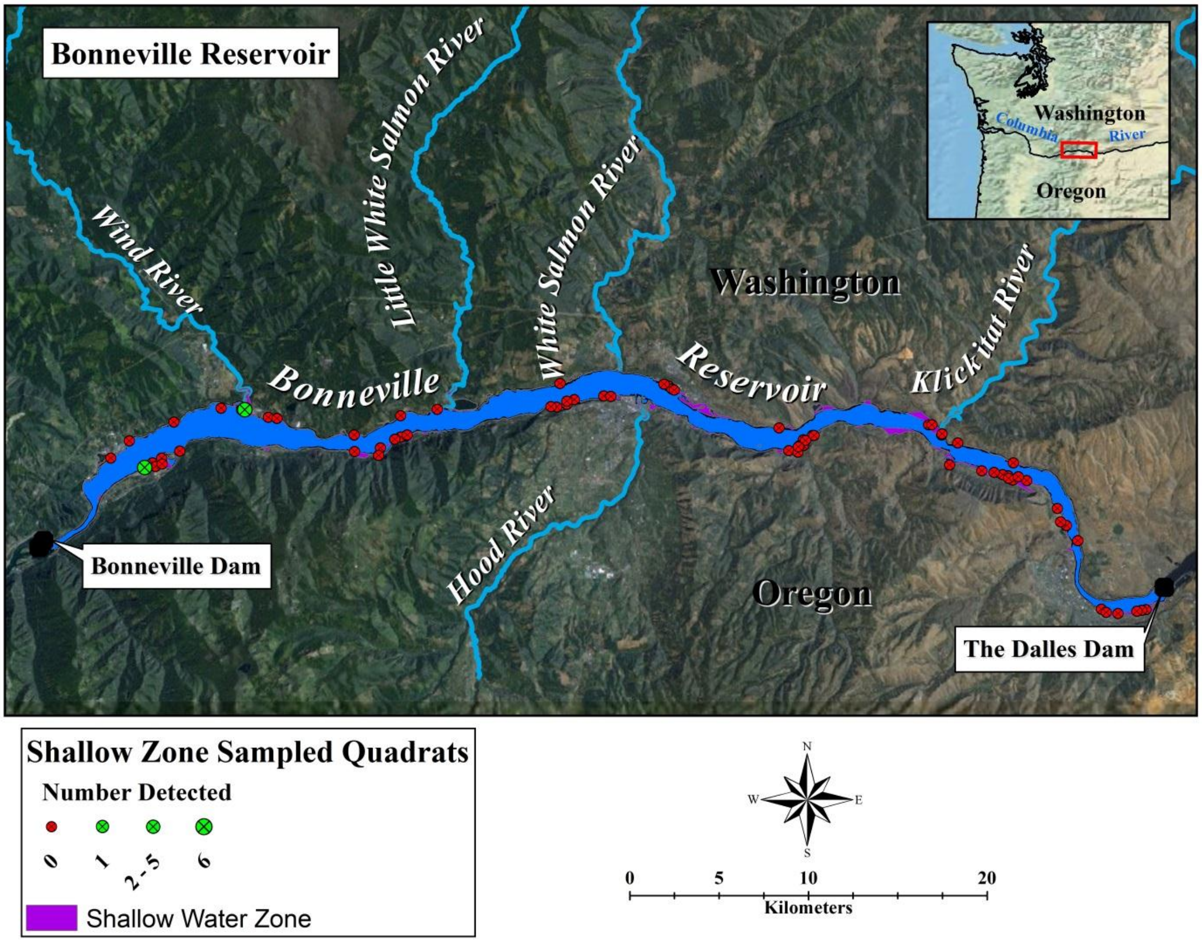

Figure 6. Shallow water strata sampling sites in Bonneville Pool in 2014.

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. There were 41,547 and 423 quadrats in The Dalles Pool and Deschutes River Mouth, 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, we assumed a relatively low to moderate detection rate of 0.07 (given an area was occupied). We estimated that 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 (>90% certainty of lamprey absence when not detected). 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 excessive velocity, or excessive depth (>21 m) were eliminated from the sample and all subsequent quadrats were increased in priority (Table 1). Furthermore, we applied modeling techniques to attempt to adjust for the large spatial scale of pool (e.g., a pool as a whole is much larger than a river mouth) and applied this to the Bonneville shallow-water strata. We estimated detection probability (d) as a function of an assumed threshold proportion of sites occupied ($Prop$), a threshold density within occupied sites (Den), and a threshold sampling efficiency to detect one individual (E) by the following equation:

$$d = Prop * (1 - (1 - E)^{Den})$$

For our sampling, we wanted to ensure we could detect larvae if we assumed that at least 5% of the sites were occupied (conservative assumption), that when occupied, a site would have a density of at least 1 individual/0.61 m^2 (i.e., at least one individual within the bell frame) and that we would collect individuals at 33% of all occupied sites. Thus, the detection probability at one random site within the area would be:

$$0.05 * (1 - (1 - 0.33)^1) = 0.0067$$

This estimate of detection probability (0.0067) for a site was used in the model by Peterson and Dunham (2002) to estimate the number of sites needed to obtain a posterior probability of area occupancy below the acceptable level, if no individuals happen to be detected. This exercise resulted in a target sampling effort of 83 quadrats to achieve a probability of occupancy of less than 20%, if no individuals were detected (i.e., we would be at least 80% certain the area was not occupied if no individuals were collected).

Table 1. Total number of quadrats delineated, visited, sampled, and occupied and species present in 2013-2014. Unidentified larval lampreys are noted as "Unid".

		Quadrats								
Reach	Date	Total	Visited	Sampled	Occupied	*d*	Pacific lamprey	*Lampetra* spp.	Unid	Total
Bonneville Pool	11/4 - 11/18	90,200	44	36	1	0.03	2	0	0	2
Hood mouth	9/12 - 10/22	514	39	35	3	0.09	3	3	0	6
Klickitat mouth	8/14	359	40	34	5	0.15	4	1	1	6
Little White Salmon mouth	11/19	1,021	36	34	3	0.09	0	4	0	4
White Salmon mouth	9/12 - 11/4	423	36	34	5	0.15	3	4	0	7
Wind mouth	8/19	353	34	34	6	0.18	4	11	1	16
The Dalles Pool	11/20 - 11/21	41,547	34	32	0	0.00	0	0	0	0
Deschutes mouth	8/7	423	35	34	3	0.09	5	0	2	7
Bonneville Pool shallow	5/30 - 7/22	6,172	80	72	2	0.03	1	1	0	2

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., ammocoete, macrophthalmia, 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.

Results

We targeted 34 quadrats per pool and tributary mouth strata (Table 1). We targeted 83 quadrats in the shallow water strata of Bonneville Pool. The feasibility of being able to sample a quadrat in each stratum was 82% to 100%. Some quadrats were not sampled because they were not feasible (dewatered conditions, excessive depth, excessive velocity). Larval lampreys were detected in all strata except The Dalles Pool (Table 1). Only lamprey larger than 60 mm TL can be confidently identified and genetic samples from those less than 60 mm TL were used to confirm genus. Pacific lamprey, *Lampetra* spp. occupied several strata. Only *Lampetra* spp. was detected at the Little White Salmon mouth and both Pacific lamprey and *Lampetra* spp. occupied the Wind, Hood, Klickitat, White Salmon mouths and Bonneville shallow water strata. All other strata were occupied only by Pacific lamprey. Detection probability was highest at the Wind mouth (d=0.18) and lowest in The Dalles Pool (d=0.00). By definition, Pacific lamprey occupied The Dalles Pool since larvae were detected in the Deschutes mouth, but as a whole, larval lamprey are likely at a level of abundance too low in the pool proper to be detected with our current sampling effort (there was a 20% chance that we failed to detect larvae when they actually occupied the pool). Detection probabilities did not differ among reaches (Fisher's Exact Test multivariate permutation technique, Brown and Fears 1981, P>0.05).

Lamprey larvae ranged in size from 14 to 138 mm TL. No differences in TL 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 0.2 to 20.7 m and larvae were detected in depths from 0.3 to 13.1 m. The total number of larvae occupying any individual quadrat ranged from 0 to 6.

Mean percent organic content ranged from 0.9 to 8.4% and was significantly higher in the Little White Salmon mouth (e.g., Drano Lake) than at the Klickitat, Hood, and Deschutes mouths, Bonneville and The Dalles pools, and Bonneville shallow water strata, in general (ANOVA, F=15.21, df=8, P<0.01; Table 2). Multiple differences in relative amount of sediments of different sizes were detected (Figure 7). Fine sediments were present in all reaches although the Little White Salmon mouth had the highest relative amount of the smallest-size particles (i.e., <0.5 mm, ANOVA, F=13.95, P<0.05) the Deschutes mouth had the highest relative amount of particles size 0.5-1 mm (F=25.62, P<0.05). Large cobble/boulder substrate (too large for the dredge) was detected at 5 sites (14%) in the Bonneville Pool, 1 site each at the Little White Salmon, White Salmon and Wind mouths (2-3%), 5 sites at the Deschutes mouth (14%), 7 sites in The Dalles Pool (23%), and 13 sites (17%) in the Bonneville shallow water strata. These substrates are likely boulders or bedrock.

Reach	Number	Mean percent organic content	Standard error
Bonneville pool	30	0.6	0.2
Hood mouth	35	0.9	0.1
Klickitat mouth	33	1.1	0.1
Little White Salmon mouth	31	8.4	0.4
White Salmon mouth	21	3.5	0.8
Wind mouth	34	6.5	1.9
Shallow water strata	62	1.5	0.2
The Dalles Pool	9	1.1	0.2
Deschutes mouth	20	0.4	0.0
Bonneville shallow	62	1.5	0.2

Table 2. Mean percent organic content in sediment in Bonneville and The Dalles pools and river mouths in 2013-2014.

Predictions of shallow water habitat in Bonneville Pool were successfully simulated using the pre-calibrated River2D model used by Hatten and Batt (2010). The predictions agreed well with subsequent field sampling, although a few points were located on dry land.

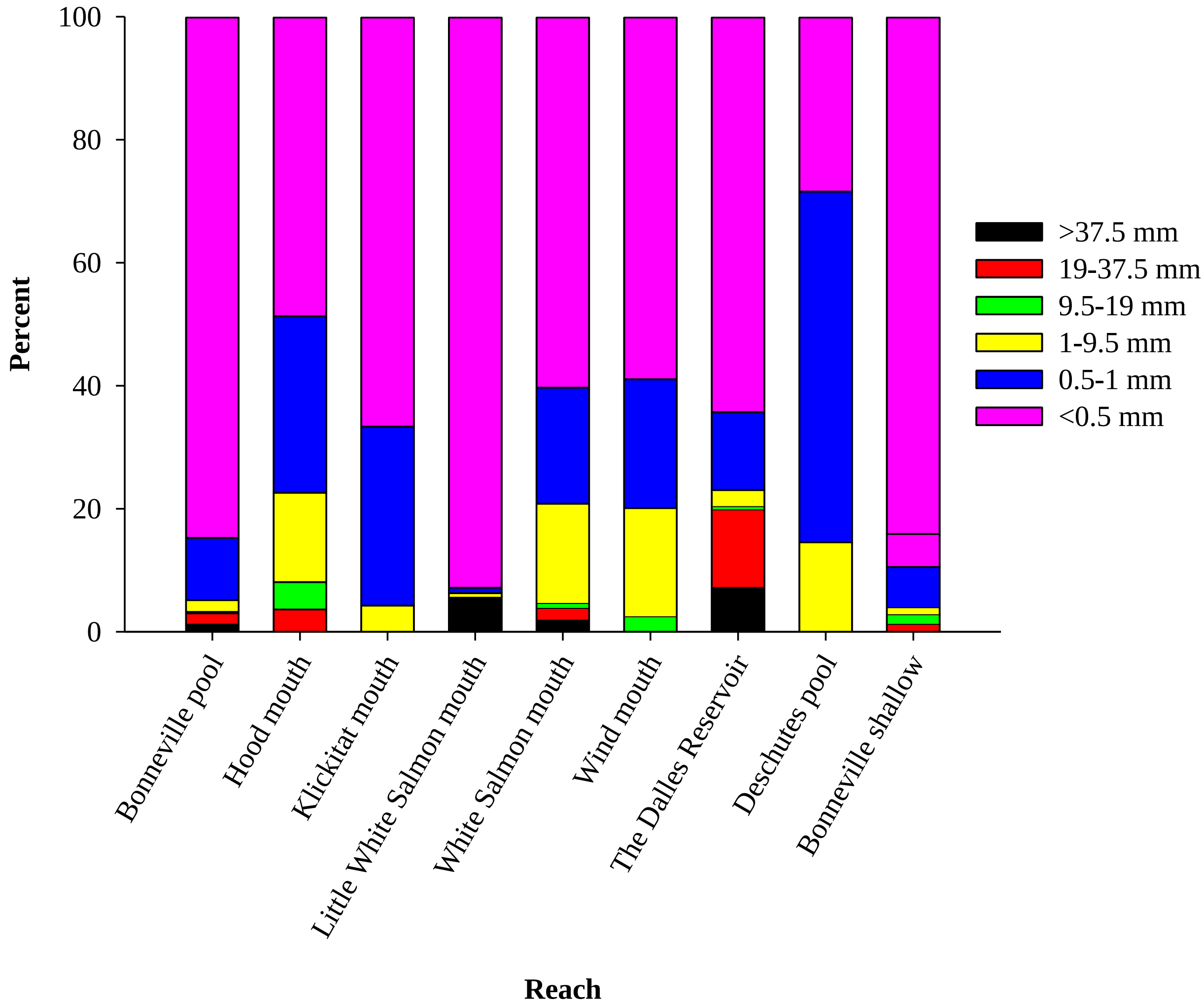

Figure 7. Mean percent of sediment in different size categories (mm) in river strata in 2013. Large cobble and bedrock categories not included.

Conclusions

Larval Pacific lampreys occupied all reaches surveyed except the Little White Salmon mouth (although *Lampetra* spp. were present) We found remarkably similar detection rates to those found in previous years where repeat sampling occurred (Jolley et al. 2012a; 2012b; 2013a; 2013b; Table 3). This might implicate these areas as consistent larval rearing locations. Detection rates were higher in tributary mouth areas than in general pool areas, suggesting potential higher density and importance of these habitats for larval rearing.

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 (14-16 m), mainstem areas of the Willamette and Columbia rivers (Jolley et al. 2011a, 2012c). In addition, the larvae we collected likely represented multiple age classes. Larvae emerge at 8-9 mm (Brumo 2006) and our smallest collections (i.e., TL<20 mm) were likely age-0 fish. Small larvae likely recruited to these areas relatively recently although accurately estimating age based on length remains difficult (Meeuwig and Bayer 2005). 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 (or a combination of the above). The preponderance of relatively high detection rates in river mouth areas might suggest the associated tributaries serve as the source for these detections. Conversely, the relative lack of suitable burrowing substrates, particularly in The Dalles Pool, might indicate that the tributary mouths serve as areas for larval recruitment from other areas. Nevertheless, the topic of determining larval origin warrants further investigation. For example, directed studies utilizing genetic tools to identify unique signatures from tributary systems may be one approach worth pursuing (Hess et al. 2014). Deepwater river spawning of lamprey has not been documented although lentic spawning has been observed (Russell et al. 1987). The pools created by dams on the Columbia River may produce habitats that historically didn't exist or were likely less abundant prior to dam construction. 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 sub-population size relative to other areas (Royle and Nichols 2003), enhanced rearing conditions in these areas, and/or tributaries serving as source sub-populations for larvae in the mainstem. The Wind River, Klickitat River, and Hood River are known to have a sub-population of larval lamprey although information is scarce (Connolly et al. 1999; Fox 2012; P. Luke, Yakama Nation Fisheries, personal communication). Identifying discrete sub-populations may allow monitoring larval dynamics, spatially and temporally. Further questions remain as to the fate of upstream migrating adults and it has been reported that up to 50% of adult lampreys approaching a dam do not pass (Moser et al. 2002). The fate of those adults that did not pass is unknown.

In 2012 and 2013, the White Salmon River mouth was markedly different in terms of substrate, largely due to the breach and removal of Condit Dam and release of impounded sediments from Northwestern Lake (Jolley et al. 2013b; present study). There is much fine sediment that is redistributing and this area has been in a constant state of flux since the dam breach. In 2011 no lampreys were detected in the White Salmon river mouth, in 2012 one Pacific lamprey larva was detected, and 7 larvae were detected in 5 quadrats in this study (Pacific lamprey and western brook lamprey; Jolley et al. 2012b; 2013b). 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 larvae detected in the mouth area is unknown (i.e., whether the larvae originated from the White Salmon River itself, or were moving 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 (W. Sharp, Yakama Nation, personal communication). 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.

Relatively high larval lamprey occupancy rates, particularly in tributary mouths, coupled with different levels of occupancy (i.e., n>1 individual detected in a single quadrat) introduce the ability to incorporate multi-state occupancy models which are an extension of standard occupancy models (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.

The Dalles Pool was occupied with larval lamprey but they were only detected in the Deschutes River mouth. Either larval lampreys are not rearing in the pool or they were at a level too low to readily detect. The Deschutes River, a relatively unaltered tributary, is known to have a population of Pacific lamprey (Gadomski and Barfoot 1998; Fox and Graham 2007; USFWS [unpublished data]). Larvae were not detected in the mouth in 2012 (Jolley 2013a) which was an unexpected finding especially since depositional sediments at river mouths in Bonneville Pool have yielded the highest detection rates observed in all of our mainstem larval lamprey surveys to date (Table 4; Jolley et al. 2012a, 2012b; 2013b). At a detection rate of 0.07 and a sampling effort of 34 quadrats, we would estimate an 8% chance that larval lampreys are actually present when not detected. In comparison, the detection rate for larval lamprey in Bonneville Pool was 0.02 in 2010 (Table 4). A sampling effort of 34 quadrats yields a 32% chance that larval lamprey are present when not detected and an effort of 63 quadrats would be necessary to achieve 80% certainty that larval lampreys are actually absent when not detected. It is possible that detection rates in The Dalles Pool may be equally low (compared to Bonneville Pool) and a higher sampling effort may be required to detect larval lamprey. In addition, the Type 1 larval rearing habitat appears to be relatively scarce in The Dalles Pool as evidenced by abundance of bedrock and coarse substrates in our sediment sampling data. The banks of this pool are steep-sided and become confined as the river enters the Columbia River Gorge. In comparison, the upstream reach of John Day Pool (the next upstream) is wider and shallow with complex backwaters and side-channels, with more sandy and silty substrates (Parsley et al 1993; Gadomski and Barfoot 1998) which may be conducive to larval lamprey rearing.

Substrate particle size and water velocity are consistently considered two of the most important fine-scale predictors of larval lamprey abundance (Beamish and Jebbink 1994; Ojutkangas et al. 1995; Beamish and Lowartz 1996) but the importance of organic matter in the sediment is less clear. Organic detritus is generally deposited in areas of slow flow where accumulations of silt and sand provide suitable substrate for burrowing larvae. Potter et al. (1986) found the presence of organic material in the substrate to be an important environmental variable predicting the density of larval pouched lamprey *Geotria australis* in three of their four seasonal models (i.e., in all seasons but winter). In their habitat selection study, Smith et al. (2011) found that, after their preference for fine sand, least brook lamprey *Lampetra aepytera* larvae exhibited a secondary preference for an organic substrate (consisting of approximately 70% decomposing leaves/stems and organic sediment particles and 30% silt/fine sand). In contrast, Malmqvist (1980) found that water current, water depth, substrate size, and chlorophyll-a content explained a large part of the variation in distribution of larval European brook lamprey *Lampetra planeri*, but found that organic content in the sediment did not improve his discriminant model. Organic content was not correlated with larval density even when simple linear regression was applied. Malmqvist (1980) thus suggested that the presence of organic material in the sediment is not a prerequisite for the larvae since they can ingest their food directly from the water column above the sediment. Rather than interpreting these findings to mean, however, that the presence of organic material in the sediment is not a prerequisite for larval lampreys, these authors suggested that the amount consumed by larvae is low relative to the amount generally present in larval streams (i.e., that organic detritus may exceed the necessary threshold to sustain larval growth in all but the most oligotrophic streams. These studies largely agree with our findings as no obvious patterns relating sediment organic content to lamprey occupancy were apparent.

Overall, lamprey larvae of multiple sizes and species occupied Bonneville and The Dalles pools and river mouth areas; we provide empirical evidence for this. These areas should be considered as relevant to the conservation and management of these imperiled species. Continuing to document patterns of occupancy by larval lamprey further upstream in mainstem Columbia and Snake rivers is warranted for a number of reasons. It is likely that the cumulative effects of multiple adult migration passage hindrances are resulting in sharply declining spawning adults to these upstream areas. Larval rearing areas may be even more important to maintaining recruitment to the population, providing pheromone-based migratory cues to adults, and preserving species subpopulations. 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 is being monitored along with the Lower White Salmon River as part of a concurrent and related project.

Year	Reach	*d*	Pacific lamprey	Western brook lamprey	Unid	Total	Source
2009	Lower Willamette River	0.07	5	6	1	12	Jolley et al. 2012c
2010	Bonneville Reservoir	0.02	1	0	0	1	Jolley et al. 2011a
	Bonneville Tailwater	0.00	0	0	0	0	
2011	Bonneville Tailwater	0.03	0	1	0	1	Jolley et al. 2012a
	Hood River mouth	0.06	1	1	0	2	
	Klickitat River mouth	0.00	0	0	0	0	
	White Salmon River mouth	0.00	0	0	0	0	
	Wind River mouth	0.29	22	9	6	37	
	Lower Klickitat River	0.26	13	0	2	15	Jolley et al. 2012b
	Lower White Salmon River	0.29	5	11	3	19	
	Lower Wind River	0.32	13	9	4	26	
2012	Klickitat River mouth	0.12	3	0	2	5	Jolley et al. 2013b
	White Salmon River mouth	0.03	1	0	0	1	
	Wind River mouth	0.29	6	15	16	37	
	Lower Klickitat River	0.03	1	0	0	1	
	Lower White Salmon River	0.09	0	4	0	4	
	Lower Wind River	0.24	4	10	1	15	
	The Dalles Pool	0.00	0	0	0	0	Jolley et al. 2013a
	Deschutes River mouth	0.00	0	0	0	0	
2013	Deschutes mouth	0.09	5	0	2	7	Jolley et al. *in prep*
	Klickitat mouth	0.15	4	1	1	6	
	Klickitat mouth	0.26	49	4	0	53	
	Klickitat mouth	0.35	34	7	1	42	
	Wind mouth	0.18	4	11	1	16	
	Wind mouth	0.21	6	17	0	23	
	Wind mouth	0.24	5	20	0	25	
	Hood mouth	0.09	3	3	0	6	
	White Salmon mouth	0.15	3	4	0	7	
	Little White Salmon mouth	0.09	0	4	0	4	
	Bonneville Reservoir	0.03	2	0	0	2	
	The Dalles Reservoir	0.00	0	0	0	0	
2014	Bonneville shallow	0.03	1	1	0	2	

Table 3. Summary of detection rate for all Columbia River mainstem larval lamprey work to date.

Acknowledgements

Funding for this project was provided by the U.S. Army Corps of Engineers through the Anadromous Fish Evaluation Program and we thank S. Tackley, S. Juhnke, and N. Zorich for valuable guidance and administrative assistance. We thank J. Archibald, D. Bulter, D. Hand, J. Harris, and M. Kavanagh for field assistance. D. Hines, D. Wills, B Haverkate, and J. Harris provided GIS, analytical, and project guidance.

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December 2014