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Occupancy and Distribution of Larval Pacific Lamprey and *Lampetra* spp. in Wadeable Streams of the Pacific Northwest

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On the cover: USFWS personnel evaluating Balm Grove Dam on Gales Creek of the Tualatin River Basin. Photo taken in June 2015 by Jeff Jolley.

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Abstract – Pacific Lamprey *Entosphenus tridentatus* are declining throughout their range. In 2015, we used an occupancy-based sampling approach to answer several questions about larval lamprey occurrence in wadeable streams to assess status and aid conservation. Specifically, our project goals were to: 1) determine detection probability in a Washington Coastal system (Chehalis River) known to be occupied by Pacific Lamprey through intensive occupancy sampling; 2) rapidly determine occupancy in a 5th level Hydrologic Unit Code (HUC 5; Middle Nisqually River) where Pacific Lamprey occupancy was not known; 3) determine occupancy at small spatial scales in two streams on the Tualatin River National Wildlife Refuge prior to stream restoration; 4) evaluate Pacific Lamprey occupancy above and below a potential passage barrier (Balm Grove Dam) in Gales Creek within the Tualatin River basin; and 5) evaluate potential recolonization of Pacific Lamprey in the White Salmon River basin following a large dam removal (Condit Dam). Using our approach, larval lampreys were highly detectable in areas of the coastal Washington Chehalis River basin known to be occupied. Only *Lampetra* spp. occupied the Nisqually River Middle HUC 5. Small streams on the Tualatin River National Wildlife Refuge were occupied by *Lampetra* spp. only. Balm Grove Dam on Gales Creek is a likely barrier to upstream passage of Pacific Lamprey, as larvae occupied below the dam but were absent above it. Pacific Lampreys were found to occupy areas above the former site of Condit Dam on the White Salmon River indicating recent colonization. The occupancy-based approach proved applicable for addressing a variety of questions over divergent spatial scales, and was efficient since larvae are highly detectable. High detectability of larvae leads to a reduced sample effort required to attain a desired level of confidence that lamprey are absent when they are not observed.

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Introduction

Pacific Lamprey *Entosphenus tridentatus* have experienced a decline in distribution and abundance across their range (Close et al. 2002). They are culturally important to Native American tribes and are also ecologically important (Docker et al. 2015). 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. However, managers lack critical information about life history, basic biology and ecology, and status (e.g., occupancy, distribution, and abundance) of Pacific Lamprey necessary to develop effective conservation strategies (Luzier et al. 2011; Mesa and Copeland 2009). Furthermore, developing range-wide occupancy and distribution data for informing threats analyses remains a necessity (Wang and Schaller 2015).

Relatively recently, occupancy sampling approaches have received considerable study and use to examine distribution and assess status of species in a landscape (MacKenzie and Royle 2005; MacKenzie et al. 2006). Occupancy can be a more efficient method to assess status as compared to abundance, but may also be more relevant to a highly fecund, panmictic species like Pacific Lamprey, since distribution may be a more important consideration for status than abundance in any particular system. The benefits of using standard approaches to data collection are many and include ease of comparison, examination of time-series, and evaluation of management regimes (Bonar et al. 2009). Standardizing sampling methods can be particularly important for occupancy sampling, since an occupancy approach can be used to answer a variety of questions (e.g., access/passage barrier, distribution, recolonization) about a species at multiple spatial scales (MacKenzie and Royle 2005; Baumgardt et al. 2014; Chandler et al. 2015).

Pacific Lampreys have a complex life history that includes larval (i.e., ammocoete), migratory juvenile (i.e., macrophthalmia), and adult marine phases (Scott and Crossman 1973). Larvae lived burrowed in fine sediments of small streams (Claire et al. 2007; Stone and Barndt 2005; Torgersen and Close 2004) and large rivers (Jolley et al. 2012). At this life stage they filter feed on detritus and organic material (Sutton and Bowen 1994) until metamorphosing (typically July to December) into the migratory juvenile life stage (McGree et al. 2008). Within the Columbia River Basin, the migration season is protracted (Mesa et al. 2015; Moser et al. 2015), with most major downstream migrations to the Pacific Ocean occurring during spring, while others begin migration in the fall (Beamish and Levings 1991; Moser et al. 2015). 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). In addition, the co-occurring River Lamprey *L. ayresii*, paired-species to the Western Brook Lamprey (Docker 2009), has a migratory parasitic life-history similar to the Pacific Lamprey (Jolley et al. 2016). Often, the larval stage is sampled to identify occupancy and assess status of lamprey species (Moser et al. 2007; Cowx et al. 2009).

We applied an occupancy-based study design to investigate and document larval lamprey occupancy in several stream basins in Oregon and Washington. Use of an efficient, statistically-rigorous, probabilistic study design allowed us to efficiently address several questions relating to occupancy in a standardized fashion to help range-wide conservation. The approach is flexible and can be adapted to a specific project objective (Jolley et al. 2012; Harris and Jolley *in review*). We applied the design to the following project goals in 2015: 1) determine detection probability in a Washington Coastal system (Chehalis River) through intensive occupancy sampling; 2) rapid determination of lamprey presence in a 5th level Hydrologic Unit Code (HUC 5; Middle Nisqually River); 3) determine occupancy at small spatial scales in two streams on the Tualatin

River National Wildlife Refuge prior to stream restoration; 4) evaluate Pacific Lamprey occupancy above and below a potential passage barrier (Balm Grove Dam) in Gales Creek within the Tualatin River basin; and 5) evaluate potential recolonization of Pacific Lamprey in the White Salmon River basin following a large dam removal (Condit Dam). Specific objectives within each goal were to: 1) evaluate whether selected areas are occupied by larvae; 2) determine species occupying selected areas; 3) determine detection probability of larvae in selected areas; and 4) describe size-structure of larvae in selected areas.

Methods

Study area descriptions

Intensive sampling for determination of detection probability specific to a Washington coastal basin

The Chehalis River Basin was selected as representative of a Washington Coastal basin. The Chehalis River is a 5th order river; the basin originates from several areas including the Cascade Mountain Range of Central Washington and the Olympic Mountain Range of Northwest Washington. The basin covers 6,889 km² and enters Grays Harbor of the Pacific Ocean (Figure 1). The study units were the subbasins of the Black (3rd order; all stream orders hereafter are expressed at the 1:100,000 scale), Skookumchuck (4th order), and Newaukum (4th order) rivers

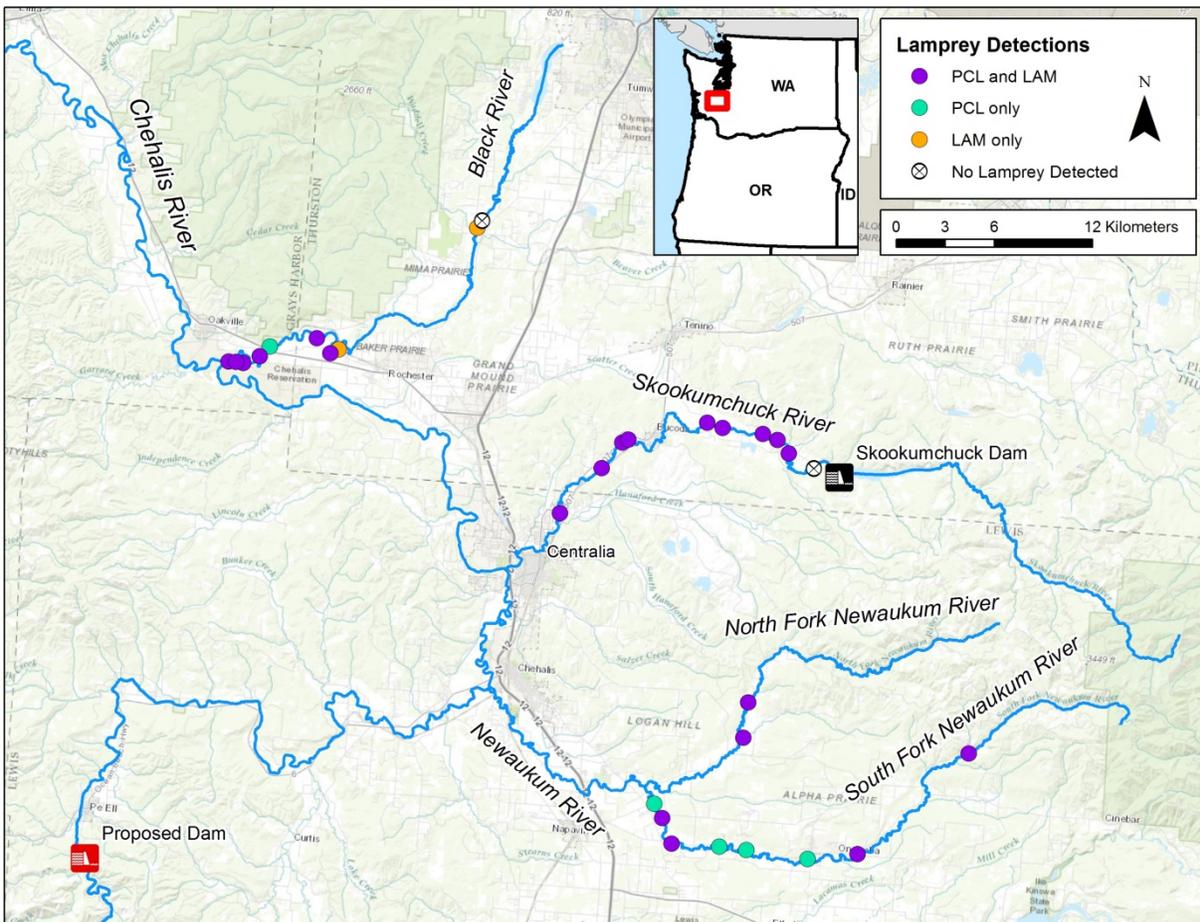


Figure 1. Larval Pacific Lamprey (PCL) and *Lampetra* spp. (LAM) occupancy in stream reaches within the Chehalis River Basin, WA in 2015.

(Table 1). Although targeted lamprey surveys have not previously occurred, the Newaukum and Skookumchuck rivers were known to be occupied with Pacific Lamprey (Pacific Lamprey Data Clearinghouse, USGS ScienceBase 2016) while recent (i.e., 10 years) occupancy within the Black River was unknown. Occupancy data for drainages of the Washington Coast were so sparse that a threats analysis was not possible (Luzier et al. 2011). We have not previously conducted directed occupancy sampling in a coastal drainage of Washington and results can inform specific detection probabilities in these habitats as well as serve as a representative sentinel basin for tracking long-term trends in occupancy and distribution. In addition, discussions are underway regarding a proposed dam on the Chehalis River upstream from our subbasins of interest (Figure 1).

Basin	Sample unit	Stream order	Reaches		d_{unit}	Reaches		Unid
			Reaches sampled	occupied by Pacific lamprey		occupied by <i>Lampetra</i> spp.	d_{unit}	
Chehalis	Black River	3	10	7	0.7	8	0.8	3
	Skookumchuck River	4	10	9	0.9	9	0.9	7
	Newaukum River	4	10	10	1.0	6	0.6	3
Nisqually	Middle Nisqually River							
	HUC 5	5	4	0	0.0	4	1.0	2
Tualatin	Chicken Creek	3	7	0	0.0	5	0.7	1
	Rock Creek South - lower	1	7	0	0.0	2	0.3	0
	Rock Creek South - upper	1	4	0	0.0	0	0.0	0
	Gales Creek - upstream of Balm Grove Dam	3	6	0	0.0	6	1.0	1
	Gales Creek - downstream of Balm Grove Dam	3	6	6	1.0	6	1.0	1
White Salmon	Trout Lake Creek	3	6	0	0.0	3	0.5	5
	Mill Creek	1	10	0	0.0	2	0.2	0
	Buck Creek	2	6	0	0.0	0	0.0	0
	Rattlesnake Creek	3	3	0	0.0	0	0.0	0
	White Salmon River mainstem	5	12	9	0.8	12	1.0	8

Table 1. Number of reaches sampled for larval lamprey occupancy, number of reaches where Pacific Lamprey, *Lampetra* spp., and unidentified larvae (Unid) were collected and associated detection probability (d_{unit}) in 2015.

Rapid determination of lamprey presence within a basin

The area of interest within the Nisqually River Basin was the Middle Nisqually River HUC 5 (Table 1). The Nisqually River is a 5th order river; the basin originates in the Cascade Mountain Range of Central Washington from the southern slope of Mount Rainier and the basin covers 1,339 km², entering the southern end of Puget Sound of the Salish Sea (Figure 2). The middle HUC5 was sampled on the Nisqually River mainstem, Ohop Creek (3rd order), the Mashell River (4th order), and an unnamed tributary to the Nisqually River (2nd order). The

Nisqually River Basin, in general, is known to be occupied with Pacific Lamprey and *Lampetra* spp. but collections have only been made in the Nisqually Lower HUC 5 (Hayes et al. 2013). Occupancy data for drainages of Puget Sound were so sparse that a threats analysis was not possible (Luzier et al. 2011). Occupancy in the middle HUC5 is unknown and the upper HUC5

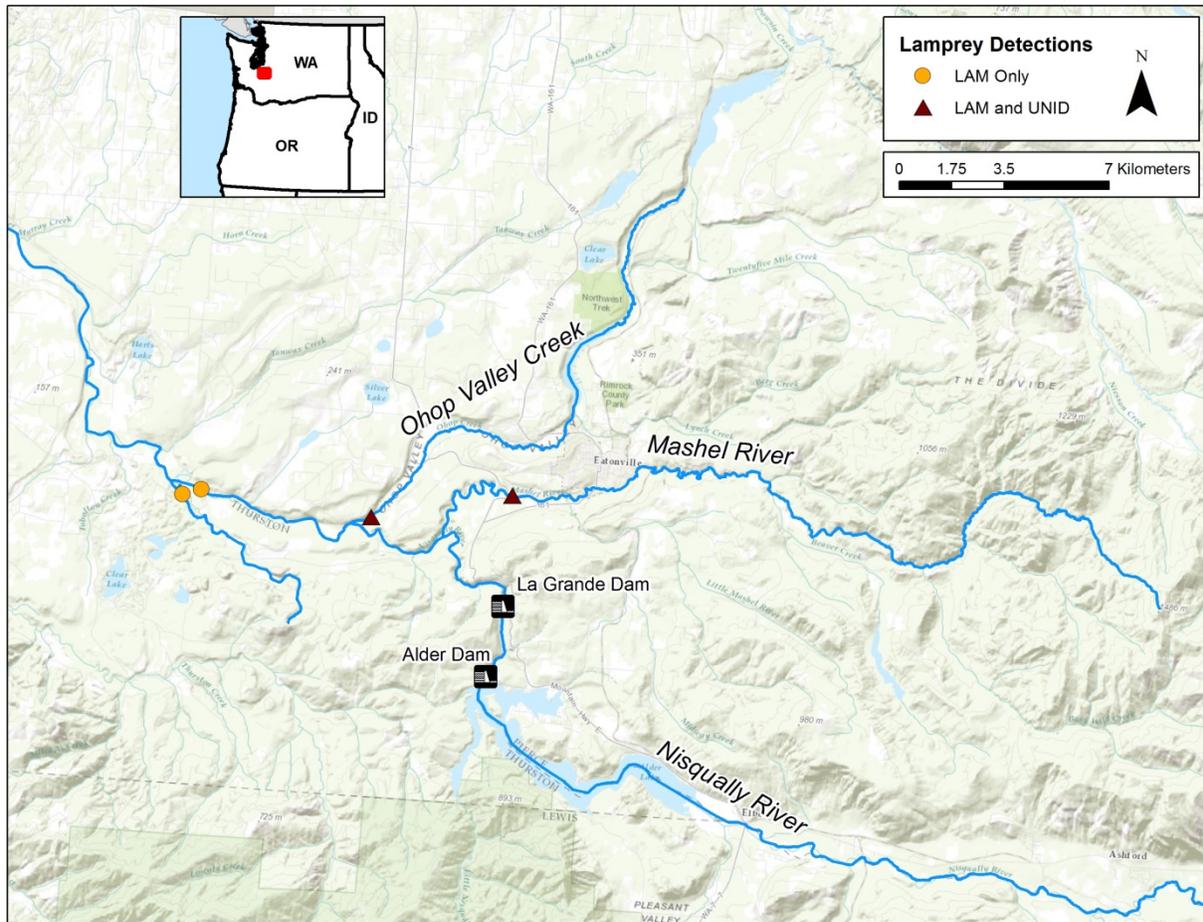


Figure 2. Larval *Lampetra* spp. (LAM) and unidentified (UNID) occupancy in stream reaches within the Nisqually River Basin, WA in 2015.

was historically blocked to fish passage in the LaGrande Gorge and currently by LaGrande Dam (Figure 2).

Determination of presence at a small spatial scale to provide information at a National Wildlife Refuge prior to stream restoration

The Tualatin River is a 5th order river; the basin originates in the Coast Range Mountains of northern Oregon and covers 1,844 km², entering the Willamette River at Rkm 46 (Columbia River Basin; Figure 3). Portions of the Tualatin River Basin are on the Tualatin River National Wildlife Refuge (TRNWR). Chicken Creek (3rd order) and Rock Creek South (1st order) within TRNWR served as pre-restoration monitoring of stream restoration projects (Figure 3). Planned stream restorations include removing the diversion on Chicken Creek allowing the creek to flow

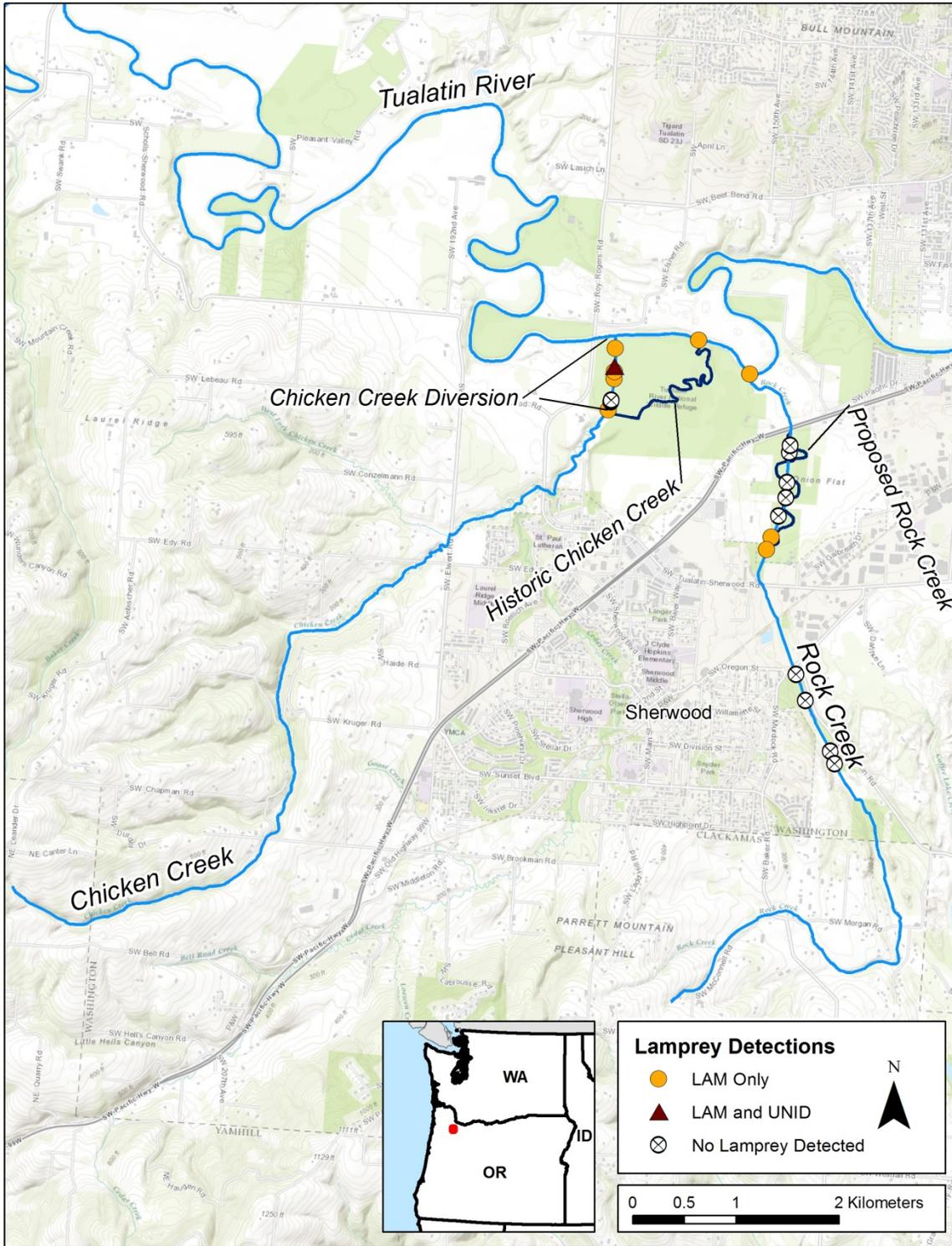


Figure 3. Larval *Lampetra* spp. (LAM) and unidentified (UNID) occupancy in stream reaches within the Tualatin River Basin, OR in 2015. All reaches were within Tualatin River National Wildlife Refuge (green shaded area).

to the historic channel. A more natural, meandering stream channel will be constructed for Rock Creek; the creek is presently ditched and channelized (Figure 3).

Evaluate a potential passage barrier to Pacific Lamprey

Gales Creek (3rd order), within the Tualatin River Basin, contained a potential Pacific Lamprey passage barrier (Balm Grove Dam; Rkm 20; Figure 4). The dam is 0.9 m tall and 2.4 m tall when flash boards are installed with a 90° corner over the top and is constructed with a concrete bottom, measuring approximately 4.6-6.1 m, with sheet flow and an additional small concrete sill at the top of the dam. If fish passage was restored, at least 40 km of stream is accessible to anadromous fish upstream of the dam (T. Stahl and T. Alsbury, 2005 memorandum to Oregon Fish and Wildlife Commission, Oregon Department of Fish and Wildlife, on Scoggins Dam Fish Passage Waiver – Net Benefit Determination, available: http://www.dfw.state.or.us/agency/commission/minutes/05/Feb/E_2_analysis.pdf).

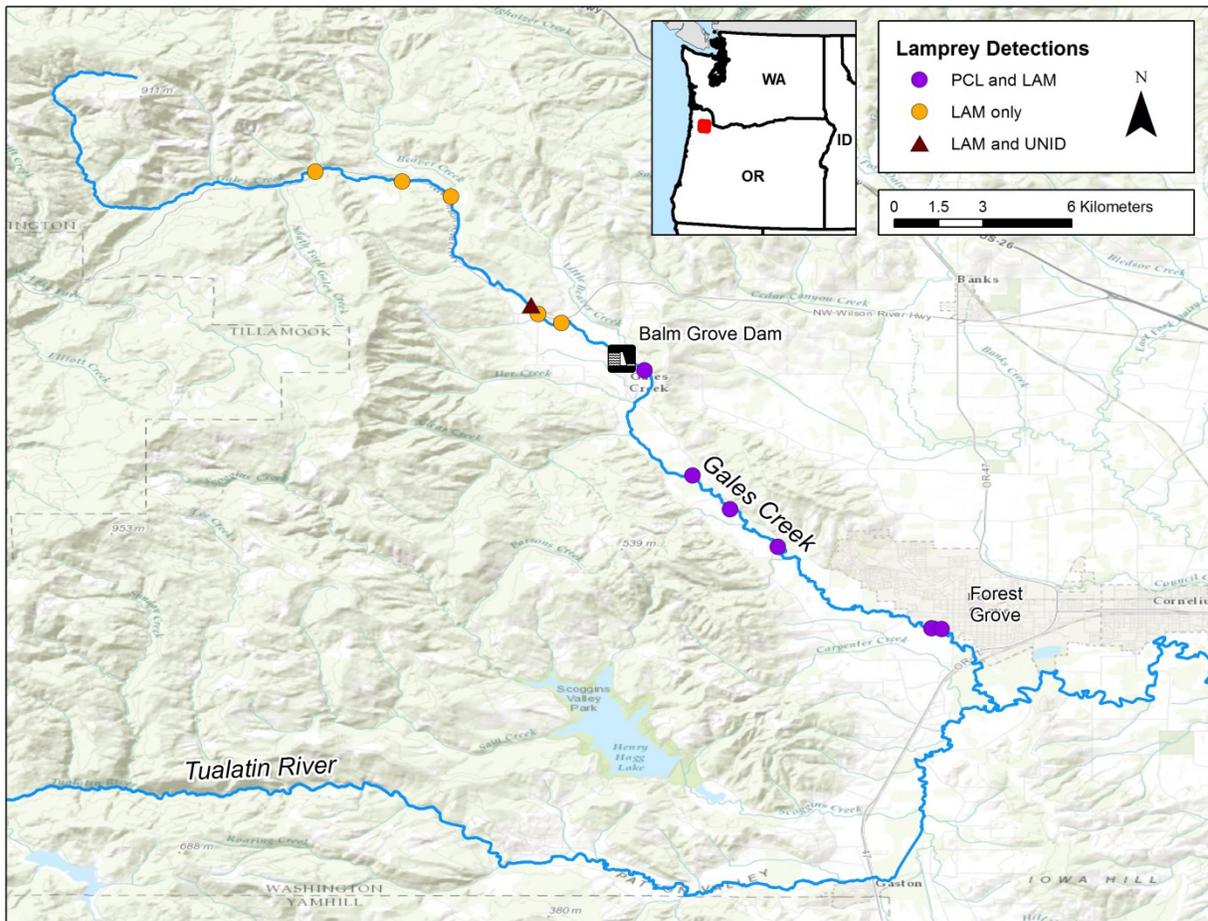


Figure 4. Larval Pacific Lamprey (PCL), *Lampetra* spp. (LAM) and unidentified (UNID) occupancy in stream reaches upstream and downstream of Balm Grove Dam within Gales Creek of the Tualatin River Basin, OR in 2015.

Evaluate potential recolonization of Pacific Lamprey following a large dam removal

The White Salmon River is a 5th order river that enters the Columbia River at Rkm 269. The 1,000 km² basin originates from the southern slope of Mount Adams in the Cascade Mountain Range of southern Washington (Figure 5). Condit Dam was located on the White Salmon River 5.3 km upstream from its confluence with the Columbia River, and was a complete barrier to upstream migrating fish for nearly 100 years. In 2011, the dam was breached and completely removed in 2012. Prior to the dam removal, larval lamprey surveys were conducted in the White Salmon River Basin above and below the dam (Silver et al. 2010). Pre-dam removal surveys indicated the following watersheds would potentially be suitable for Pacific Lamprey recolonization following dam removal: the mainstem White Salmon River above the former dam site, Rattlesnake Creek (3rd order), Buck Creek (2nd order), and Mill Creek (1st order). Trout Lake Creek (3rd order) was found to be occupied with *Lampetra* spp. larvae but may not be accessible to anadromous Pacific lamprey. In 2015, these watersheds were sampled for larval lamprey.

Occupancy assessment

We used an adaptive probabilistic framework to identify the number and the specific location of sampling sites needed to assess occupancy and to estimate detection probability within a unit. When presence is established (see below) in a unit, occupancy is known with a probability of 1; however, when presence is not established, the unit could be truly unoccupied or it could be occupied but not enough individuals were detected. The posterior probability of unit occupancy if presence is not established, $P(F|C_o)$, can be estimated by a model developed by Peterson and Dunham (2003):

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

$P(F)$ is the prior probability of larval lamprey presence and $P(\sim F)$ is the prior probability of absence (i.e., $1 - P(F)$). We set $P(F) = P(\sim F) = 0.5$ (uninformed) since larval lamprey presence in each unit was considered unknown. $P(C_o|F)$ is the probability of not detecting presence when it occurs (C_o = no detection; Peterson and Dunham 2003) and is a function of detection probability and the number of sites sampled, n . Detection probability, or the probability of detecting presence from a random site within an occupied unit, d_{unit} , is based on sampling method and gear. For practical purposes we assumed d_{unit} was the proportion of sampled sites in which presence of the specific larval lamprey species was observed. $P(C_o|F)$ is then estimated as $(1 - d_{unit})^n$. Thus, identifying n requires a unit- and gear-specific detection probability (assumed or estimated) and a predetermined acceptably low level for $P(F|C_o)$, the posterior probability of unit occupancy if larval lamprey presence is not established.

Sample effort varied depending on the objective for each project goal. To select the number of sample sites, we drew on information from previous occupancy sampling in other basins, with detection rates commonly higher than 0.75 (Poirier et al. 2010; Silver et al. 2010). We assumed a relatively conservative detection rate of 0.40 (given an area was occupied). We chose sampling efforts to meet the goals of different objectives to achieve a chosen level of certainty of lamprey absence when they are not detected (Table 1).

In the Chehalis Basin, we set our sampling effort at 10 reaches (reaches are defined below) per subbasin which would yield greater than 99% certainty of lamprey absence when they were not detected (given an assumed $d=0.4$). The more intensive effort also allows empirical

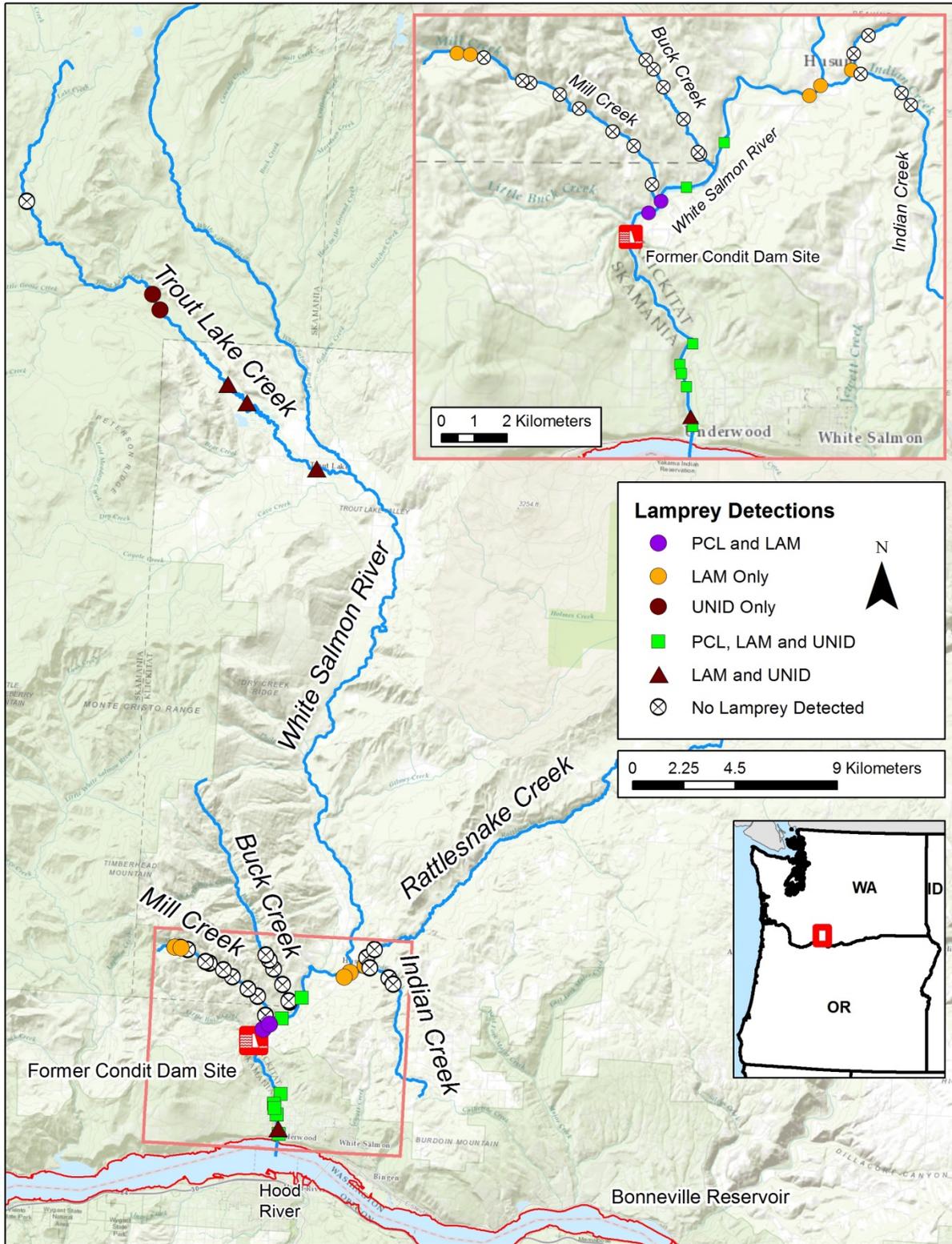


Figure 5. Larval Pacific Lamprey (PCL), *Lampetra* spp. (LAM), and unidentified (UNID) occupancy in stream reaches within the White Salmon River Basin, WA in 2015.

determination of detection probability for a representative coastal system, for which one has not been explicitly determined in these habitats.

We targeted four reaches in the middle Nisqually HUC 5 which would yield over 80% certainty that lampreys were absent if we did not detect them (given an assumed $d=0.4$). We wanted to sample the minimum number of reaches in this area to rapidly determine if larval lamprey were present in the HUC5.

Seven reaches in Chicken Creek and Rock Creek South within the Tualatin River National Wildlife Refuge were sampled and only four reaches were sampled in Upper Rock Creek South due to unfavorable conditions. This effort would yield 97% and 89% certainty of lamprey absence when they were not detected (given an assumed $d=0.4$).

Gales Creek within the Tualatin River Basin was divided into two study areas downstream and upstream of Balm Grove Dam. We sampled six reaches below (12 Rkm) and above (17 Rkm) Balm Grove Dam which would yield a 96% certainty of lamprey absence when they were not detected (given an assumed $d=0.4$).

In the White Salmon River basin, we targeted up to 10 reaches, (but most often fewer were sampled due to passage barriers) in each of Mill, Buck, Rattlesnake, and Trout Lake creeks, and 12 reaches in the White Salmon River mainstem, 6 upstream and 6 downstream of the former Condit Dam site (96% certainty).

We used a Generalized Random Tessellation Stratified (GRTS) approach, to produce sampling reaches in a random, spatially-balanced order (Stevens and Olsen 2004). This approach was used to generate an unbiased sample design that would allow the quantification of detection probabilities.

Field sampling

After the stream reach was located, a 50-m reach upstream of the point was measured and flagged, and water temperature and conductivity were recorded. Sampling for larval lampreys was conducted using an AbP-2 backpack electrofisher (ETS Electrofishing Systems, Madison, WI). The electrofisher delivered three pulses per second DC at 125 V and 25% duty cycle, with a 3:1 burst pulse train (i.e., three pulses on, one pulse off). Electrofishing effort within each reach was targeted at preferred larval lamprey rearing habitat where depositional silt and sand substrates are dominant (henceforth Type I habitat, Slade et al. 2003), while areas with hard bedrock and boulder substrates were sampled less intensively. Habitats that were too deep to wade or had high water velocity were not sampled.

Collected lampreys were anesthetized in a solution of tricaine methanesulfonate (MS-222), and those fish >60 mm total length (TL) were identified as Pacific Lamprey or *Lampetra* spp. according to caudal pigmentation (Goodman et al. 2009; Docker et al. 2016), and classified according to developmental stage (i.e., ammocoete, macrophthalmia, or adult). Most lampreys <60 mm TL were difficult to identify and were deemed “unidentified”. A sample of caudal fin tissue was removed from a subset of larvae and stored in ethanol for future determination or verification of species using genetic methods (Spice et al. 2011; Docker et al. 2016). Lampreys were measured (TL in mm), placed in a recovery bucket of fresh river water, and released after resuming active swimming behavior. Occupancy of a reach was defined as collection of two larvae of the same species that were greater than 20 mm difference in TL or five individuals of the same species that were within 20 mm in TL. If these criteria are not met, we conservatively erred with the determination that the area is not occupied. Length-frequency histograms were constructed for each species to describe size structure.

Results and Discussion

Intensive sampling for determination of detection probability specific to a Washington coastal sentinel basin

Pacific Lamprey and *Lampetra* spp. were widespread and occupied all subbasins sampled within the Chehalis River Basin. Detection rates were high for both species ranging from 0.6 to 1.0 (Table 1). There was a wide size range of larvae (Figure 6); a total of 163 Pacific Lamprey larvae (49-123 mm TL), 139 *Lampetra* spp. larvae (48-138 mm TL), 5 Pacific Lamprey transforming (92-116 mm TL), 2 *Lampetra* spp. transforming (122-123 mm TL), and 3 Western Brook Lamprey adults (118-132; definitive species identification is possible at adult stage) were captured (Table 2).

High detection rates of larvae in the Chehalis River Basin was similar to other studies (Poirier et al. 2010; Silver et al. 2010; Dunham et al. 2013; Reid and Goodman 2015) and further corroborate that the sampling approach is effective at quickly determining occupancy in an area. Furthermore, high detection rates yield minimal reach effort requirements to attain a high level of certainty of larval lamprey absence when they are not detected. The Chehalis River mainstem is undammed and free-flowing and could contain high abundance of larval Pacific Lamprey. It is possible that the high detection rates encountered are related to high abundance. Overall, our study suggests a robust population of Pacific Lamprey is currently present in the Chehalis River Basin.

Construction of a new dam to provide flood control for the cities of Chehalis and Centralia is being proposed. This could have a negative effect on lamprey populations in the Chehalis Riverbasin, as dams on the mainstem Columbia and Snake rivers have been implicated as a major contributor to the decline of Pacific Lamprey (Moser et al. 2002; Mesa et al. 2010; Jackson and Moser 2012; Keefer et al. 2012). In some cases dam construction and operation has led to the extirpation of Pacific Lamprey in upstream areas (Beamish and Northcote 1989). The proposed dam site is upstream of the basins sampled in this study, thus the extent of impacts to lamprey in areas affected by the dam is currently unknown although Pacific Lamprey are known to occur in this area (M. Winkowski, Washington Department of Fish and Wildlife, personal communication). Nevertheless, given the abundance and widespread occurrence of Pacific Lamprey in the Chehalis River basin, it is imperative that any dam constructed on the river in the future be equipped with fish ladders engineered to facilitate upstream passage of adult Pacific Lamprey.

Rapid determination of lamprey presence within a basin

The Nisqually River middle HUC5 was occupied with *Lampetra* spp. but not with Pacific Lamprey larvae. *Lampetra* spp. occupied all four sites sampled in the basin (Ohop Creek, Mashell River, and mainstem Nisqually River). Assuming the lowest detection rate found for Pacific Lamprey in the nearby Chehalis River Basin of 0.7, we are over 99% confident that Pacific Lamprey larvae are absent within the Nisqually River middle HUC5 given the lack of detection in four sampled reaches. A wide range of sizes of larvae were collected (Figure 7); a total of 37 larvae (49-162 mm TL) and 1 transforming (122 mm TL) *Lampetra* spp. were captured (Table 2). Hayes et al. (2012) collected juvenile Pacific Lamprey in the lower Nisqually River with salmonid juvenile screw traps indicating some use of the Nisqually River by Pacific Lamprey. It is unclear why we did not detect any Pacific Lamprey larvae as no barriers to adult migration were known in these areas.

Table 2. Mean total length (TL), standard error (SE), and number (N) of Pacific Lamprey and *Lampetra* spp. collected in 2015.

Basin	Sample unit	Pacific lamprey			<i>Lampetra</i> spp.		
		Mean TL	SE	N	Mean TL	SE	N
		75	2	40	90	3	58
Chehalis	Black River						
	Skookumchuck River	78	2	57	74	3	49
	Newaukum River	81	2	66	89	4	32
					82	4	37
Nisqually	Middle Nisqually HUC5	-	-	-			
Tualatin	Chicken Creek	-	-	-	101	7	18
	Rock Creek South lower	-	-	-	143	5	20
	Gales Creek below Balm Grove Dam	91	3	33	90	2	73
	Gales Creek above Balm Grove Dam	-	-	-	85	3	65
White							
Salmon	Trout Lake Creek	-	-	-	69	3	66
	Rattlesnake Creek	-	-	-	65	-	1
	Mill Creek	-	-	-	93	4	10
	Mainstem White Salmon above Condit	52	3	13	61	3	107
	Mainstem White Salmon below Condit	58	4	43	79	3	122

Determination of presence at a small spatial scale to provide information at a National Wildlife Refuge prior to stream restoration

Pacific Lamprey larvae did not occupy Chicken Creek or Rock Creek South of the Tualatin River National Wildlife Refuge. *Lampetra* spp. occupied Chicken Creek and lower Rock Creek South but not in the upper Rock Creek South. A wide range of sizes were collected (Figure 8); a total of 38 *Lampetra* spp. larvae (43-188 mm TL) and 13 adult Western Brook Lamprey (119-157 mm TL) were captured (Table 2).

Although equivocal, these relatively smaller order tributaries are more likely to be occupied by Western Brook Lamprey (i.e., *Lampetra* spp.) while Pacific Lamprey are more often found in larger order streams (Stone 2006). Pacific Lamprey larvae are known to occur in the Tualatin River Basin (Schultz et al. 2016) and restoration of natural meanderings and function of refuge stream reaches might lead to recolonization of Pacific Lamprey. Pacific Lamprey can detect pheromones released by larvae (Yun et al. 2011) but it is unknown if the pheromone signal from *Lampetra* spp. larvae may provide this cue. It is unknown if Pacific Lamprey larvae occupy the remainder of the Chicken Creek watershed above the refuge or if adult migrating lampreys are able to successfully navigate the diversion structure. Most stream habitat restoration projects in the Pacific Northwest have a salmonid focus; it is unknown how these actions may benefit lamprey species. Our study provides baseline data for lamprey occupancy in these areas but future work should invest in documenting impacts of habitat changes to lamprey

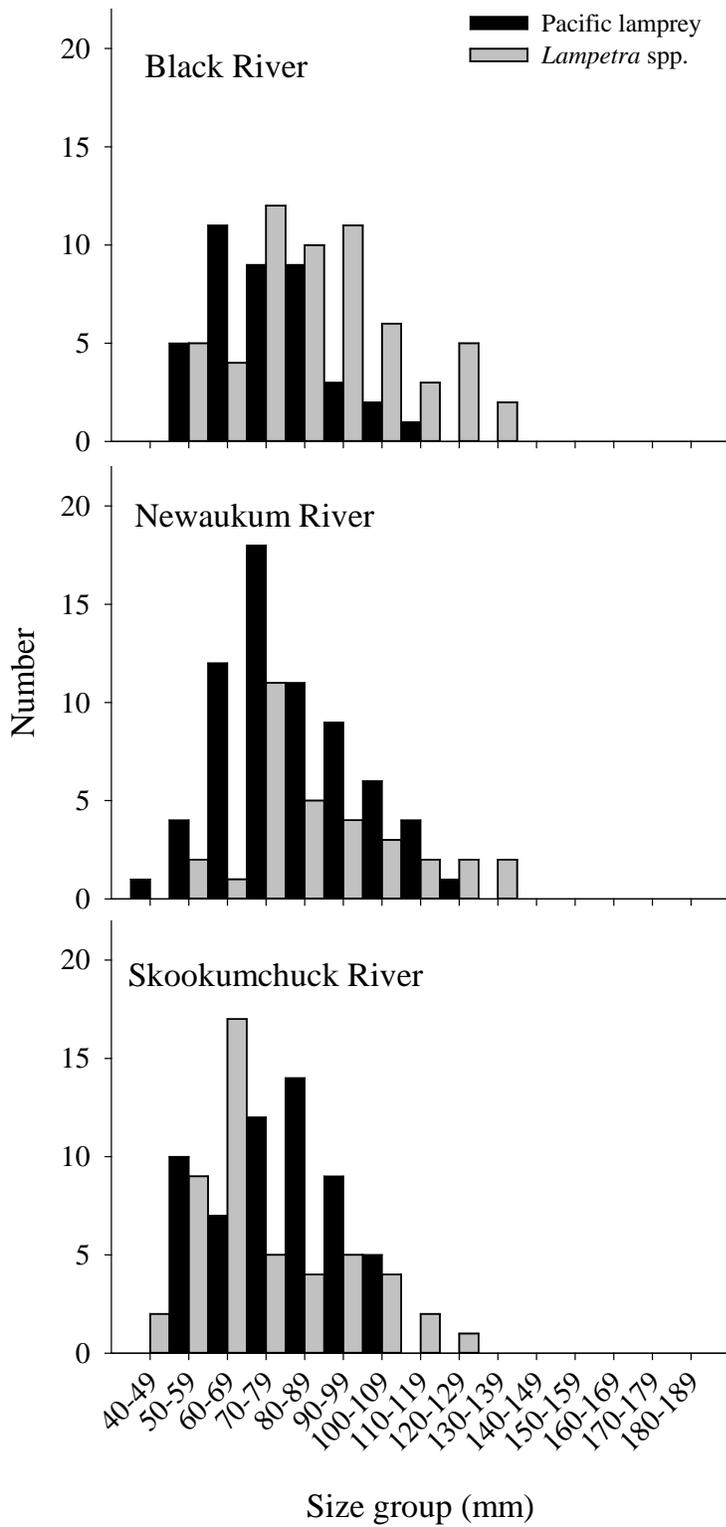


Figure 6. Length frequency (total length in mm) of Pacific Lamprey and *Lampetra* spp. larvae collected in the Chehalis River Basin, WA in 2015.

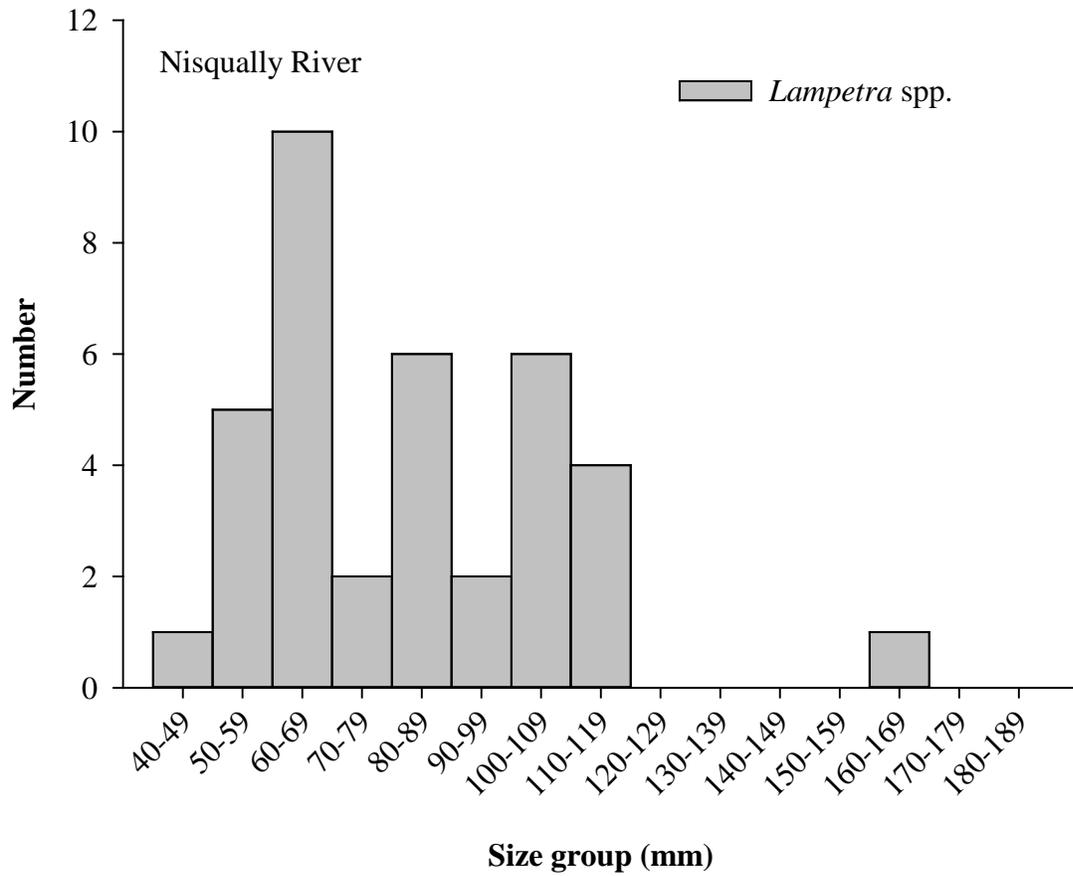


Figure 7. Length frequency (total length in mm) of and *Lampetra* spp. larvae collected in the Middle Nisqually River Basin, WA in 2015.

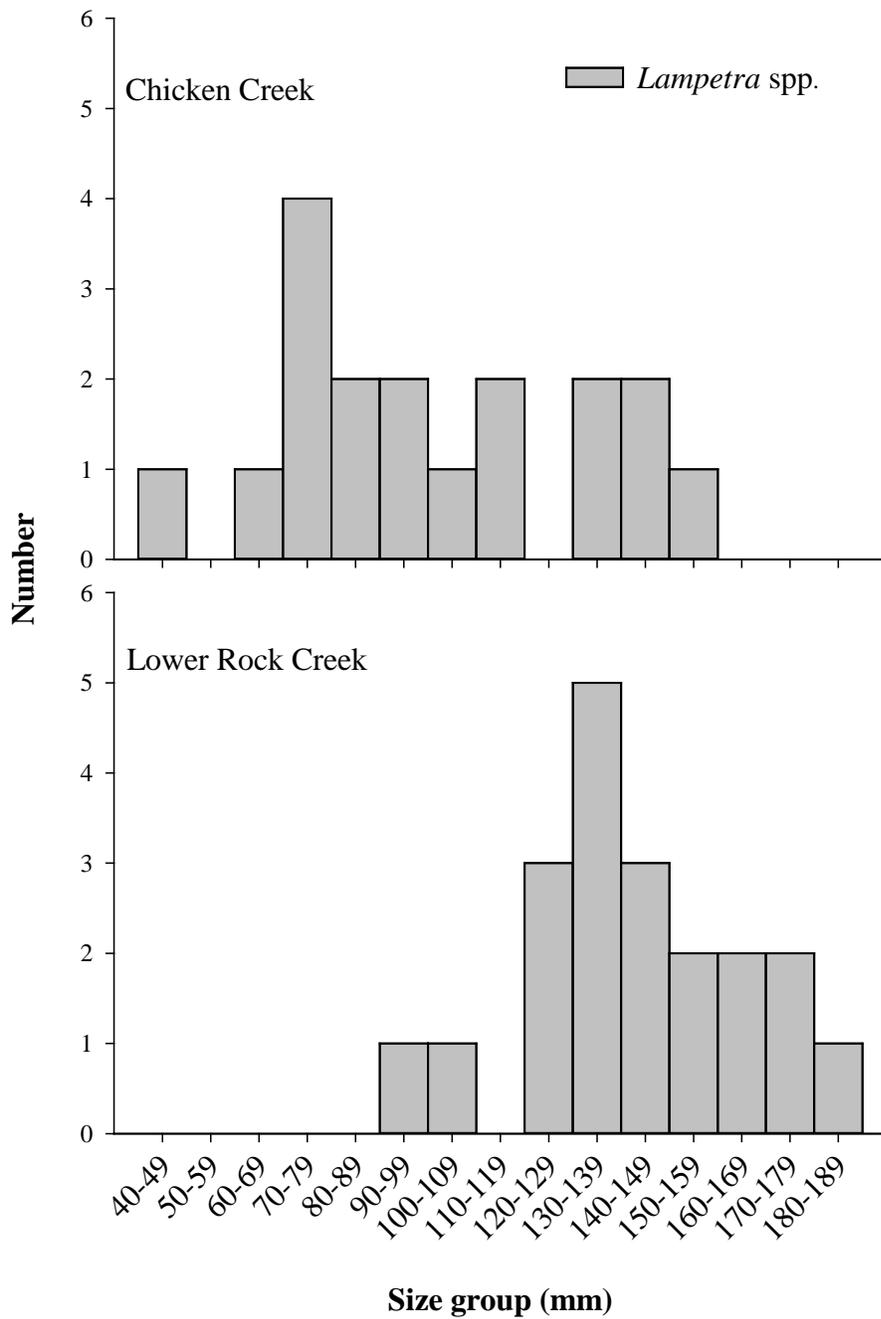


Figure 8. Length frequency (total length in mm) of *Lampetra* spp. larvae collected in the Tualatin River National Wildlife Refuge within the Tualatin River Basin, OR in 2015.

species. An increased effort is necessary to monitor lamprey populations associated with stream restoration activities to provide information on beneficial conservation actions.

Evaluate a potential passage barrier to Pacific Lamprey

Pacific Lamprey and resident *Lampetra* spp. larvae occupied all six reaches ($d_{unit}=1.0$) below Balm Grove Dam on Gales Creek of the Tualatin River while only *Lampetra* spp. occupied reaches above the dam ($d_{unit}=1.0$). A wide range of sizes were collected (Figure 9); a total of 33 Pacific Lamprey larvae (69-134 mm TL) and 138 *Lampetra* spp. larvae (42-147 mm TL) were captured (Table 2). Moderately abundant Pacific Lamprey spawning habitat was observed downstream of Balm Grove Dam, in the most proximate reaches. Potential Pacific Lamprey redds were observed, likely from earlier in the season. The lower sampling reaches, located within the floodplain and agricultural areas, were more degraded, slack, and composed of over 90% Type 1 habitat (Slade et al. 2003). Moderately abundant Pacific Lamprey spawning habitat was observed above the dam but there were no signs of recent spawning use. The availability of adult Pacific Lamprey spawning habitat, the abundant larval rearing habitat (highlighted by the abundant *Lampetra* spp. larvae), and lack of detection of Pacific Lamprey larvae above the dam strongly suggests that Balm Grove Dam is a passage barrier to migrating adults. The height and physical configuration of the dam is likely unpassable by migrating adults (Moser et al. 2002). Balm Grove Dam has also been suggested as a partial or complete passage barrier to migrating salmonids (Bio-Surveys 2015). We recommend the removal of this defunct dam to improve passage conditions for migrating adult Pacific Lamprey and salmonids, and to reconnect the stream corridor. There is 40-56 km of stream upstream of the dam that would likely be accessible to anadromous fish (T. Stahl and T. Alsbury, 2005 memorandum to Oregon Fish and Wildlife Commission, Oregon Department of Fish and Wildlife, on Scoggins Dam Fish Passage Waiver – Net Benefit Determination, available: http://www.dfw.state.or.us/agency/commission/minutes/05/Feb/E_2_analysis.pdf).

Evaluate potential recolonization of Pacific Lamprey following a large dam removal

In the White Salmon River Basin, five reaches in Trout Lake Creek were occupied with *Lampetra* spp. ($d_{unit}=0.83$). *Lampetra* spp. occupied two reaches of Mill Creek, and one larva was detected in 1 of 6 reaches in the Rattlesnake Creek basin, which did not meet our definition of occupancy. No reaches in Buck Creek were occupied by lampreys. In the White Salmon River mainstem above the former dam site, *Lampetra* spp. occupied six reaches and Pacific Lamprey occupied four reaches. Larval Pacific Lamprey and *Lampetra* spp. were detected downstream of Condit Dam after the removal in 6/6 reaches ($d_{unit}=1.00$; Table 1) in wadeable areas of the mainstem of the White Salmon River. A wide range of sizes were collected throughout the basin (Figure 9); 43 Pacific Lamprey larvae (10–107 mm TL), and 122 *Lampetra* spp. larvae (6–143 mm TL), and 7 *Lampetra* spp. transforming (120–170 mm TL) were captured. Pacific Lamprey larvae occurred in several areas within the White Salmon River Basin that were unavailable to them prior to the removal of Condit Dam. The presence of anadromous Pacific Lamprey upstream of the former dam site suggests natural recolonization and habitat utilization of new areas by Pacific Lamprey can occur relatively rapidly after barrier removal (i.e., about three years; Silver et al. 2010). Pacific Lamprey larvae were detected in four reaches above the dam site, as well as in newly created habitats formed by sediment deposition at the river mouth following dam breach and removal (Silver et al. 2010). This is the first rigorously documented

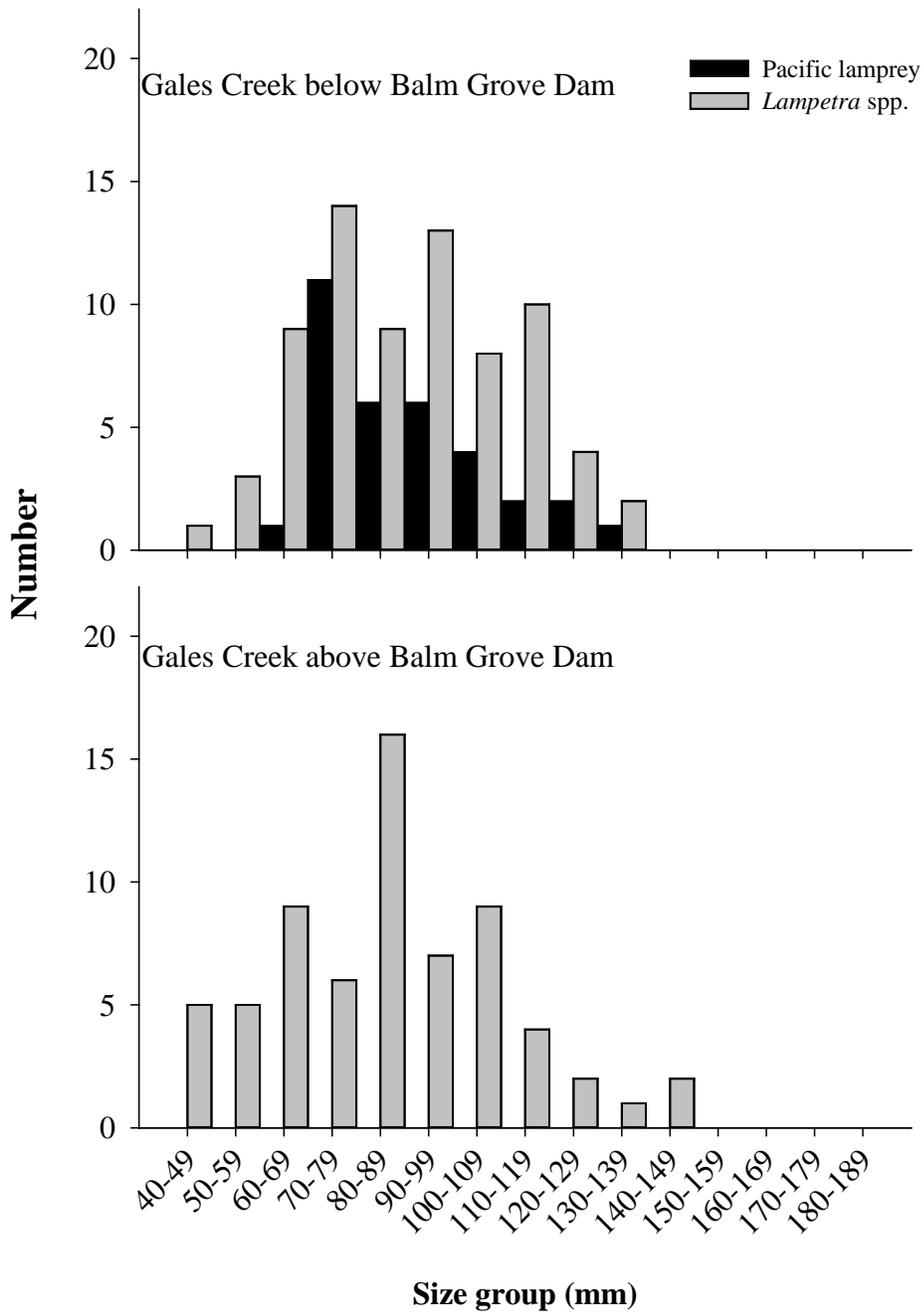


Figure 9. Length frequency (total length in mm) of Pacific Lamprey and *Lampetra* spp. larvae collected above and below Balm Grove Dam on Gales Creek of the Tualatin River Basin, OR in 2015.

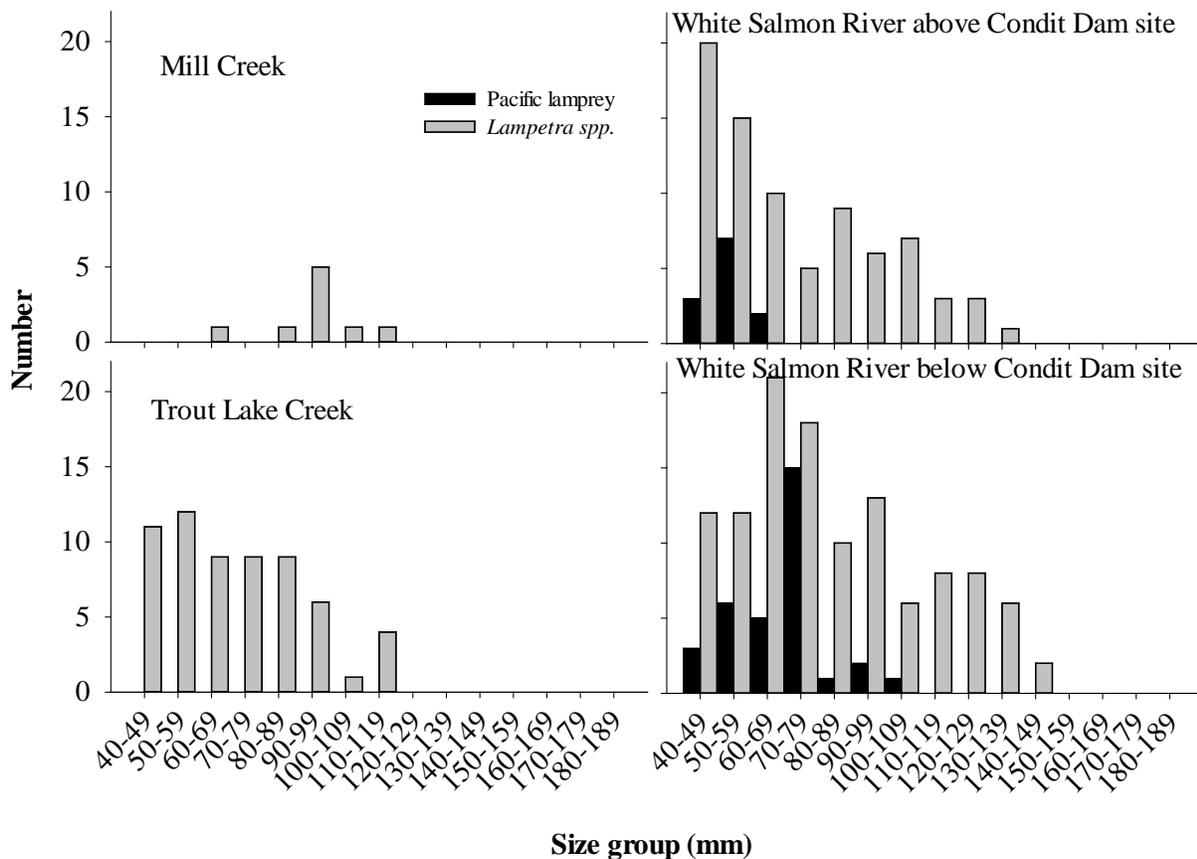


Figure 10. Length frequency (total length in mm) of Pacific Lamprey and *Lampetra* spp. larvae collected above and below the former Condit Dam site on the White Salmon River, WA and selected tributaries in 2015.

natural recolonization by Pacific Lamprey following a dam removal. The dam was breached in October of 2011, and the structure was fully removed by September of 2012. Pacific Lamprey naturally recolonized the North Fork Toutle River which was devastated after the eruption of Mount St. Helens in 1980 (Lin et al. 2008) and colonized Babine Lake in British Columbia after the removal of rockslide that was a suspected barrier (Farlinger and Beamish 1984). Pacific Lampreys have also recolonized Indian Creek of the Elwha River after the removal of Elwha Dam in 2012 (R. Paradis, Lower Elwha Klallam Tribe, personal communication). Sea Lampreys have been shown to recolonize portions of stream basins rapidly following dam removals (Hogg et al. 2013; Lasne et al. 2014) when they were already present downstream of the dam. Colonization of new or completely vacant stream basins may be slower (Pess et al. 2014; Starr 2008) which may be due to the lack of a larval pheromone signal. Pheromones from stream-rearing larvae have been shown to orient adult migrating Sea Lamprey (Bjerselius et al. 2000; Johnson et al. 2012) and experimentally for Pacific Lamprey (Yun et al. 2011).

The small size of the Pacific Lamprey larvae upstream of the Condit Dam site (26-67 mm TL) further corroborates that these individuals were likely produced from recent spawning events. Although adult Pacific Lamprey spawning migrations are protracted (Clemens et al.

2009) they typically enter river basins in spring (Beamish 1980) and continue spawning activities into the summer (Stone 2006); there were three full migration seasons for adults to enter the basin (2013-2015). Although estimating age from length is prone to large error rates (Meeuwig and Bayer 2005) as size at age is highly variable (Hess et al. 2015) these larvae were likely age 0, age 1 and age 2. Meeuwig and Bayer (2005) reported mean length of 46 mm and 51 mm for age 1 and age 2 Pacific Lamprey larvae, respectively. Quintella et al. (2003) reported Sea Lamprey larvae were 50 mm at 12 months and Potts et al. (2015) reported age 1 Sea Lamprey were 30-60 mm TL.

The extent of the White Salmon River basin that could be available and recolonized by Pacific Lamprey remains unclear. Because spawning substrates of Pacific Lamprey and anadromous Rainbow Trout *Oncorhynchus mykiss* (i.e., steelhead trout) overlap (Bjornn and Reiser 1991; Scott and Crossman 1973), anadromous steelhead trout intrinsic spawning habitat potential (Burnett et al. 2007; NMFS 2013) has been used to predict habitats where Pacific Lamprey may occur (Luzier et al. 2011). Although Rattlesnake Creek had a high intrinsic potential for steelhead trout (NMFS 2013) no lamprey larvae were detected in 2007 (Silver et al. 2010) and one *Lampetra* spp. larva was detected in 2015. Rattlesnake Creek is a potential area in the system that Pacific Lamprey could recolonize since it has habitat that is suitable for larval rearing. It is also unclear what constitutes a natural passage barrier for adult Pacific Lampreys as they can climb some structures (Close et al. 2002; Kemp et al. 2009) but detailed evaluations of their full capabilities have not been conducted. There are a series of waterfalls on the mainstem White Salmon River including Husum Falls (Rkm 12.6), BZ Falls (Rkm 20), and Big Brother Falls (Rkm 27). Allen (2012) suggested that a series of falls beginning at Rkm 25 is likely a barrier to all anadromous fish. Other anadromous fish have rapidly recolonized the basin up to Husum Fall including anadromous steelhead trout, Chinook Salmon *O. tshawytscha* (Allen et al. 2016), as well as an anecdotal report of an adult Bull Trout *Salvelinus confluentus* (Engle et al. 2013). A Chinook Salmon redd was also reported in 2012 upstream of Husum Falls. The importance of stream connectivity to the resident Western Brook Lamprey is unclear and it is curious that a robust population is present in Trout Lake Creek, located upstream of all the aforementioned passage barriers. If Pacific Lamprey were to navigate those barriers, there appears to be abundant rearing habitat in the streams of Trout Lake Valley.

Conclusions

The occupancy-based sampling techniques outlined in this study can be adapted to assess potential passage barriers or within-basin distribution across multiple spatial scales. Adopting a probabilistic sampling scheme that utilizes concepts of occupancy and detection probability has shown to be an efficient and valuable method for rapidly establishing occupancy for a variety of applications (Jolley et al. 2012; Harris and Jolley *in review*). The study design is adaptable and efficient because larval lampreys are highly detectable when they occupy an area (Dunham et al. 2013; Reid and Goodman 2015). Data generated through occupancy sampling opens up new avenues such as abundance estimation and modeling the effects of habitat covariates (Bailey et al. 2004; Chelgren and Dunham 2015; Harris and Jolley *in review*). Adherence to a random-based approach to site selection assures inferences can be applied to entire study units of interest and are not limited to specific habitats. Increasing the amount of intensive-sampling applied to a broad range of situations will allow application across the range. Follow-up monitoring of restoration areas (habitat, barriers) will allow an increased understanding of the effectiveness of

these conservation actions. Establishing sentinel basins across the range could allow long-term evaluation of an increasing or decreasing regional or range-wide population trend and help inform management in prioritizing and reducing population stressors.

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