Occurrence, Detection, and Habitat Use of Larval Lamprey in Columbia River Mainstem Environments: Bonneville Reservoir and Tailwater.

2010 Annual Report

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Introduction

Pacific lamprey *Entosphenus tridentatus* have experienced a great decline in abundance (Close et al. 2002), specifically in the Columbia River Basin (CRB) 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). 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 a three to seven year larval (ammocoete), migratory juvenile (macrophthalmia) and adult marine phase (Scott and Crossman 1973). Ammocoetes and macrophthalmia are strongly associated with stream and river sediments. Ammocoetes live burrowed in stream and river sediments for periods up to seven years after hatching, where they filter feed detritus and organic material (Scott and Crossman 1973; Sutton and Bowen 1994). Ammocoetes metamorphose into macrophthalmia from July to December (McGree et al. 2008) and migrate downstream to the Pacific Ocean. The sympatric western brook lamprey *Lampetra richardsoni* do not have a migratory or marine life stage but are also likely under population threats similar to those of Pacific lamprey (ODFW 2006; Mesa and Copeland 2009). For Pacific lamprey and western brook lamprey, the majority of the information on 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 systems (Farlinger and Beamish 1984; Russell et al. 1987; Gunckel et al. 2009). Lamprey ammocoetes are known to occur in sediments of shallow streams but their use of larger river (i.e., >4th order [1:100 scale]) habitats in relatively deeper areas is unknown. Anecdotal observations exist regarding larval lamprey occurrence in large river habitats mainly at hydropower facilities or in downstream bypass reaches (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 supposedly migrating ammocoetes have been made in large river habitats (Beamish and Youson 1987; Beamish and Levings 1991). Furthermore, larval Pacific lamprey apparently rearing in nearshore areas of large rivers has also been observed (Silver et al. 2008).

Sea lamprey *Petromyzon marinus* ammocoetes have been documented in deepwater habitats in tributaries of the Great Lakes and 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*). References to other species occurring in deepwater or lacustrine habitats are scarce (American brook lamprey *Lampetra appendix*; Hansen and Hayne 1962). A pilot study of Pacific lamprey and *Lampetra* spp. use of mainstem habitat of the Willamette and Columbia rivers was initiated in 2007 (Silver et al. 2008). Pacific lamprey and western brook lamprey of a broad range in size were found utilizing nearshore areas of the Willamette and Columbia Rivers. Those surveys were made using an AbP-2 backpack electrofisher in wadeable areas less than 1 m deep. Thus, although larval lamprey generally occupied these mainstem areas, knowledge of lamprey presence in deeper areas was unknown. Sampling of ammocoetes in deepwater areas is a challenge because of specialized gear requirements as well as presumed patchy distributions. Successful sampling of deepwater areas for sea lamprey ammocoetes has occurred in tributaries to the Great Lakes using a modified electrofisher with suction (Bergstedt and Genovese 1994). This technique has shown promise in pilot studies in the Lower Willamette River (Windward Environmental 2005). However, one problem encountered when sampling for distribution and abundance of infaunal organisms is associated with the uncertainty in detection probabilities and capture efficiencies. One goal of this study was to develop a statistically robust design to evaluate the distribution (i.e., occupancy) of larval lamprey in the Columbia River. In part, statistical robustness can be improved by determining detection probability (DP). Knowledge of detection probabilities can inform sample design (e.g., required site visits giving 80% certainty of lamprey absence when not detected) and data analysis.

We previously conducted a study of lamprey distribution in the Lower Willamette River, using a boat-mounted, deepwater electrofisher in 2009 (Jolley et al. 2010). We used a generalized randomized tessellation stratified (GRTS) approach to select sampling quadrats in a random, spatially-balanced order. We calculated reach- and quadrat-specific detection probabilities and the required amount of sampling effort for 80% confidence of larval lamprey absence when they were not detected. Pacific lamprey (30%), *Lampetra* spp. (59%), and unidentified lamprey (11%) occupied the mainstem Willamette River. Larvae were detected in all areas except the Multnomah Channel. Lampreys were widespread and detected at depths up to 16 m. Detection probabilities were 0.08 (reach) and 0.23 (quadrat). The sampling required for 80% confidence of lamprey absence when they were not detected was 17 quadrats (in the reach) and 6 subquadrats (in a quadrat). Differences in lamprey detection by depth were not detected. A wide range of sizes was collected (20-144 mm TL) indicating the likely occurrence of multiple ages of larvae. Our study documented the first quantitative information on larval Pacific lamprey and *Lampetra* spp. occupancy in mainstem river habitats. This study established our ability to effectively use the deepwater electrofishing technology and apply a statistically robust and rigorous sampling scheme to explore patterns of distribution, occupancy, and detection. Furthermore, these quantitative techniques formed a foundation for comparisons of lamprey occupancy and detection in other mainstem areas; the GRTS approach provides the venue for statistical inference.

To this end we sampled mainstem areas of the Columbia River associated with Bonneville Dam (Bonneville Reservoir and Bonneville Dam tailwater (i.e., a reach of the Columbia River downstream of Bonneville Dam but upstream of any significant tributary inputs) to further document the presence of larval lampreys (the Lower Willamette reach previously studied was downstream of any dam in the Willamette and Columbia rivers). Specifically, we wanted to evaluate patterns of occupancy and distribution above and below a major anthropogenic structure (i.e., Bonneville Dam) which alters the natural structure and function of the Columbia River. In general, we attempted to document presence or absence of larval Pacific and *Lampetra* spp. throughout the Bonneville Reservoir and compare that to information from the Bonneville Dam tailwater and determine detection probabilities using a deepwater electrofisher. Our specific objectives were as follows:

1) Document presence of lamprey ammocoetes throughout the Bonneville Reservoir.
2) Document presence of lamprey ammocoetes in the Bonneville Dam tailwater.
3) Determine the probability of detecting larval lamprey in the Bonneville Reservoir with a deepwater electrofisher, given it was occupied.
4) Determine the probability of detecting larval lamprey in the Bonneville Dam tailwater with a deepwater electrofisher, given it was occupied.
5) Evaluate larval lamprey spatial clustering near tributary inputs within Bonneville Reservoir.
6) Describe the age (i.e., size) distribution of larval lamprey.
7) Describe the species composition of larval lamprey.

Methods

We estimated occupancy of larval lamprey in the Columbia River within several explicit spatial scales by adapting an approach used by Peterson and Dunham (2003) and refined by the U.S. Fish and Wildlife Service (USFWS 2008) to evaluate patch occupancy and detection probability for bull trout *Salvelinus confluentus*. We used this approach in a previous study (Jolley et al. 2010). 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, 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 Bonneville Reservoir, d_{res}, and the Bonneville Dam tailwater, d_{tail}, areas presumed 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 to inform 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 (Peterson and Dunham 2003).

Bonneville Reservoir is impounded by Bonneville Dam (RKm 234) and The Dalles Dam (RKm 314) is the next upstream hydropower project. The reservoir is 75 km long and 7,632-ha at full pool (22.6 m above sea level). Bonneville Reservoir was sampled from 29 July 2010 to 16 September 2010, from The Dalles Dam to Bonneville Dam (Figure 1). The Bonneville Dam tailwater was sampled 9 September 2010 to 29 September 2010, from approximately 3 km downstream of the dam (the closest to the dam we could safely and effectively sample) to approximately RKm 216 in the vicinity of Skamania Island and Multnomah Creek (Figure 2).

Sampling occurred in summer and early fall when water velocities were presumably the lowest and most conducive to sampling.

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) and techniques were similar to Fodale et al. (2003*b*). 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).

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 the study reaches (Figure 3). There were 90,200 quadrats from The Dalles Dam to Bonneville Dam and 16,873 quadrats in the Bonneville Dam tailwater reach that we sampled. 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 each study reach. 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. Previous work in the Lower Willamette River mainstem indicated a sampling effort of 17 quadrats were required to be 80% confident that larval lamprey were absent when undetected (Jolley et al. 2010). Thus, we set a conservative goal of goal of 34 quadrats (i.e., twice the estimated number to be 80% certain of lamprey absence when not detected). To that end 53 quadrats were ultimately selected and visited; 8 (16%) quadrats were not feasible (e.g., dewatered, inaccessible, physical impediment, excessive depth for our configuration) and were eliminated from the sample through reconnaissance surveys. All subsequent quadrats then increased in priority. This resulted in 45 quadrats being sampled, up to a depth of 20 m. We adapted our sample size in the Bonneville Dam tailwater based on the sampling results in the Bonneville Reservoir (i.e., 63 quadrats targeted in the tailwater).

Although we anticipated that larval lamprey would occupy the Bonneville Reservoir, we did not know if lamprey occupied tributary mouth areas of the reservoir. Thus, we identified major tributary inputs to Bonneville Reservoir (i.e., stream order > 3^{rd} order [1:100,000 scale]). Tributaries were the Wind River, Little White Salmon River, Big White Salmon River, Klickitat River, and Hood River (Figure 1). We omitted the Fifteenmile Creek mouth because it is in a restricted area of the immediate tailrace of The Dalles Dam. A tributary mouth area was defined as the area within 0.5 km of the center point of the tributary at the intersection of the Columbia River. The fifty-three lowest ordered quadrats (generated from the original GRTS exercise) were identified in these areas.

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) and caudal fin tissue was collected and preserved in 95% ethanol for subsequent genetic analysis to confirm genus identification. Lampreys were placed in a recovery bucket of fresh river water and released after resuming normal swimming behavior.

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.

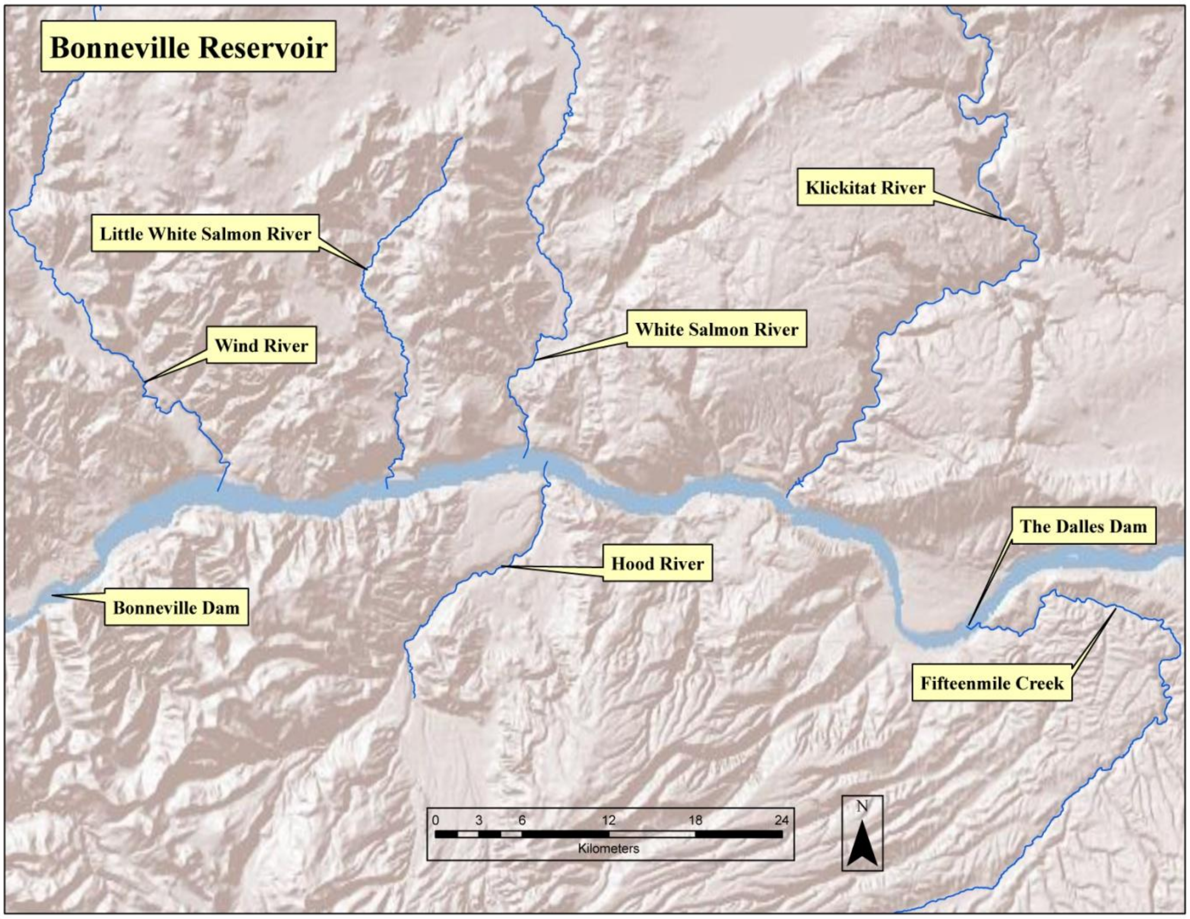

Figure 1. Map of the study area in Bonneville Reservoir and tributary inputs of the Columbia River in 2010.

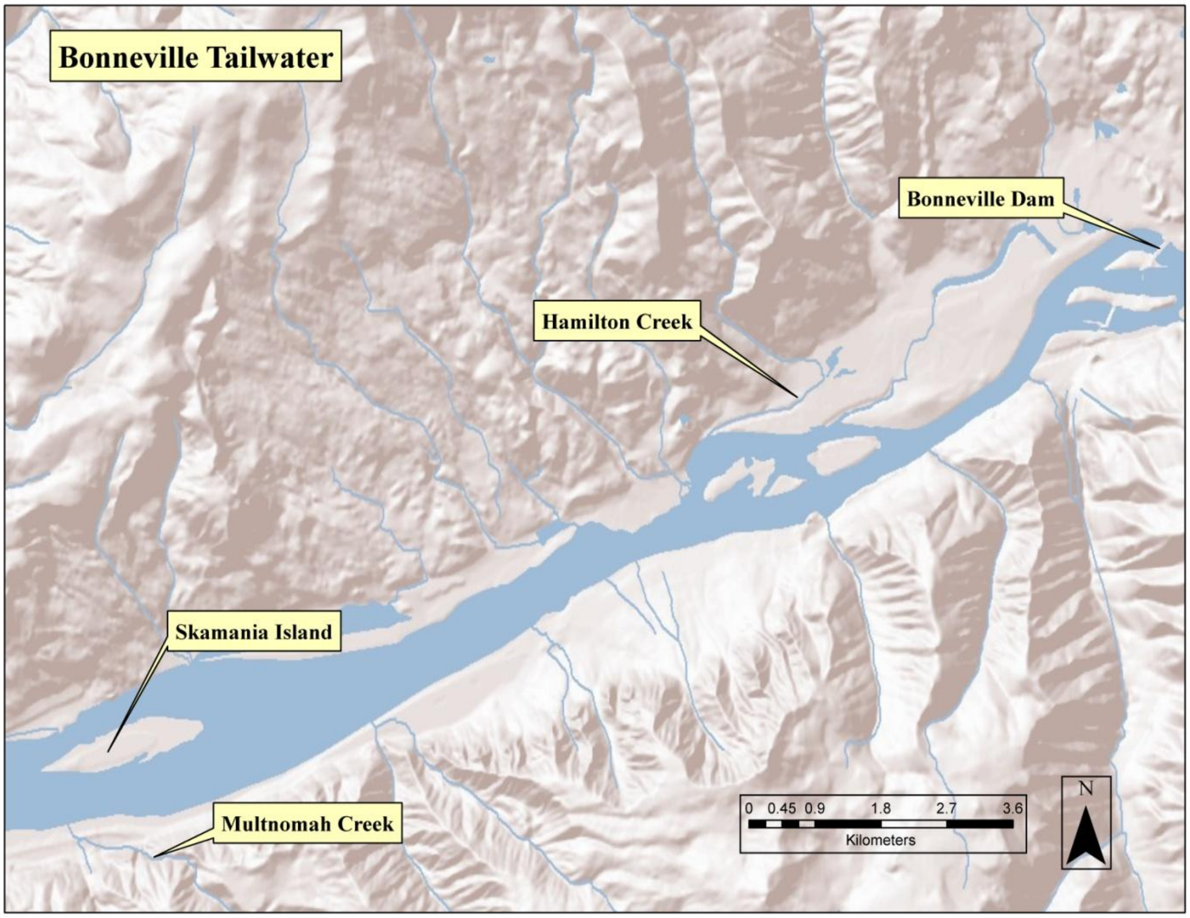

Figure 2. Map of the study area in the Bonneville Dam tailwater of the Columbia River in 2010.

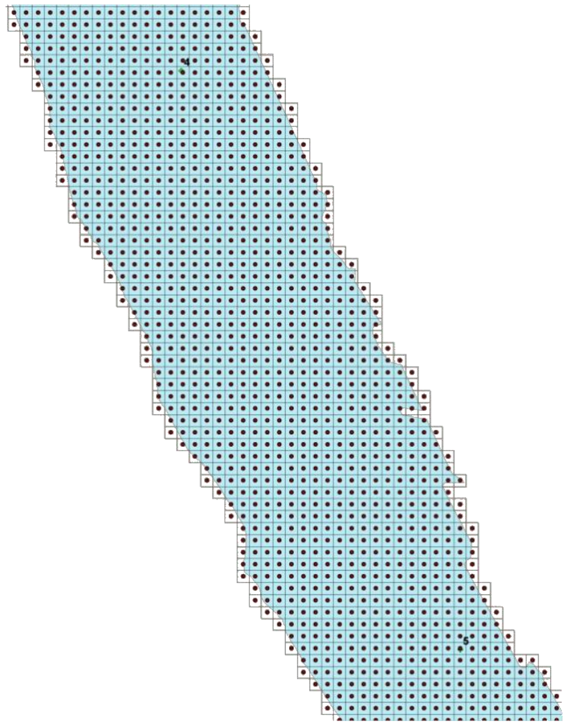

Figure 3. A schematic showing a section of the Columbia River divided into 30 m x 30 m quadrats and associated UTM center points.

Results

A total of 53 quadrats were visited in Bonneville Reservoir of which, 45 (85%) were sampled and 8 (15 %) were not sampled because they were not feasible (e.g., excessive depth > 20 m or dewatered conditions). Overall, one larval Pacific lamprey (TL=72 mm) was detected at 1 (2%) of the quadrats sampled in Bonneville Reservoir (Table 1). This quadrat was 5.8 km upstream of the Wind River mouth at a depth of 14 m (Rkm 254). Given the d_{res} of 0.02, the estimated level of quadrat sampling effort to be 80% certain that larval lamprey are absent when undetected, was 63 quadrats (Figure 4).

Table 1. Number of quadrats sampled and occupied and species present at different locations in Bonneville Reservoir and the Bonneville Dam tailwater, 2010.

Reach	Quadrats sampled	Quadrats where detected	Detection probability	Pacific lamprey
Bonneville Reservoir	45	1	0.02	1
Wind River mouth	5	1	0.20	1
Bonneville Dam tailwater	67	0	0.00	0

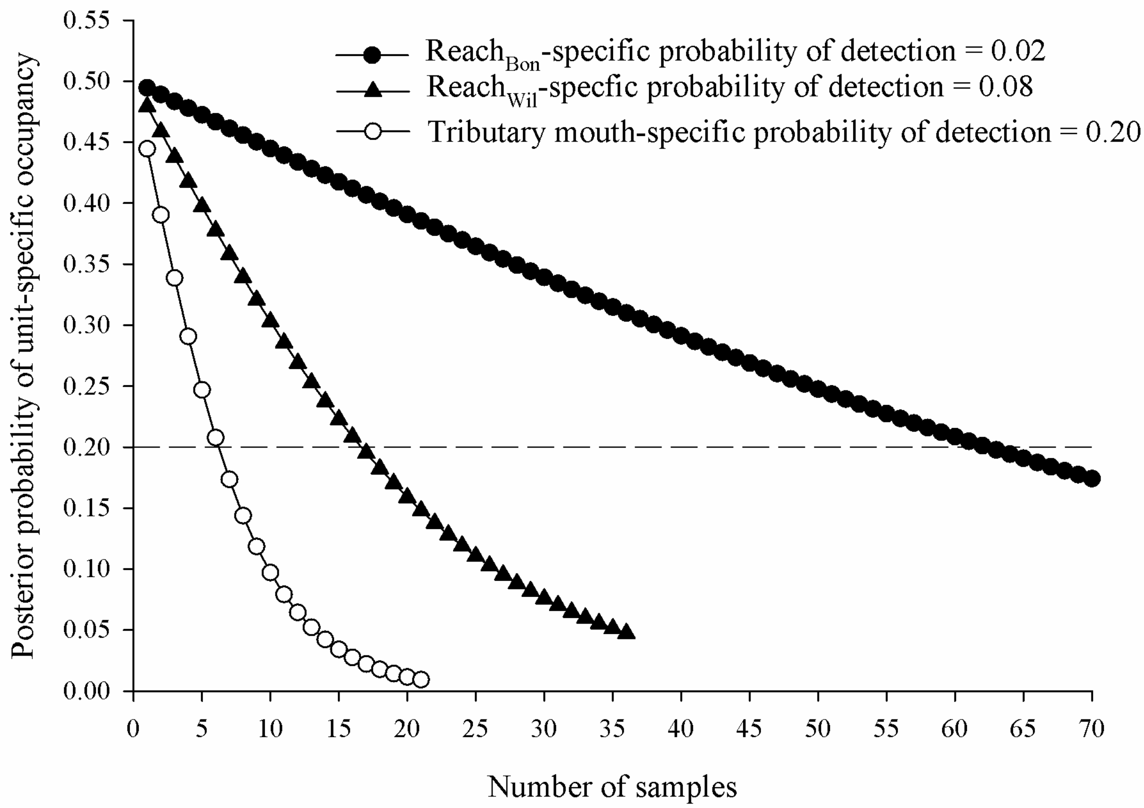

Figure 4. Reach-specific detection probability given varying levels of sampling effort in the Lower Willamette River (Wil) in 2009, Bonneville Reservoir (Bon), and a tributary mouth in 2010. Broken line represents 80% confidence of lamprey absence when not detected.

Five quadrats within the Wind River mouth were sampled (Table 1) and one larval Pacific lamprey (TL=59 mm) was detected in one quadrat (20%) at a depth of 5 m. Given a d=0.20, the estimated level of quadrat sampling effort to be 80% certain that larval lamprey are absent when undetected, was 7 quadrats (Figure 4) in river mouth areas. No additional river mouth areas were sampled and this component of the study is ongoing. Tissue was removed from collected individuals for genetic confirmation of genus; genetic analyses are ongoing.

A total of 82 quadrats (of 16,873 quadrats) were visited in the Bonneville Dam tailwater of which, 67 (82%) were sampled and 15 (18 %) were not sampled because they were not feasible (e.g., excessive water velocity or dewatered conditions). We selected a higher number of quadrats to sample based on the low detection probability found in the Bonneville Reservoir. No larval lampreys were detected in our sampling in this reach.

In Bonneville Reservoir, 38 sediment samples were analyzed and 55 samples were analyzed from the Bonneville Dam tailwater. Mean percent organic content was 1.4% (SE ± 0.3) and 1.5% (SE ± 0.2; Table 2) in Bonneville Reservoir and the Bonneville Dam tailwater, respectively. Mean percent organic content in the Wind River mouth was 6.5% (SE ± 1.9, N=5). Organic content was significantly higher in the Wind River mouth than Bonneville Reservoir or the Bonneville Dam tailwater (ANOVA, F=22.37, df=2, P<0.0001). Sediment particle sizes were generally larger in the Bonneville Dam tailwater (Table 2).

Table 2. Sediment mean percent in size categories (mm), and organic content in in Bonneville Reservoir and the Bonneville Dam tailwater in 2010. Standard errors are in parentheses.

	Mean percent particle size (mm)							
Reach	>37.5	37.5-19.0	19.0-9.5	9.5-1.0	1.0-0.5	<0.5	Mean percent organic content	Number
Bonneville Reservoir	0.0 (0.0)	2.3 (2.3)	0.7 (0.5)	2.6 (0.9)	7.6 (2.2)	86.7 (3.6)	1.4 (0.3)	38
Wind River mouth	0.0 (0.0)	0.0 (0.0)	2.7 (1.6)	29.4 (13.1)	9.6 (4.3)	55.6 (17.4)	6.5 (1.9)	5
Bonneville Dam tailwater	0.0 (0.0)	7.6 (0.0)	8.7 (2.4)	23.0 (3.8)	2.9 (0.6)	57.8 (5.2)	1.5 (0.2)	55

Findings

Larval Pacific lampreys occupy deepwater areas in Bonneville Reservoir. 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) and deepwater tributaries (Bergstedt and Genovese 1994; Fodale et al. 2003*b*). It is unknown if the larval lampreys collected in the Columbia River mainstem actively migrated , were passively washed out of tributary habitats, or hatched there. Deepwater river spawning of lamprey has not been documented although lentic spawning has been observed (Russell et al. 1987). The reservoirs created by many dams on the Columbia River may create habitats (e.g., relatively slower velocity, increased sediment deposition) that didn't exist prior to dam construction or were likely less abundant. Larval lamprey may use these areas at a disproportionally higher rate than pre-dam construction. Conversely, the habitats directly below dams (e.g., increased scouring, suppression of natural flow regime) may be inhospitable to larval lamprey use. Historically, it is conceivable that larval lamprey used the large river habitats more evenly in the Columbia River where they naturally occurred (e.g., natural depositional areas). Future opportunities to explore this topic may arise associated with smaller dam removal projects (given lamprey occur above and below the dam). Studies of ammocoete migration distance, as well as passage routes and survival rates at Columbia River dams would significantly improve our understanding of the relative importance and potential impacts of mainstem residency on larval lamprey. Overall, larval lamprey distribution and habitat usage of mainstem areas in the Columbia River, including above and below hydropower projects, remains largely uninvestigated.

We failed to detect larval lampreys in the 18 km below Bonneville Dam (excluding the immediate 3 km directly below the dam due to unfeasible velocities). Scouring as evidenced by the occurrence of relatively coarse substrate below Bonneville Dam may preclude habitat use by ammocoetes in this area. Our sampling techniques were not feasible in the increased velocities directly below Bonneville Dam; exploration of alternate techniques may be warranted. The GRTS approach provided a statistically robust probabilistic technique for estimating the required sampling effort.

The sampling in the tributary mouth areas is preliminary and that work is ongoing. The detection probability generated for the Wind River mouth is based on a low sample size and should be interpreted as preliminary. An increased effort will be made in this area and will likely significantly alter this original estimate.

Shipping channel and harbor modifications (i.e., dredging) may negatively affect larval lampreys. Although river lamprey *Lampetra ayresii* macrophthalmia have been found in dredge spoils from the Fraser River, British Columbia (Beamish and Youson 1987), it is unknown if lamprey are removed in dredging activities of the Columbia River. Sampling of Columbia River dredge spoils has been recommended (Kostow 2002) and investigation of in situ occurrence of lamprey in pre- and post-dredge areas may be useful. Examination of larval lamprey mainstem river habitat use is ongoing.

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