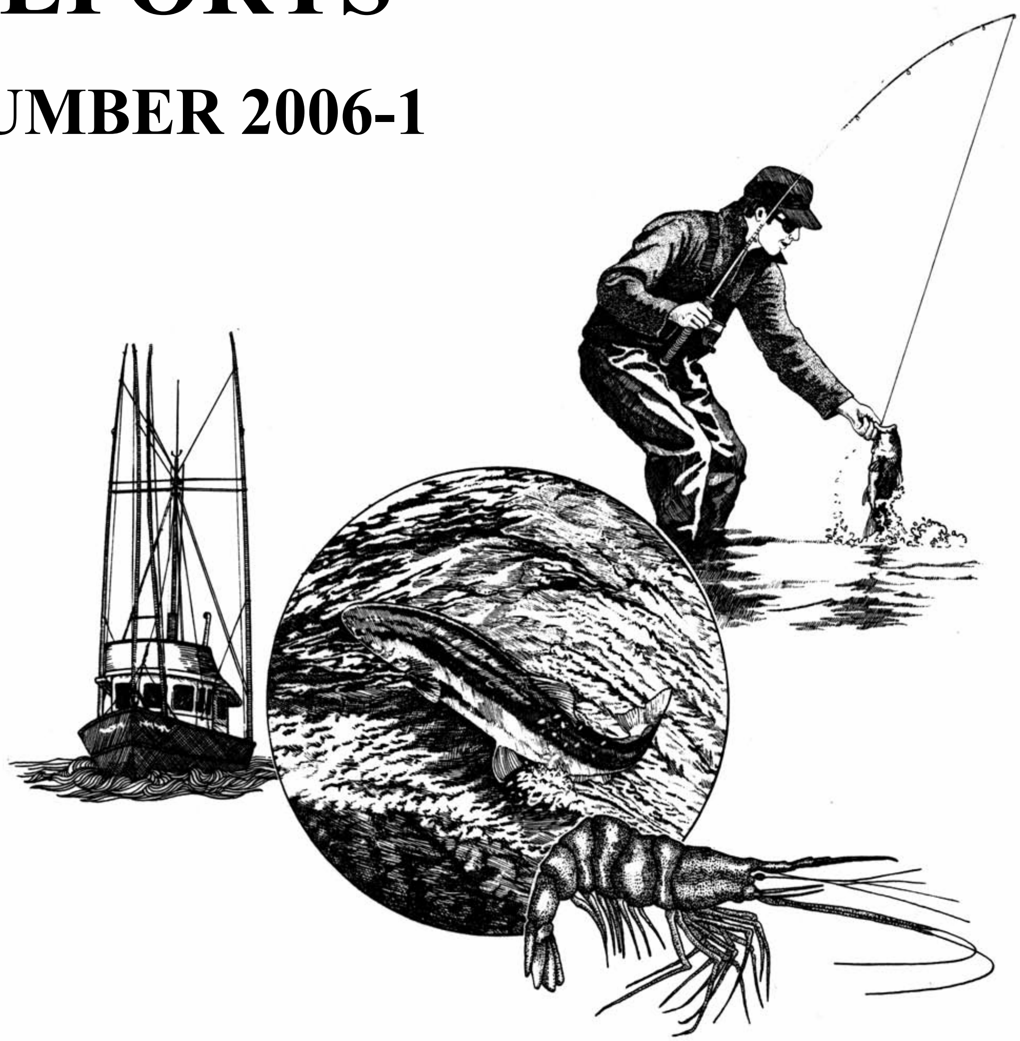
# INFORMATION REPORTS

## NUMBER 2006-1



# FISH DIVISION

## Oregon Department of Fish and Wildlife

Spawning distribution and habitat use of adult Pacific and western brook lamprey in Smith River, Oregon

Spawning distribution and habitat use of adult Pacific and western brook lamprey in Smith River, Oregon

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This project was financed in part through the following funding:

US Fish and Wildlife Service Wildlife Conservation and Restoration, Contract R-5-1

US Fish and Wildlife Service Endangered Species Act Section 6, Contracts 1448-13420-03-J346 and 134204M148

Oregon Department of Fish and Wildlife State of Oregon Funds

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## INTRODUCTION

Coastal Oregon populations of Pacific lamprey *Lampetra tridentata* and western brook lamprey *L. richardsoni* are considered depressed due to habitat loss and passage problems (Close et al. 2002, Nawa 2003, ODFW 2006). Pacific lamprey was listed as an Oregon state sensitive species in 1993 and in 1996 was protected through restriction of harvest (ODFW 2006). Western brook lamprey is not protected and has no special state status. Abundance of Pacific lamprey throughout the coast and Columbia River has declined dramatically since the1960s. Dam counts at Winchester, Bonneville, and Leaburg dams show a dramatic decrease from historical levels (Kostow 2002, Nawa 2003, ODFW 2006). In 2003, eleven environmental groups petitioned the U.S. Fish and Wildlife Service to list Pacific, western brook, and two other lamprey species as endangered in the Pacific Northwest and California (Nawa 2003). Even though the petition cited habitat losses due to reduced in-stream flows, water diversions, dredging, scour and channnelization issues, pollution and degradation of riparian communities, the U.S. Fish and Wildlife Service determined the petition did not contain adequate information to warrant a listing (Federal Register, 69 (27 December 2004) 77158-77167). The Oregon Department of Fish and Wildlife recently reviewed the status of western brook and Pacific lamprey and found populations to be 'at risk' of extinction (ODFW 2006) due to habitat loss, passage barriers and pollution. However data necessary to conduct a thorough and detailed assessment are lacking.

Much of the data lacking are critical to the effective management and conservation of Oregon's coastal lamprey species. The Columbia River Basin Lamprey Technical Workgroup (CRBLTW 2005) and members of Columbia River Inter-Tribal Fish Commission (CRITFC 2004) have identified and prioritized critical data gaps for Pacific lamprey, many of which also apply to western brook lamprey. Among these are 1) methods to assess distribution and abundance of all life stages and appropriate techniques for monitoring population status; 2) population structure and delineation; 3) population dynamics; 4) basic biology including interspecific and community level relationships; 5) limiting factors and threats including passage issues, and 6) habitat needs and requirements.

This study addresses information needs pertaining to distribution and habitat use in addition to providing basic descriptive ecology. Our goal was to identify habitat variables associated with spawning Pacific and western brook lamprey in order to infer distribution throughout coastal Oregon. The objectives of this study were to 1) determine distribution of spawning Pacific and western brook lamprey in the Smith River basin; 2) describe redds of both species; and 3) describe associations of spawning Pacific and western brook lamprey in relation to habitat unit and reach scale habitat characteristics.

### *Life history*

Pacific lamprey is the largest of the Oregon coast lamprey species as adults (up to 70 cm) and can be distinguished from other species by three cusps of the large supra-oral lamina ('teeth') (Wydoski and Whitney 2003). Pacific lamprey are parasitic as adults and express an anadromous life history strategy. Juveniles (ammocoetes) reside in silt and fine sediments of depositional riverine habitats for 4-7 years (Kan 1975, Beamish and Levings 1991, Close et al. 2002). As filter feeders, ammocoetes consume algae, detritus, and diatoms (Close et al. 2002). During metamorphosis ammocoetes develop functional eyes, an oral disk and 'teeth' (Wydoski and Whitney 2003), and newly metamorphosed adults outmigrate to the ocean from July through November (Close et al. 2002). The ocean phase extends 20-40 months (Kan 1975) during which Pacific lamprey parasitize salmon, rockfish, flounder, and other marine species (Close et al. 2002) feeding primarily on body fluids. Pacific lamprey have been captured as far as 100km off the Pacific coast (Kan 1975, Beamish 1980). Adults re-enter freshwater between April and June (Beamish 1980) and migrate upstream where they overwinter beginning in September. Adults do not feed once they enter freshwater. Mature adults spawn March through June and die within one month after spawning (Kan 1975, Beamish and Levings 1991).

Western brook lamprey are the most common and widely distributed of Oregon lamprey species (Kostow 2002). The adults are the smallest of the three coastal species, less than 180 cm and can be distinguished by a small undeveloped oral disc and 'teeth' (Wydoski and Whitney 2003). The life history of western brook lamprey occurs entirely in freshwater. Ammocoetes reside in silt and fine sediment in slow water habitats of creeks and small rivers for up to 6 years feeding on diatoms, algae and other detritus (Pletcher 1963, Kostow 2002). Metamorphosis occurs between August and November, during which individuals develop eyes, a rudimentary oral disc, and experience changes in gills and the enlargement of the nasopineal gland (Kostow 2002). After metamorphosis, western brook lamprey enter a quiescent period lasting until the following March (Pletcher 1963). They are sexually mature when they emerge from dormancy, possibly migrating a short distance upstream before they spawn from March through June (Pletcher 1963, Kostow 2002). As adults, western brook lamprey do not feed.

## METHODS

### *Study area*

This study was conducted in the Smith River, a tributary of the Umpqua River (Figure 1). The study area consists of 463 kilometers of mainstem and tributary streams upstream of Smith River Falls (river km 48). The basin area above Smith River Falls is approximately 525 km$^2$. The riparian community is dominated by red alder (*Alnus rubra*) with an understory of sword fern (*Polystichum munitum)*, salal (*Gaultheria shallon*), and vine maple (*Acer circinatum*) (Jepsen and Rogers 2004). Smith River above the Falls is inhabited by Pacific and western brook lamprey, coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*), steelhead (*O. mykiss*) and coastal cutthroat trout (*O. clarkii*), large scale sucker (*Catostomus macrocheilus*), redside shiner (*Richardsonius balteatus*), long nose dace (*Rhinichthys cataractae*), and Umpqua pikeminnow (*Ptychocheilus umpquae)*. Land is owned predominately by the US Bureau of Land Management (BLM) and private forest companies and managed for timber harvest.

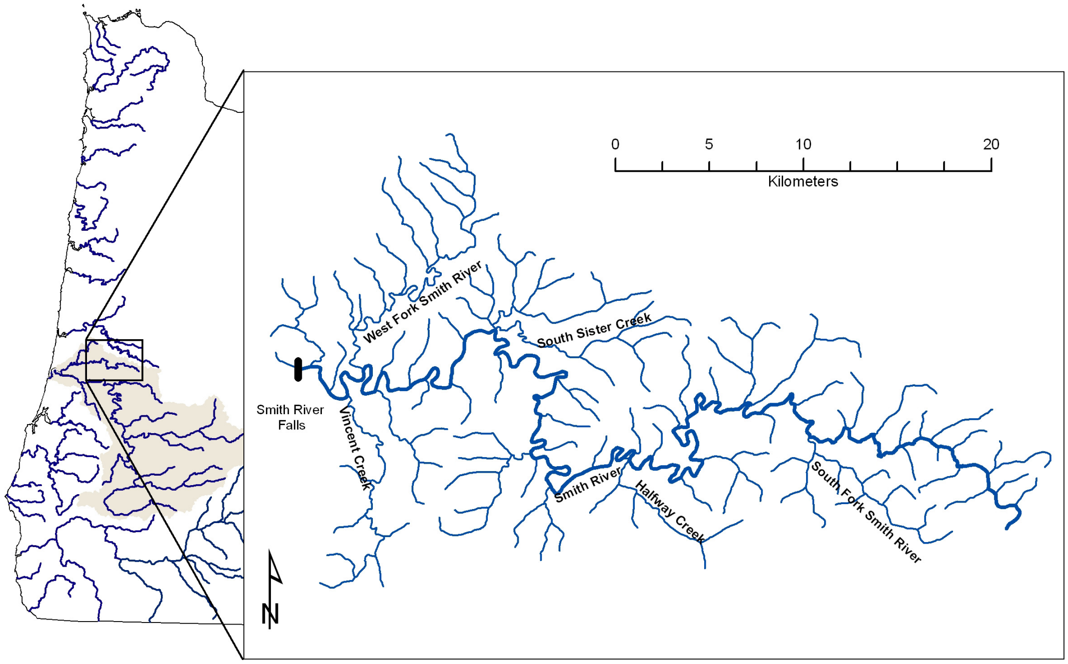


**Figure 1.** Smith River study area in Oregon and the Umpqua River basin.

### *Sample Site Selection*

In each of 2004 and 2005, 50 sample sites were selected from a frame representing the presumed salmonid rearing distribution above Smith River Falls. Given the lack of available information regarding Pacific and western brook lamprey distribution, the salmonid rearing sample frame offers the best starting point to describe potential lamprey distribution in the basin. This distribution was determined using a combination of the sample frame for ODFW's Western Oregon Rearing Project (WORP) Smith River Study (Jepsen and Rodgers 2004) and the large water sample frame for ODFW's Oregon Adult Salmonid Inventory and Sampling Project (OASIS) steelhead trout spawning surveys (G. Susac, ODFW Corvallis Research Lab, personal communication). Sites were selected using EPA's Environmental Monitoring and Assessment Program (EMAP) protocols (Dias-Ramos et al*.* 1996, Stevens 2002) and are randomly selected and spatially balanced ensuring an unbiased and representative sample. The sites selected in 2004 were the same sites visited by the WORP (42 sites) and the OASIS (8 sites) in 2002. In 2005, selected sites were the same as those visited by the WORP (38 sites) and the OASIS (12 sites) in 2004. No sites were surveyed in both years.

Each sample site was associated with geographic coordinates. Sites were plotted on USGS 1:24K topographic maps and uploaded into a handheld GPS unit. Field crews located the precise position of each site using the map, compass, and GPS units. The point represented the downstream end of the sample site. If the beginning and end points of the site had not been previously identified by the WORP or OASIS staff, then crews measured a channel distance of 1000 meters upstream to locate the upper end of the site.

### *Spawning Surveys*

All sites were surveyed bi-weekly from mid March through early June. Newly observed lamprey redds were measured, recorded, and flagged. For each redd, crews noted species, measured length, width, and depth of the redd, depth of the water, water velocity, and distance to the nearest cover and conducted a pebble count. Velocity was measured at the midpoint of the lengthwise axis, on the thalweg side of the redd (Figure 2). Calipers were used to measure the maximum diameter of 15 neighboring (touching) pebbles along both a lateral and vertical transect originating at the top-thalwag corner of the redd (Figure 2) to represent pre-excavation substrate.

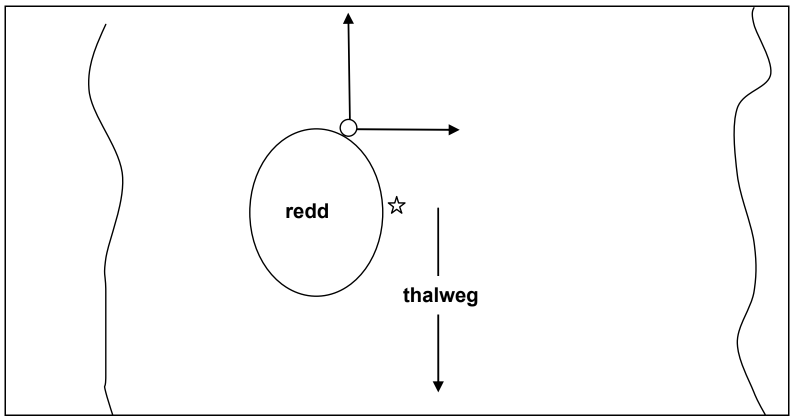


**Figure 2.** Location of water velocity measurement (✮) and origin of pebble counts (O) in relation to the lamprey redd and thalweg.

### *Habitat Surveys*

Habitat surveys were conducted at the end of the season after most spawning activity had ceased. Stream habitat was quantified according to methods described by Moore et al. (2003) with some modifications. The modifications included 1) omission of riparian surveys, 2) measurement of length and widths for all habitat units, and 3) the addition of 'pool tailout' as a unit separate from other pool units. A total of 54 reach scale and 38 habitat unit scale variables were summarized for each site. In general, descriptions were recorded for channel dimensions, streambed composition, geomorphic reach characteristics and riparian cover and shade. In order to associate habitat and reach scale data with each redd, specific redds were noted in the habitat units of which they occurred.

### *Spawning Survey Analysis*

Basic descriptive statistics were used to describe spawn timing, redd characteristics and abundance of redds at each site. Distribution within the study area was examined and displayed using a Geographic Information System (GIS). An estimate of the total redd count in the basin for each species was generated using analytical algorithms developed by the EMAP (Stevens 2002).

### *Habitat Association Analysis*

The reach scale habitat dataset was reduced by removing highly correlated variables as determined by correlation analysis. Of two or more highly correlated variables, we retained the variable with the more accurate or precise measurement. Non-metric multidimensional scaling (NMS) was used to ordinate all sites based on the reach scale variables (Kruskal 1964, McCune and Mefford 1999). NMS ordinations were generated using a relative Sorenson's distance measure. Three hundred iterations were used for each run to evaluate stability and each analysis was conducted 10 times to ensure the lowest possible stress. We overlaid the response variables (presence of lamprey and redd density) on the ordination and orthogonally rotated it to load the maximum variation associated with the response variable on the first axis. Correlation coefficients of habitat variables to the ordination axis 1 were used to identify factors related with presence of spawning lamprey. Analyses of associations at the habitat unit scale were conducted in the same manner, except only those habitat units comprising sites where lamprey were detected were included in the analysis.

## RESULTS AND DISCUSSION

We surveyed 31 sites in each 2004 and 2005. Of the original sample draw of 50 sites, 2 were dry, 2 were not surveyable, and 3 were surveyed by OASIS crews where lamprey data were not consistently collected in 2004; 1 site was not surveyable in 2005. Field crews were unable to incorporate the remaining sites (12 in 2004 and 18 in 2005) into the bi-weekly survey rotation. Surveys were conducted between 29 March and 24 June 2004, and 28 March and 30 June 2005.

In 2004, field crews counted a total of 313 western brook lamprey redds between 6 April and 7 June, with the maximum observed within a two-week period occurring during the 19 May and 1 June survey cycle (Figure 3). In 2005, western brook lamprey spawning activity commenced one week later than in 2004. A total of 249 western brook lamprey redds were detected between 25 April and 16 June, where the maximum number of redds was counted during the 24 May - 6 June survey.

A total of 60 Pacific lamprey redds were counted between 5 April and 5 May 2004, with the peak count occurring during the 7 April and 20 April survey cycle (Figure 3). In 2005, Pacific lamprey redds were first detected one week later than in 2004; 69 Pacific lamprey redds were counted between 14 April and 6 June. Two peak counts were noted in 2005. The first peak occurred between 26 April and 9 May and the second between 24 May and 6 June. The delay in Pacific lamprey spawning activity in 2005 was similar to that observed on the SF Coquille River (Brumo and Markle 2006) and may be related to higher stream flows and cooler water temperatures that spring.

Using the EMAP protocol we estimated a total of 4692 (±76%, 95%CI) western brook lamprey redds in 2004 and 4265 (±91%, 95%CI) redds in 2005. Pacific lamprey redds were estimated to be 504 (±67%, 95%CI) in 2004 and 459 (±110%, 95%CI) redds in 2005. The precision of these estimates is less than desired. A 95% confidence interval less than 45% is acceptable and less than 35% is ideal. The large confidence intervals were likely due to the large sample frame and high variance between sites. Tailoring the sample frame to the distribution of each species, increasing sample size, and refining survey protocol may result in a more precise estimate, and should be considered if redd surveys using the EMAP protocol is to be implemented as a long term monitoring strategy.

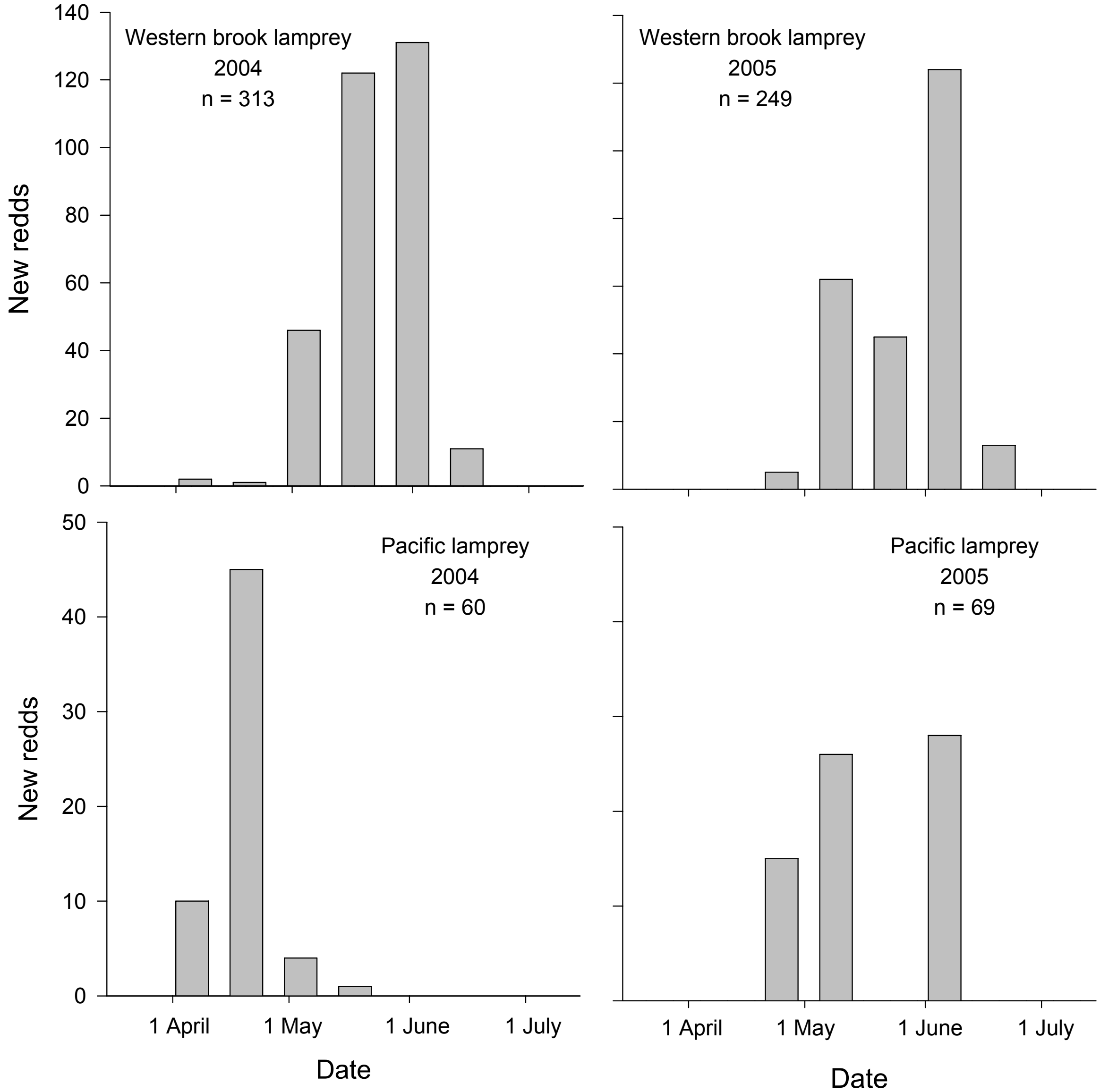


**Figure 3.** Spawn timing of western brook and Pacific lamprey in 2004 and 2005. Each bar represents a two week survey cycle. Surveys were conducted from 29 March through 24 June in 2004 and 28 March through 30 June in 2005.

### *Redd Characteristics*

Generally lamprey redds were identified as round depressions in gravel or cobble substrates. Rocks moved by lamprey to dig the depression typically were piled on all sides of the depression rim and were lighter colored due to the exposure of non-algae covered surfaces. A plume of finer substrate carried by the current was downstream of the depression as a result of spawning and egg burial (Figure 4), however in places with low flow these finer substrates were not apparent. In many instances few large rocks were left in the bottom of the depression. Pacific and western brook lamprey redds differ in size and substrate size. Redd characteristics for each species are summarized in Table 1.

Western brook lamprey redds were found in gravel rich and relatively shallow habitats, predominantly pool tailouts (46.3%), low gradient (slope < 2%) riffles (22.2%), steps over cobble (16.1%) and lateral scour pools (13.1%). Redds were associated with a variety of cover types, most commonly rocky substrates (58.1%), wood (11.9%), and vegetation (8.9%). Because western brook lamprey redds are small, large cobble substrates serve as adequate cover. Fourteen percent of redds were not associated with any cover.

Pacific lamprey redds were most frequently observed in low gradient riffles (50.4%), pool tailouts (36.8%) and lateral sour pools (11.2%). Only 43.2% of Pacific lamprey redds were associated with cover, predominately large substrates (26.4%), vegetation (8.0%) and wood (6.5%). The remaining 56.8% of the 125 redds were observed away from channel features that could serve as cover.

**Figure 4.** Pacific lamprey redd (Photo by G. Susac, OASIS).

**Table 1.** Summary of western brook and Pacific lamprey redds. Redd depth is the distance from the bottom of the depression to the surface of the substrate; water depth is the distance from the substrate to the water surface; Substrate is the average maximum diameter of 30 pebbles.

| Variable | Median | Min | Max | S. D. |
|---|---|---|---|---|
| | | **Western brook lamprey n = 539** | | |
| Length (cm) | 12.0 | 4.0 | 115.8 | 7.8 |
| Width (cm) | 11.0 | 4.5 | 73.2 | 7.8 |
| Redd Depth (cm) | 3.0 | -3.5 | 12.2 | 2.1 |
| Water Depth (cm) | 13.0 | 0.3 | 51.0 | 7.6 |
| Velocity (m/sec) | 0.2 | 0.0 | 0.7 | 0.1 |
| Substrate (mm) | 24.0 | 7.8 | 65.2 | 9.0 |
| | | **Pacific lamprey n = 125** | | |
| Length (cm) | 39.0 | 21.3 | 210.0 | 18.3 |
| Width (cm) | 36.6 | 20.0 | 270.0 | 23.9 |
| Redd Depth (cm) | 7.6 | -12.0 | 18.3 | 3.8 |
| Water Depth (cm) | 44.0 | 16.0 | 105.0 | 23.2 |
| Velocity (m/sec) | 0.6 | 0.2 | 1.0 | 0.2 |
| Substrate (mm) | 48.1 | 27.0 | 88.8 | 12.9 |

Four factors complicated the identification of redds. First, in 27 instances (24 western brook lamprey, and 3 Pacific lamprey) redds were identified in large areas of cleaned and disturbed gravel, usually containing 2-5 depressions. These areas were 2-3 times the size of a typical redd. It was evident substrate had been cleared due to lamprey spawning activity, but it was not obvious how many redds these areas represented. Each identifiable depression was counted as an individual redd but measurements were made with considerable uncertainty. These redds were not included in the summaries described in Table 1.

Second, in a few instances field crews observed both western brook and Pacific lamprey filling in newly created redds. Lamprey moved small gravel and cobble from upstream into the depression until it was filled and flush with the substrate surface. In some cases the depression was filled where it mounded above the surface of the substrate (depicted as negative values in minimum depth measurements in Table 1). This behavior may make the detection of redds difficult where this behavior is common.

Third, in a few instances field crews observed western brook lamprey spawning in redds of Pacific lamprey. Field staff were diligent about revisiting old redds of both species to capture any superimposition by western brook lamprey. Studies in the SF Coquille River and Lewis River in Washington have also observed this behavior (Pirtle et al. 2003, Brumo and Markle 2006).

Last, crews were careful to properly identify western brook lamprey redds. In places where redds could be easily confused with large elk tracks, the presence of a lamprey positively identified the redd. If a lamprey was not present then the redd was not counted or measured. Similarly, Pacific lamprey redds could be confused with steelhead redds. Again, field crews made conservative redd calls and only identified redds certain to be created by lamprey.

These complications are likely sources of error for quantitative redd counts and should be taken into consideration if using redd surveys for population monitoring purposes. Similar to redd surveys for bull trout and other salmonids, crew experience is one method to minimize error associated with misidentification, superimposition and lamprey spawning behavior. In addition, frequent surveys (no less than biweekly surveys) can ensure positive identification of redds and minimize error. In many instances crews observed redds on one survey that were filled in, superimposed, or otherwise unidentifiable on the subsequent visit.

### *Site Occupancy and Distribution*

Field crews detected western brook lamprey redds in 20 of 31 sites in 2004 and 16 of 31 sites in 2005 (Table 2). Pacific lamprey redds were identified in fewer sites, 8 in 2004 and 9 in 2005.

**Table 2.** Occupancy statistics for sites surveyed for lamprey redds in the Smith River Basin, 2004 and 2005.

| Year | Sites Surveyed | Sites Occupied | Minimum number at occupied site | Maximum number at occupied site |
|---|---|---|---|---|
| **Western brook lamprey redds** | | | | |
| 2004 | 31 | 20 | 1 | 136 |
| 2005 | 31 | 16 | 1 | 114 |
| **Pacific lamprey redds** | | | | |
| 2004 | 31 | 8 | 1 | 15 |
| 2005 | 31 | 9 | 1 | 48 |

Generally, western brook lamprey were widespread in the smaller order tributary streams (Figure 5), whereas Pacific lamprey only occupied large mainstem reaches of Smith River and West Fork Smith River (Figure 6). This pattern of distribution is similar to that observed on Cedar Creek in the Lewis River system, where Pacific lamprey spawning locations were in the lower sections of Cedar Creek and western brook lamprey were found in the upper tributaries (Pirtle et al. 2003).

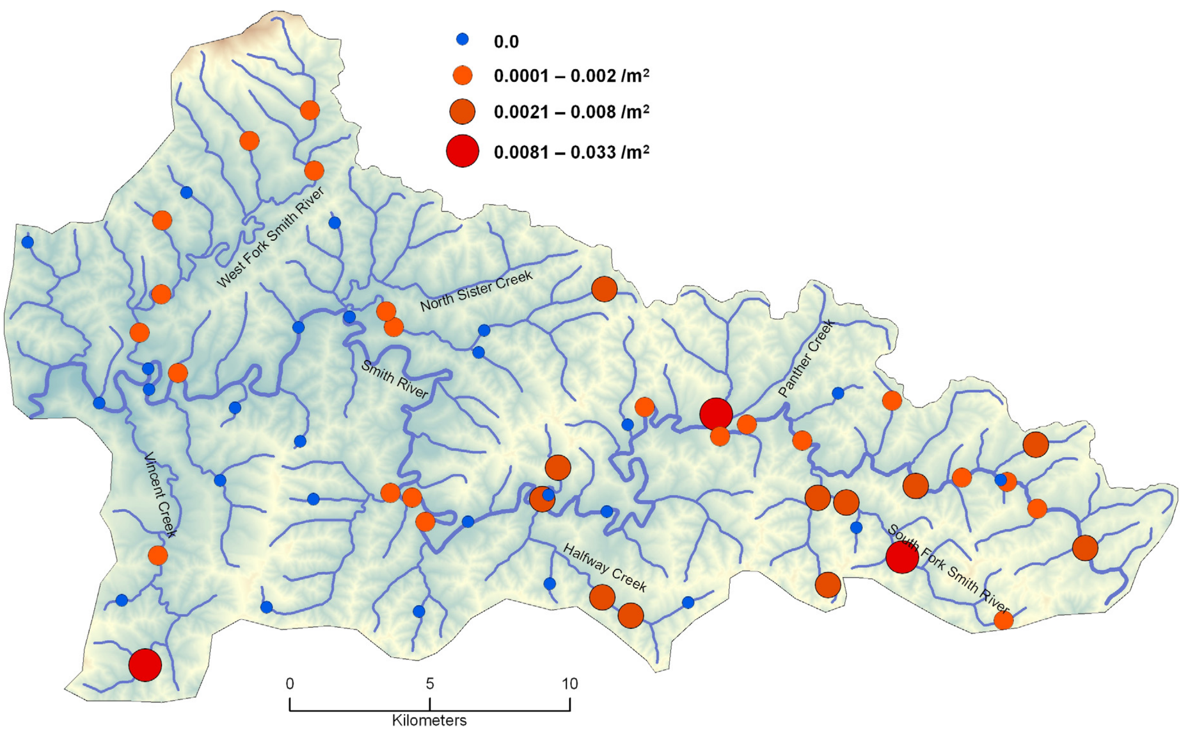


**Figure 5.** Site occupancy and redd density for western brook lamprey in the Smith River Basin, 2004 and 2005.

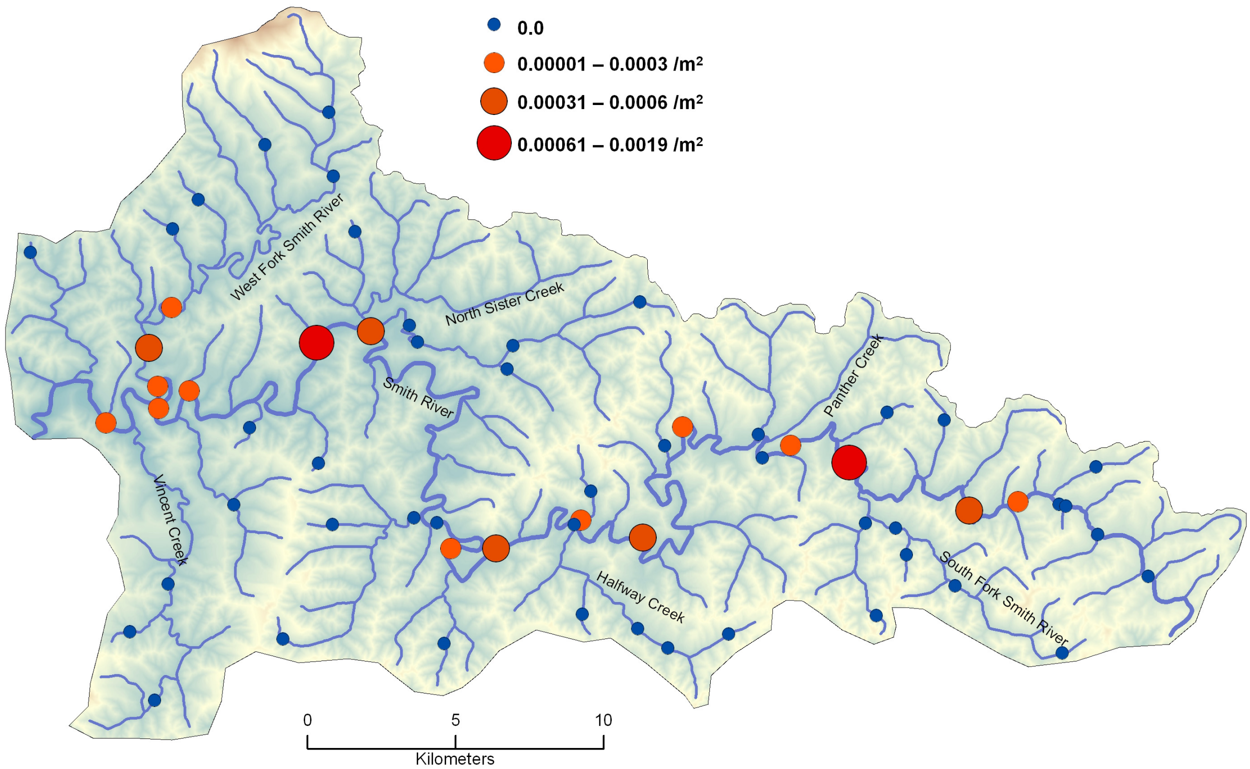


**Figure 6.** Site occupancy and redd density for Pacific lamprey in the Smith River Basin, 2004 and 2005.

### *Habitat Associations*

Habitat surveys were completed at 56 of the 62 sites where redd surveys were conducted. Habitat was quantified at all sites where lamprey were detected, however in 2005 six sites were dropped from the habitat survey rotation where lamprey were absent. Time was a limiting factor and crews were unable to complete all habitat surveys.

The dataset was too small to describe the association between habitat characteristics and redd density at each site and habitat unit, therefore our response variable was limited to lamprey presence.

#### *Reach Scale Analysis*

The reach scale habitat dataset was reduced from 54 to 19 variables (Appendix A-1) and was best described in a two dimensional ordination that explains 93% of the total variation within the data set. When orthogonally rotated to load the variation associated with the presence of Pacific lamprey redds on the first axis, the ordination shows Pacific lamprey redds were present in sites at lower elevations and with a wider active channel (Figure 7). Axis 1 explains 85% of the variation and is negatively associated with elevation ($r^2$ = 0.656) and positively associated with active channel width ($r^2$ = 0.851). The remaining reach scale variables are weakly correlated with either axis. Table 3 describes the median and range of these explanatory variables for all sites and those at which Pacific lamprey redds occur.

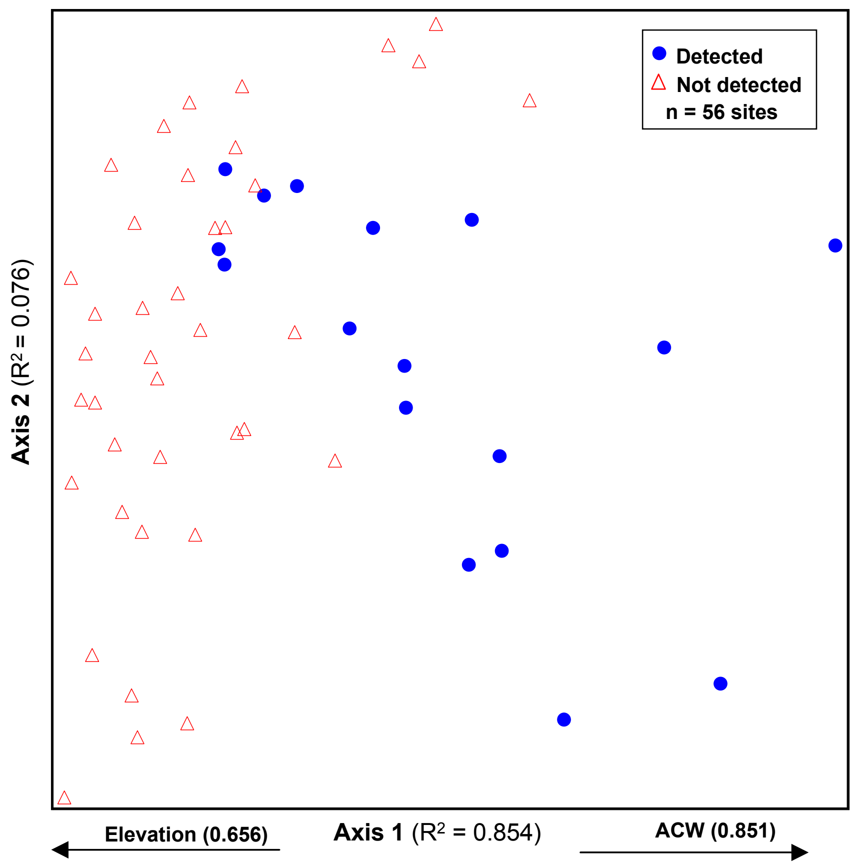


**Figure 7.** NMS ordination of sites as described using reach scale habitat variables. Sites characterized by presence or absence of Pacific lamprey redds. Only variables highly correlated with Axis 1 are shown.

When rotated to load variation associated with the presence of western brook lamprey redds on the first axis, the ordination shows that western brook lamprey redds were predominantly detected at higher elevation sites with a smaller active channel width. Axis 1 explains 88% of the variation and is positively correlated with elevation ($r^2$ = 0.849) and negatively correlated with active channel width ($r^2$ = 0.772) (Figure 8). However, this relationship is relatively weak given the detection of western brook lamprey redds at some low elevation sites. Table 3 describes the median and range of elevation and active channel width for all sites and those at which western brook lamprey redds occur.

**Table 3.** Summary of reach scale variables associated with sites where the presence of Pacific and western brook lamprey redds were detected.

| | Median | Min. | Max. |
|---|---|---|---|
| | **All sites n = 56** | | |
| Elevation (ft) | 600 | 160 | 880 |
| ACW (m) | 9.62 | 2.64 | 47.3 |
| | **Western brook lamprey occupied sites n = 36** | | |
| Elevation (ft) | 640 | 240 | 880 |
| ACW (m) | 9.5 | 3.3 | 33.5 |
| | **Pacific lamprey occupied sites n = 17** | | |
| Elevation (ft) | 420 | 160 | 800 |
| ACW (m) | 13.6 | 5.8 | 35.4 |

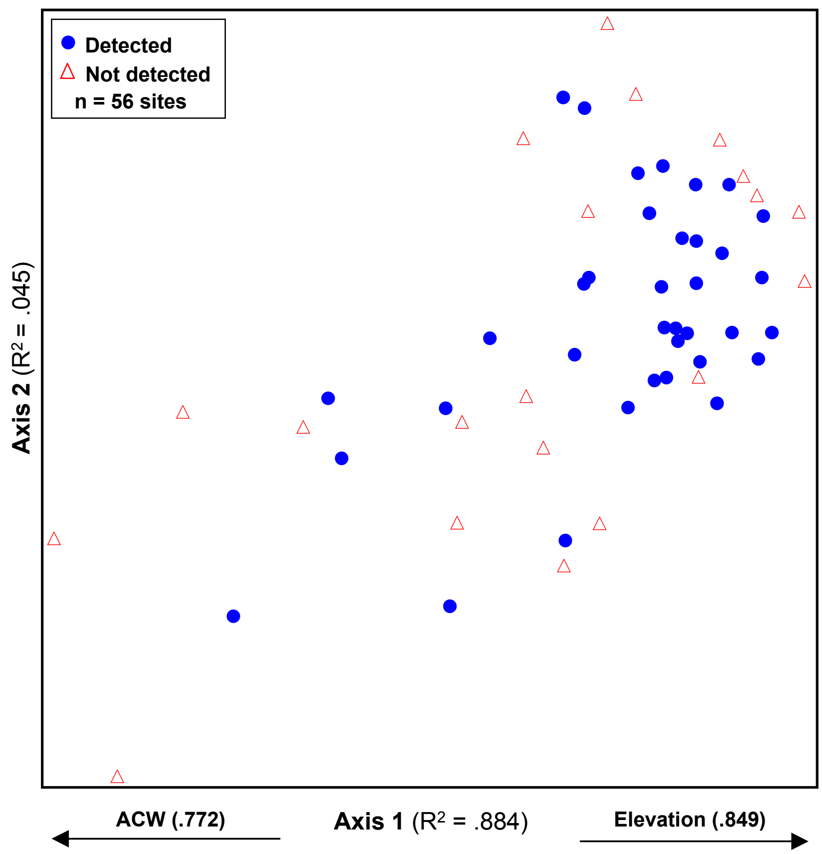


**Figure 8.** NMS ordination of sites as described using reach sale habitat variables. Sites characterized by presence or absence of western brook lamprey redds. Only variables highly correlated with Axis 1 are shown.

Results of the multivariate analysis of reach scale habitat data corresponds well to the distribution maps (Figures 5 and 6). Pacific lamprey are found primarily in the wider, high order streams, whereas western brook lamprey are more widespread, but concentrated in the headwater and low order streams.

*Habitat Unit Scale Analysis*

The habitat unit scale dataset was reduced from 38 variables to 15 variables (Appendix A-1). A 2-dimensional NMS ordination of all habitat units comprising the 7 sites where Pacific lamprey redds were detected shows redds occurred at a relatively higher proportion of sites with less bedrock and more cobble and gravel (Figure 9a). The ordination was orthogonally rotated to load the variation associated with the presence of Pacific lamprey redds on the first axis. Axis 1 explains 63% of the variation associated with all habitat units and is negatively correlated with percent bedrock ($r^2$ = 0.938) and positively correlated with percent gravel ($r^2$ = 0.518) and cobble ($r^2$ = 0.446). However, the presence of redds at sites with bedrock suggests that this relationship is weaker than that described at the reach scale. The remaining habitat unit scale variables are poorly correlated with either axis. Table 4 describes significant values for these variables at sites with and without Pacific lamprey redds.

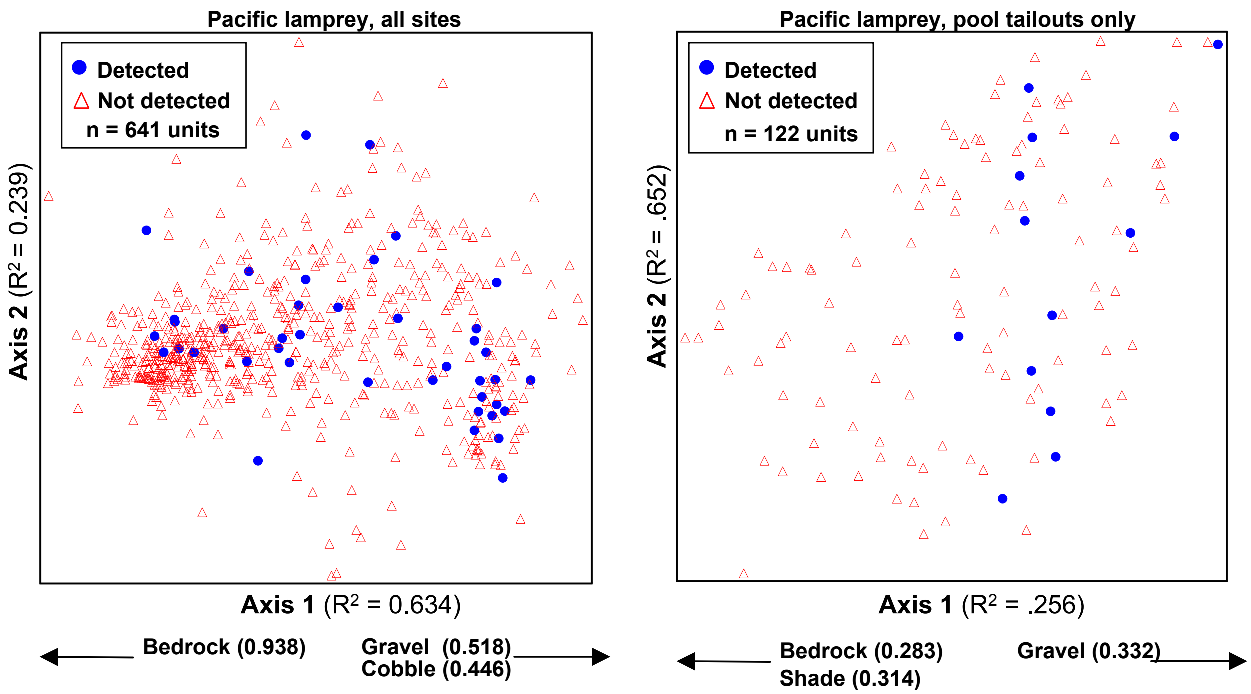


**Figure 9.** NMS ordination of a) all habitat units and b) pool tailouts only comprising sites where Pacific lamprey redds were detected. Only variable correlated with axis 1 are shown.

To ensure that analysis of all habitat units types combined didn't mask trends within habitat types, we examined each habitat unit type separately and found similar results. For example, a NMS ordination of habitat unit scale variables of pool tailouts only (Figure 9b) weakly suggests that Pacific lamprey redds are correlated with substrate. The presence of redds is loosely correlated with percent gravel ($r^2$= 0.332) and negatively correlated with percent bedrock ($r^2$ = 0.283), however axis 1 explains just 25% of the variation within the ordination.

**Table 4.** Summary of habitat unit scale variables correlated with sites where the presence of Pacific lamprey redds were detected.

| | Occupied Units | | | All Units | | |
|---|---|---|---|---|---|---|
| | Median | Min. | Max. | Median | Min. | Max. |
| | | | **All Unit Types** | | | |
| | | n = 41 | | | n = 641 | |
| %Gravel | 25 | 4.8 | 90 | 9.9 | 0 | 95 |
| %Bedrock | 19.8 | 0 | 90 | 50 | 0 | 100 |
| | | | **Pool Tailouts Only** | | | |
| | | n = 13 | | | n = 122 | |
| %Gravel | 60 | 5 | 80 | 20 | 0 | 85 |
| %Bedrock | 10 | 0 | 90 | 30 | 0 | 100 |

The analysis of habitat unit characteristics comprising the 36 sites where western brook lamprey redds were detected reveals results similar to those for Pacific lamprey. The presence of western brook lamprey redds was weakly correlated with a high percentage of gravel and low percentage of bedrock. A 3-dimensional ordination of all units explained 75.5% of the variation among units (Figure 10a). When rotated to load the variation associated with the presence of western brook lamprey redds on the first axis, axis 1 explains 61% of the variation. Axis 1 was negatively associated with unit area ($r^2$ = 0.427), depth ($r^2$=0.336), and percent bedrock ($r^2$=0.328) and positively associated with percent gravel ($r^2$=0.278), though associations were relatively weak. Table 5 describes significant values for these variables for sites with and without western brook lamprey.

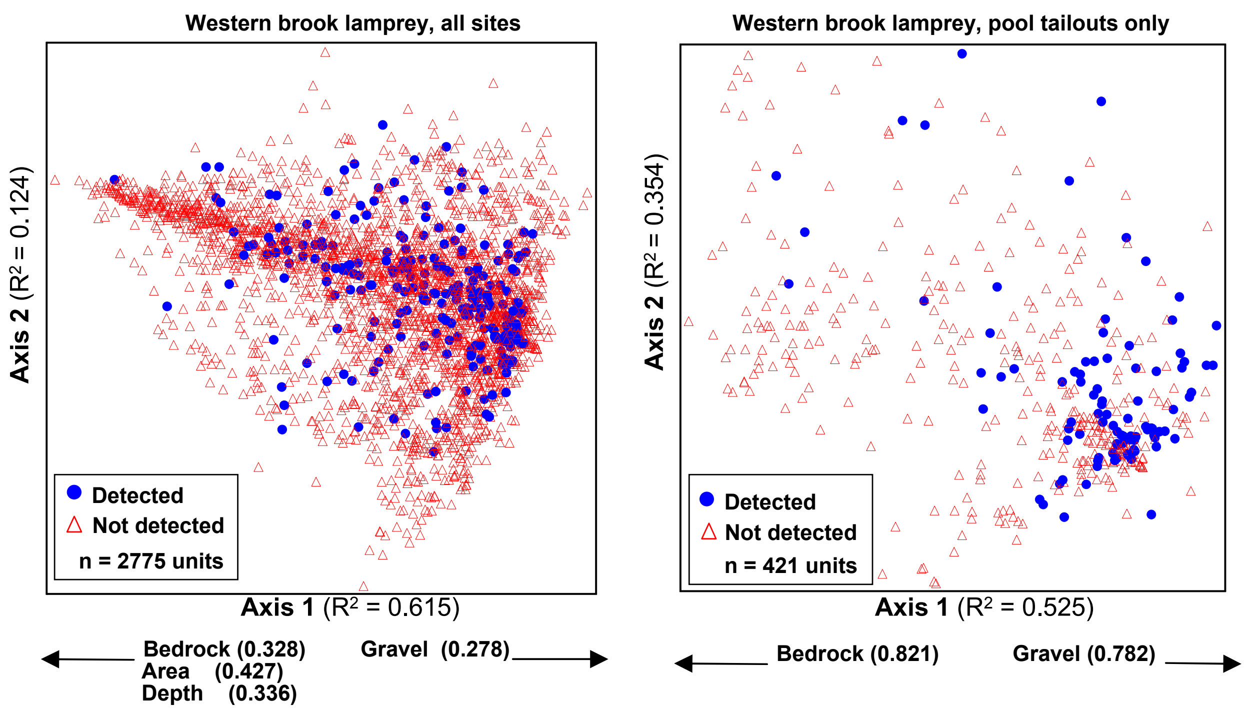


**Figure 10.** NMS ordination of a) all habitat units and b) pool tailouts only comprising sites where western brook lamprey redds were detected. Only variable correlated with axis 1 are shown.

Examination of unit scale variables of pool tailouts only show similar results as those for analyses of all unit types combine and separately. A 2-dimensional ordination of unit scale variables describing all pool tailouts, orthogonally rotated to maximize variation associated with the presence of western brook lamprey redds, shows axis 1 is positively correlated with percent gravel ($r^2$ = 0.782) and negatively correlated with percent bedrock ($r^2$ = 0.821) (Figure 10b). Axis 1 explains 53% of the variation within the variables.

**Table 5.** Summary of habitat unit scale variables correlated with sites where the presence of western brook lamprey redds were detected.

| | **Occupied Units** | | | **Total Units** | | |
|---|---|---|---|---|---|---|
| | **Median** | **Min.** | **Max.** | **Median** | **Min.** | **Max.** |
| **All Unit Types** | | | | | | |
| | | **n = 251** | | | **n = 2775** | |
| %Gravel | 65 | 5 | 100 | 40 | 0 | 100 |
| %Bedrock | 0 | 0 | 100 | 0 | 0 | 100 |
| Unit Area ($m^2$) | 25.2 | 0.8 | 1168.0 | 60.6 | 1.5 | 1284.8 |
| Unit Depth (m) | 0.15 | 0.03 | 1.4 | 0.15 | 0.01 | 0.60 |
| **Pool Tailouts Only** | | | | | | |
| | | **n = 94** | | | **n = 421** | |
| %Gravel | 80 | 5 | 100 | 50 | 0 | 100 |
| %Bedrock | 0 | 0 | 90 | 0 | 0 | 100 |
| Unit Area ($m^2$) | 9.6 | 0.8 | 325.6 | 7.6 | 0.2 | 325.6 |
| Unit Depth (m) | 0.15 | 0.05 | 0.60 | 0.15 | 0.03 | 0.60 |

The multivariate analyses show there are habitat units not occupied by lamprey that have similar character to those occupied by lamprey, even within the same reach. Thus at fine scales, other ecological factors may have a stronger influence on spawning distribution than habitat structure. The presence of lamprey at a particular site may influence the behavior of other individuals. It is theorized that Pacific and western brook lamprey are attracted to streams and spawning sites by pheromones released by ammocoetes and mature adults as are sea lamprey (*Petromyzon marinus*) (Bjerselius et al. 2000, Li et al. 2002, Vrieze and Sorensen 2001). This phenomena may be evident at one particular site on Smith River where 48 Pacific lamprey redds were detected, a value much greater than the mean (Table 3, Appendix A-2). Habitat characteristics at this site were not significantly different from those of other sites and cannot explain the unusually high density of redds. Lamprey pheromones may have a greater influence on distribution than habitat structure. In addition, even though this study quantified a myriad of habitat characteristics, it may not have measured the correct habitat unit scale variables to fully explain habitat unit selection of spawning lamprey.

Connectivity and distribution of habitats may also have a significant influence on spawning site selection. For example, sites upstream of high quality rearing habitat for western brook lamprey or Pacific lamprey over-wintering habitat may more likely be occupied than sites of similar character but not near optimal habitats for other life stages. This study did not account for stream network distribution of other habitats important to western brook and Pacific lamprey.

This study found reach scale habitat variables correlated with stream size were the best descriptors of potential distribution of spawning lamprey of both species. Pacific lamprey spawn at low elevation sites in large stream sizes. Western brook lamprey were associated with high elevation sites and small streams, but were relatively widespread. At the habitat unit scale, unit type and dominant substrate were only weakly correlated with spawning lamprey. Both species spawn predominantly in pool tailouts and low gradient riffles, both gravel rich habitat types.

## ACKNOWLEDGEMENTS

This study would not have been possible without the efforts of many dedicated people. We would like to recognize the field crews who collected the data, Michael Scheu, Jeremiah Bernier, Brian Bangs and Peter Baki. Staci Stein and Brian Bangs completed the data entry and Charlie Stein assisted with the analysis of the habitat data.

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## APPENDIX A

**Habitat variables and site data for locations surveyed for lamprey in Smith River, 2004 and 2005**

**Table A-1.** Redd and habitat variables included in the analyses. Habitat unit and reach variables were measured according to Moore et al. (2003).

| Scale | Variable | Definition |
|---|---|---|
| **Redd** | Length | length of redd, (cm) |
| | Width | width of redd, (cm) |
| | Depth | distance from the bottom of the depression to the surface of the substrate, (cm) |
| | Water depth | distance from the substrate to the water surface, (cm) |
| | Velocity | Water velocity at the redd, (m/sec) |
| | Substrate | Average maximum diameter of 30 pebbles, (mm) |
| | Cover | Cover type |
| **Habitat Unit** | Unit Type | Unit type designation |
| | Unit Area | Length times width, ($m^2$) |
| | Slope | Unit slope, measured with clinometer (%) |
| | Percent Shade | Percent of 180$^o$ that topography or vegetation occludes the sky, measured with clinometer, |
| | Depth | Maximum depth of pools, modal depth of fast water units, (m) |
| | Percent silt/organic | Percent of wetted substrate surface area |
| | Percent Sand | Percent of wetted substrate surface area |
| | Percent Gravel | Percent of wetted substrate surface area |
| | Percent Cobble | Percent of wetted substrate surface area |
| | Percent Bedrock | Percent of wetted substrate surface area |
| | Large Boulders | Number of boulders >0.5m above water surface, roughness index |
| | Percent Undercut | Percent of right and left bank |
| | Large Wood | Number of large wood pieces |
| | Large Wood Volume | Large wood volume ($m^3$) |
| | No. of Key Wood Pieces | Wood ≥ 10m x 0.6m |
| **Reach** | Elevation | Meters above sea level at downstream end of site |
| | Gradient | Gradient measured with clinometer |
| | Channel Form | Channel morphology and constraint |
| | Land Use | Dominant land use |
| | VWI | Valley width divided by active channel width |
| | Active Channel Width | Width of active channel, (m) |
| | Percent Silt | Percent of wetted substrate surface area |
| | Percent Sand | Percent of wetted substrate surface area |
| | Percent Gravel | Percent of wetted substrate surface area |
| | Percent Cobble | Percent of wetted substrate surface area |
| | Percent Bedrock | Percent of wetted substrate surface area |
| | Large Boulders | Number of boulders >0.5m above water surface, roughness index |
| | Percent Undercut | Percent distance of left and right bank |
| | Large Wood | Volume of large wood |
| | Width:Depth | Mean width divided by mean depth |
| | Percent Pool Area | Percent of wetted area |
| | No. Pools/100m | Number of pools per 100 meters |
| | Mean Pool Depth | Average pool depth |
| | No. of Complex Pools | Number of pools associated with wood |

**Table A-2.** Site location, year visited, and lamprey redd numbers for each site surveyed.

| Site | Stream | Year | UTM Easting | UTM Northing | Length (m) | No. of western brook lamprey redds | No. of Pacific lamprey redds |
|---|---|---|---|---|---|---|---|
| 2.02 | Smith River | 2004 | 450030 | 4845262 | 1064 | -- | 6 |
| 6.02 | Smith River | 2004 | 461875 | 4848532 | 1000 | 12 | 15 |
| 7.02 | Smith River | 2004 | 439531 | 4850269 | 1040 | 1 | 5 |
| 10.02 | Smith River | 2004 | 456219 | 4849552 | 1000 | 1 | 1 |
| 11.02 | Smith River | 2004 | 436745 | 4849104 | 1117 | -- | 10 |
| 15.02 | Smith River | 2004 | 454987 | 4845776 | 1000 | -- | 4 |
| 18.02 | Smith River | 2004 | 470334 | 4846344 | 1000 | 4 | -- |
| 22.02 | Smith River | 2004 | 458947 | 4848583 | 900 | 8 | -- |
| 23.02 | Smith River | 2004 | 445594 | 4852455 | 1360 | -- | 15 |
| 145.02 | South Fork Smith River Trib | 2004 | 463906 | 4845494 | 600 | -- | -- |
| 146.02 | Smith River | 2004 | 465996 | 4847040 | 989 | 17 | 4 |
| 148.02 | Gold Creek | 2004 | 441845 | 4858667 | 1089 | 2 | -- |
| 149.02 | Halfway Creek | 2004 | 455960 | 4842148 | 1123 | 13 | -- |
| 150.02 | East Fork Mosetown Creek | 2004 | 448381 | 4842029 | 1000 | -- | -- |
| 151.02 | Vincent Creek | 2004 | 438595 | 4839887 | 1000 | 136 | -- |
| 152.02 | Big Creek | 2004 | 447261 | 4846244 | 1002 | 7 | -- |
| 155.02 | Johnson Creek | 2004 | 434033 | 4854770 | 509 | -- | -- |
| 156.02 | Clabber Creek | 2004 | 453143 | 4847312 | 652 | 8 | -- |
| 157.02 | South Fork Smith River | 2004 | 469272 | 4842370 | 575 | 1 | -- |
| 158.02 | Carpenter Creek | 2004 | 441605 | 4849083 | 323 | -- | -- |
| 159.02 | South Sister Creek | 2004 | 446865 | 4852670 | 1375 | 3 | -- |
| 160.02 | Jeff Creek | 2004 | 450236 | 4851298 | 1000 | -- | -- |
| 161.02 | Elk Creek | 2004 | 465045 | 4850054 | 1000 | 1 | -- |
| 164.02 | West Fork Smith River | 2004 | 443920 | 4859777 | 1000 | 8 | -- |
| 168.02 | Halfway Creek | 2004 | 452628 | 4846163 | 1000 | 22 | -- |
| 169.02 | Little South Fork Smith River | 2004 | 462490 | 4846484 | 1000 | 17 | -- |
| 174.02 | Scare Creek | 2004 | 441162 | 4846472 | 1193 | -- | -- |
| 179.02 | Vincent Creek | 2004 | 439020 | 4843705 | 1000 | 1 | -- |
| 181.02 | South Fork Smith River | 2004 | 465671 | 4844272 | 1000 | 38 | -- |
| 185.02 | Halfway Creek | 2004 | 454927 | 4842711 | 1000 | 13 | -- |
| 196.02 | South Sister Creek | 2004 | 450373 | 4852160 | 1000 | -- | -- |
| 1.04 | Little South Fork Smith River | 2005 | 462609 | 4843900 | 823 | 8 | -- |
| 2.04 | Smith River | 2005 | 467551 | 4847268 | 956 | 6 | 1 |
| 3.04 | Big Creek Trib. | 2005 | 444962 | 4845998 | 1084 | -- | -- |
| 4.04 | West Fork Smith River | 2005 | 444228 | 4857601 | 1076 | 8 | -- |
| 5.04 | Haney Creek | 2005 | 458754 | 4849370 | 850 | 114 | -- |
| 6.04 | Big Creek | 2005 | 443446 | 4841895 | 1078 | -- | -- |
| 7.04 | Vincent Creek Trib. | 2005 | 437798 | 4842016 | 850 | -- | -- |
| 8.04 | Halfway Creek Trib. | 2005 | 453009 | 4843733 | 800 | -- | -- |
| 9.04 | Halfway Creek | 2005 | 457922 | 4842689 | 900 | -- | -- |
| 10.04 | South Sister Creek | 2005 | 454350 | 4853697 | 781 | 8 | -- |

| Site | Stream | Year | UTM Easting | UTM Northing | Length (m) | No. of western brook lamprey redds | No. of Pacific lamprey redds |
|---|---|---|---|---|---|---|---|
| 11.04 | Crane Creek | 2005 | 439040 | 4855247 | 1184 | 5 | -- |
| 12.04 | Yellow Creek #2 | 2005 | 455688 | 4848881 | 845 | -- | -- |
| 13.04 | Smith River | 2005 | 472010 | 4845054 | 1416 | 19 | -- |
| 14.04 | Beaver Creek #2 | 2005 | 443906 | 4848056 | 400 | -- | -- |
| 15.04 | South Sister Creek | 2005 | 447190 | 4852218 | 1002 | 5 | -- |
| 17.04 | South Fork Smith River | 2005 | 463470 | 4846424 | 963 | 36 | -- |
| 18.04 | Salmonberry Creek | 2005 | 463072 | 4850155 | 850 | -- | -- |
| 19.04 | Moore Creek | 2005 | 439738 | 4856688 | 969 | -- | -- |
| 20.04 | Russell Creek Trib | 2005 | 445131 | 4855432 | 800 | -- | -- |
| 21.04 | Summit Creek | 2005 | 470131 | 4848651 | 1189 | 17 | -- |
| 64.04 | West Fork Smith River | 2005 | 438927 | 4853097 | 1027 | 1 | 3 |
| 78.04 | Smith River | 2005 | 443761 | 4852272 | 1165 | -- | 48 |
| 81.04 | West Fork Smith River | 2005 | 438201 | 4851599 | 1062 | 4 | 6 |
| 99.04 | Smith River | 2005 | 438595 | 4850540 | 947 | -- | 1 |
| 120.04 | Smith River | 2005 | 438542 | 4849374 | 973 | -- | 5 |
| 152.04 | Smith River | 2005 | 459960 | 4849129 | 951 | 12 | 1 |
| 197.04 | Smith River | 2005 | 468342 | 4847668 | 993 | -- | -- |
| 198.04 | Smith River | 2005 | 469059 | 4847304 | 954 | 4 | -- |
| 210.04 | Smith River | 2005 | 452628 | 4846401 | 846 | -- | 3 |
| 213.04 | Smith River | 2005 | 448305 | 4846033 | 1009 | 1 | -- |
| 237.04 | Smith River | 2005 | 448476 | 4845253 | 970 | 1 | 1 |

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