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PACIFIC LAMPREY RESEARCH AND RESTORATION PROJECT

Annual Report 1998

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PACIFIC LAMPREY RESEARCH AND RESTORATION PROJECT

ANNUAL REPORT 1998

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May 2000

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EXECUTIVE SUMMARY

This document is the 1998 annual progress report for studies of Pacific lampreys (*Lampetra tridentata*) conducted by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Columbia River Inter-Tribal Fish Commission, and University of Minnesota (U of M). Bonneville Power Administration (BPA) funded activities through Project 94-026.

The Pacific Lamprey Research and Restoration Project began after completion of a status report of Pacific lamprey in the Columbia River in 1995. The project started as a cooperative effort between the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), Columbia River Inter-Tribal Fish Commission (CRITFC), and Oregon State University (OSU).

Lamprey are a valuable subsistence food and cultural resource for Native Americans of the Pacific Northwest. The once abundant Pacific lampreys above Bonneville Dam are currently depressed (Close et al. 1995). Declines in Pacific lampreys have impacted treaty secured fishing opportunities by limiting tribal members catch and access to Pacific lampreys in the interior Columbia basin. Tribal members now harvest lampreys in lower Columbia River locations such as Willamette Falls near Oregon City, Oregon.

Pacific lampreys are also an important part of the food web of North Pacific ecosystems, both as predator (Beamish 1980; Pike 1951; Roos and Gillohousin 1973), and prey (Semekula and Larkin 1968; Galbreath 1979; Roffe and Mate 1984; Merrell 1959; Wolf and Jones 1989) and as a vehicle for recruitment of marine nutrients.

The decline of Pacific lampreys in the interior Columbia River basin has become a major concern. Effective recovery measures for Pacific lampreys can only be developed after we increase our knowledge of the biology and factors that are limiting the various life history stages. Prior to developing a restoration plan, we have carried out studies to review status, distribution, abundance, homing ability, and stock structure. These studies will culminate in the development and implementation of a restoration plan for the Umatilla River.

Multiple pass electrofishing surveys to assess densities and distribution of lamprey larvae in the Umatilla River were conducted in 1998. Electrofishing surveys in the Umatilla River are useful for baseline comparison. Forty-two index sites were sampled from the mouth to river kilometer (RK) 124. Lamprey larvae were found in 4 of the 42 index plots. All sites with larvae were found at and below RK 9.3. Nine larvae were captured during the surveys. However, no larvae were caught on the second pass in each plot.

Pacific lamprey larvae and adult lampreys were studied to determine their ability to produce and detect pheromones. Larval gall bladders were removed and gall bladder fluid was extracted and analyzed by high performance liquid chromatography (HPLC). Adult lampreys ability to detect pheromones were tested using electro-olfactogram (EOG) methods. Fifteen compounds including Petromyzonol sulfate (PS), a migratory pheromone found in sea lamprey larvae (*Petromyzon marinus*) (Li et al. 1995) were tested. Larval lampreys produced large amounts of (PS). Adult Pacific lamprey can detect PS and have an olfactory sensitivity to pheromones that is similar to sea lampreys.

Pacific lamprey abundance, as indexed by fish ladder counts in 1998, was; Bonneville 37,478; The Dalles 7,665; John Day 12,579; McNary 3,393; Ice Harbor 763; Lower Monumental 69; Little Goose 90; Lower Granite 110; Rock Island 1,410; and Rock Reach 819 dams, respectively. Enumerating Pacific lamprey at counting stations remained extremely problematic, since excessive up- and downstream movement at the counting windows reduces the confidence in fish ladder passage estimates. This may be an indication of passage problems encountered by Pacific lampreys.

In-season homing of Pacific lamprey was studied using radio telemetry. Pacific lampery were captured at Willamette Falls and Bonneville Dam, outfitted with radio transmitters and released approximately 26 km downstream of the Willamette River confluence. A total of 50 fish were instrumented. Results will be presented in next year's report. Natal homing was also investigated using mtDNA analysis of fish captured at Bonneville Dam and from Willamette Falls. These results will also be presented next year.

We collected lamprey tissues, from fish captured in several locations throughout the Columbia River Basin, to develop a genetic database for use in determining population structure. Additional samples for populations outside the Columbia River Basin were used to scale the results. Results from this investigation will be presented in next year's annual report.

Since the initiation of the CTUIR lamprey research and restoration project, additional lamprey studies have been proposed that have created uncertainties regarding the prioritization of projects and needs of lampreys. At the request of the Northwest Power Planning Council, a multi-agency Pacific lamprey technical workgroup (TWG) was established in 1996. Annual meetings are held to coordinate projects and prioritize research needs. The TWG identified critical uncertainties and needs to help in determining priorities of ongoing and proposed projects (Appendix A). Finally, an annotated bibliography of relevant lamprey literature was compiled (Appendix B).

ACKNOWLEDGEMENTS

We thank individuals from Oregon State University, Columbia River Inter-Tribal Fish Commission, Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, and Confederated Tribes of the Umatilla Indian Reservation Fisheries Program that assisted with the project activities. We extend special thanks to tribal members and ODFW staff that provided detailed interviews. We appreciate the assistance of Debbie Docherty, Project Manager, Bonneville Power Administration.

CHAPTER ONE

Historical and current observations of Pacific lampreys (*Lampetra tridentata*) in Northeastern Oregon and Southeastern Washington

by

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Introduction

The Pacific lamprey *Lampetra tridentata* maintains a place of cultural significance in the Columbia and Snake River Basins. Tribal people of the Pacific Coast and interior Columbia Basin have harvested these fish for subsistence, ceremonial, and medicinal purposes for many generations (Close et al.1995). Due to the decline of Pacific lampreys in the interior Columbia and Snake Rivers, tribal members have been traveling to lower Columbia River tributaries such as the Willamette River to gather lampreys.

In 1994, the Northwest Power Planning Council approved the Confederated Tribes of the Umatilla Indian Reservation's (CTUIR) Pacific lamprey Research and Restoration Project (7.5F.1). In 1995, a status report of the Pacific lamprey in the Columbia River basin was completed. In 1996 and 1997 work was started to research uncertainties such as indicators of stress, effects of radio-tags, oral histories, gathering information from agencies regarding known numbers of lampreys in our study areas. Further, in 1998 work regarding genetics and homing behavior was carried out by CRITFC in cooperation with CTUIR.

Before rehabilitation actions are taken, it is critical to determine the current status of Pacific lampreys in the John Day, Umatilla, Walla Walla, Tucannon, and Grande Ronde Rivers. There is also a need to better understand the reasons for the decline in lamprey populations. Subsequent study years will build upon this effort and eventually lamprey restoration plans and recommendations will be made for each of the subbasins if needed.

Our 1998 work was a continuation of work began in 1996 (Jackson et al. 1997). Our objectives in 1998 were to: 1) document past and current presence and distribution of lampreys in the John Day, Grande Ronde, Tucannon, Walla Walla, Umatilla, River subbasins and 2) collect habitat information relevent to lamprey production in the John Day, Grande Ronde, Tucannon, Walla Walla and Umatilla River subbasins.

Methods

Study Area

The study area included the John Day, Umatilla, Walla Walla, Tucannon, and Grande Ronde Rivers in the Columbia and Snake River basins (Fig. 1)

Historical Observations

Oral surveys - Telephone and/or personal interviews were conducted with tribal members (n = 18) and past and current employees (n = 20) of various state and federal agencies who work or have worked in the project subbasin(s). Historical and current records and literature were reviewed.

Figure 1. Map of the Columbia River drainage showing the John Day, Umatilla, Walla Walla, Tucannon, and Grande Ronde Rivers study areas.

Field Sampling

Electrofishing surveys - Forty-two index sites were systematically sampled in the Umatilla River basin. The Tucannon, Walla Walla, John Day and Grande Ronde river subbasins were not surveyed in 1998.

Electrofishing Protocol – The ABP-2 electroshocker developed by the University of Wisconsin was used for larval surveys. The ABP-2 has become the standard for larval surveys in the Great Lakes by the U.S. Fish and Wildlife Service (USFWS) (Weisser 1994). A setting of 125 volts with 3 pulses per second and a 25% duty cycle was used to withdraw larvae from the substrate. Once larvae emerged from the substrate, 30 pulses per second was applied to stun and capture (Hintz 1993; Weisser 1994). Forty-two 7.5 m^2 plots were systematically sampled up the mainstem Umatilla River. Habitat classifications for larval lampreys consisted of three types of habitats based on substrate characteristics. The classification was developed by individuals at the U.S. Fish and Wildlife Service Marquette Biological Station, Michigan. The following definitions were used to classify larval habitat:

Type I habitat - preferred larval habitat that usually consists of a mixture of sand and fine organic matter. Often, some cover (detritus, aquatic vegetation) exists. Substrate having fine organic matter usually is formed in depositional areas. Components of type I are consistent from river to river.

Type II habitat – acceptable, but not preferred larval habitat. Substrate compositions are often shifting sand, and may contain some gravel and very little fine organic matter. Substrate is soft enough for larvae to burrow into. Components of type II habitat are consistent from river to river.

Type III habitat – unacceptable habitat because larvae cannot burrow into it. Substraight is often bedrock or hardpan clay but may include rubble and course gravel. Interstices in course substrates may contain some type I or type II material, but these areas are dismissed if they make up less than 0.1m on a transect.

Sampling sites were conducted in Type I habitat and began near the mouth of the Umatilla River continuing up river to RK 124. The larvae were anaesthetized in a 0.05% tricaine methanesulfonate (MS-222) solution, and measured to the nearest millimeter. Larvae were then keyed to species, placed in recovery buckets for 5-10 minutes, and then released back into sample site. Population estimates in the 7.5 m^2 plots were determined by methods described in Zippin (1958).

Incidental observations or catch – Fisheries personnel were contacted within the Umatilla, Tucannon, Walla Walla, John Day, and Grande Ronde River subbasins and asked about lamprey observations.

Results

Historical Observations

Oral surveys.- Oral history interview information concerning the John Day, Grande Ronde, Tucannon, Umatilla, and Walla Walla subbasins were partially presented in Jackson et al. (1996; 1997). Interviews will be continued through 1999 and results reported in the 1999 annual report.

Field Sampling

John Day River subbasin

Electrofishing surveys – Systematic electrofishing surveys were not conducted in the John Day subbasin in 1998. However, electrofishing was used to collect larval lampreys in the North Fork (n=31), Camas Creek (n=20), and the Middle Fork (n=49) for genetics work. Surveys are planned for summer 1999 in the John Day River basin.

Incidental observations or catch - In July 1998, we observed two redds and two adult lamprey in Granite Creek, a tributary to the North Fork John Day RK 140, just above the confluence of Clear Creek.

We collected 35 adult Pacific lampreys by hand at Tumwater Falls RK 16 above the confluence with the Columbia River in July and August. Collections were taken at night from 10:00 pm to ~3:00 am. We observed hundreds of lampreys at the falls, however catching them was difficult. In June, one adult Pacific lamprey was harvested in the North Fork John Day River by a Umatilla tribal member (pers. com. D. Wolf, CTUIR, 1998).

ODFW electrofished 31 larvae in the upper mainstem of the John Day River at RK 436. Three larvae were sampled in the Flat Creek screen trap, and one in Butte Creek RK 25.

Umatilla River subbasin

Electrofishing surveys – Sampling was conducted at 42 sites during the summer in the Umatilla River. Nine larvae were found in 4 of the 42 index plots.   Densities were as follows: RK 4.0 (0.005/m^2 and 0.002/m^2), RK 7.4 (0.002/m^2), and RK 9.3 (0.001/m^2). However, no larvae were captured during the second pass in each plot, therefore no confidence intervals were calculated. All sites with larvae were found at and below RK 9.3, and lengths ranged from 68 to 132mm. Water temperature was ~16 to 22^{o}C, and silt depth ranged from 13 to 18cm.

Incidental observations or catch - We initiated videography at the fish counting window at Three Mile Falls Dam (RK 6.6). We observed 5 adult lampreys on video from June 1 through December 31, 1998.

No adult or larval lampreys were observed at screen bypass facilities in the Umatilla River basin (per. com. B. Kilgore, ODFW, 1998) or observed in the Three Mile Falls Dam trap (per. com. B. Zimmerman, CTUIR, 1998).

There were 557 larval and metamorphosed lampreys captured in a rotary screw trap operated by ODFW near the mouth of the river RK 2.4. In total 196 lampreys were keyed to species and length measurements taken. Lengths ranged from 90 to 184mm (Fig. 2). Of the 557 lampreys, 455 were larvae and 102 were metamorphosed. Electroshocking surveys for salmonids were conducted throughout the Umatilla River. However, they did not capture or observe any lampreys in the Umatilla River basin.

Walla Walla River subbasin

Electrofishing surveys - Systematic electrofishing surveys were not conducted in the Walla Walla subbasin in 1998. We collected western brook (*Lampetra richardsoni*) larvae from the mainstem Touchet (n=19), South Fork Walla Walla (n=21) Rivers, and Yellowhawk Creek (n=52) for genetic studies. Surveys are planned for summer 1999 in the Walla Walla River basin.

Incidental observations or catch – Observations of 168 western brook larvae were made in the Little Walla Walla River diversion screen trap in the South Fork Walla Walla River (per. com. B. Kilgore, ODFW, 1998).

WDFW electrofished 20 larval lampreys in the South Touchet River, 1 larvae in the North Fork Touchet River, and 2 larvae in the Wolf Fork River (per. com. S. Martin, WDFW, 1998).

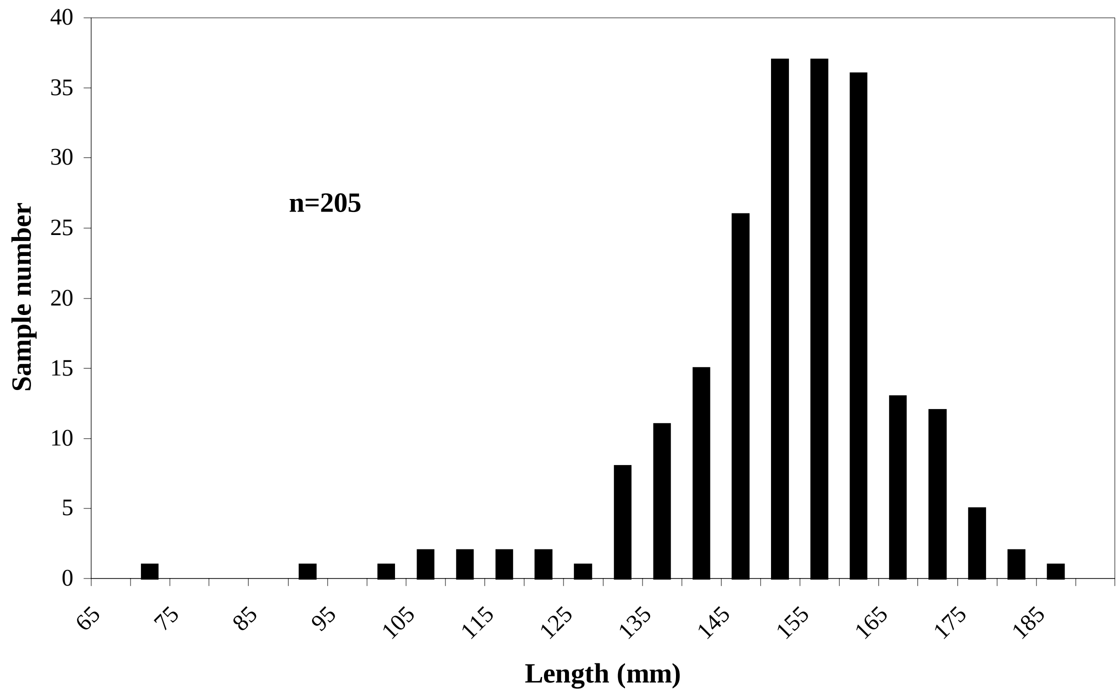

Figure 2. Length-frequency distributions of larvae and macrophthalmia (metamorphosed larmpreys) sampled in the Umatilla River in 1998. Data includes samples from Three Mile Falls Dam n=48; rotary screw trap (n=148) at RK 2.4, and CTUIR's Electrofishing Survey (n=9).

Tucannon River subbasin

Electrofishing surveys – Systematic electrofishing surveys were not conducted in the Tucannon subbasin in 1998. Surveys are planned for summer 1999 in the Tucannon basin.

Incidental observations or catch – One hundred thirty larvae and eight adult lampreys were captured in a rotary screw trap at RK 3 (per. com. J. Bumgarner, WDFW, 1998).

Grande Ronde River subbasin

Electrofishing surveys – Electrofishing surveys were not conducted in 1998 due to time constraints. Sampling is planned for 1999.

Incidental observations or catch - Rotary screw traps on the Wallowa and upper Grande Ronde Rivers captured no lampreys (per. com. M. L. Keefe, ODFW, 1998). No lampreys were captured in rotary screw trap in Lookingglass Creek at RK 2.5 (per. com. P. Lofy, CTUIR, 1998).

No lampreys were sampled or observed in any field activities in the Grande Ronde River subbasin in 1997 and 1998 (per. com. T. Walters, ODFW, 1998).

Discussion

The John Day River seems to have the highest abundance of Pacific lampreys of the five subbasins examined, based on preliminary electrofishing and observations of adults. The ODFW screen trap data in the John Day drainage may not reflect the numbers of larvae in the system. This could be due to design of screen traps and low trapping efficiency. Many of the traps have screen mesh large enough for larvae to escape. Both Pacific and western brook lampreys have been identified in the John Day drainage.

The Umatilla River has low lamprey production. Electrofishing surveys found very few larvae and they were found in the lower portion of the river. Oral surveys from tribal members and state fisheries personnel indicate that lampreys declined severely after the state chemically treated the Umatilla River with rotenone in 1967 and 1974. However, there seem to be a few adult lampreys that still enter the Umatilla River to spawn.

The Walla Walla River contains western brook larvae. No Pacific lampreys were sampled during our collections for genetic samples.

The Tucannon River has low lamprey production. The incidental catch of larvae in the rotary screw trap was less than the Umatilla River. However, it is difficult to say much more until we electrofish the river in 1999.

The Grande Ronde River either has very low numbers of lampreys or none. Even with all the salmonid trapping, no lampreys were sampled. We are also planning electrofishing surveys for this river in 1999.

We will continue in 1999 to work on the objective to describe the distribution of larvae in all five subbasins. We will also report all oral interviews and map the life history information gathered. Our second objective was to collect habitat information relevant to lamprey production in all five subbasins. Due to time constraints this objective was not initiated in 1998. However, we will pursue the objective in 1999 or 2000.

In summary, The John Day River seems to have the higher levels of lampreys than the other rivers examined. The Umatilla, Walla Walla, and Tucannon Rivers have some level of lamprey production. However, the Walla Walla may not have Pacific lampreys. The Grande Ronde River does not appear to have any lamprey production currently.

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CHAPTER TWO

The olfactory system of migratory adult Pacific lampreys
(*Lampetra tridentata*)

by

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Introduction

The number of Pacific lampreys (*Lampetra tridentata*) migrating in the Columbia and Snake Rivers declined over the last two decades (Close et al. 1995). As a result, The Northwest Power Planning Council approved the Confederated Tribes of the Umatilla Indian Reservation's Research and Restoration Project into the Columbia Basin Fish and Wildlife Program. Our study is a result of the need to better understand the biology of Pacific lampreys to aid in recovery efforts. We were specifically interested in the sense of smell because lampreys have an extraordinarily developed olfactory sense (it is larger than their brain). Further, in sea lamprey (*Petromyzon marinus*) it is now well established that adults use bile acid-derived pheromones (conspecific chemical signals) to locate streams for spawning (Li. et al. 1995; Bjerselius et al. 2000). So important is this pheromone to adult sea lampreys that if their olfactory sense is blocked, their return rates to rivers will drop by nearly 90% (Sorensen, unpublished data; progress reports Great lakes Fisheries Commission 1997, 1998). Two unique bile acids petromyzonol sulfate (PS) and allocholic acid have been strongly implicated as components in sea lamprey larval pheromone. Both bile acids have been found to be released to the water in significant quantities by actively feeding larvae (Polkinghorne et al. 2000). Adult sea lampreys have an olfactory system with a sensitivity ranging down to picomolar (approximately 1 gram in 40 billion liters; Li et al. 1995; Li and Sorensen 1997), and was shown to drive adult migratory behavior (Bjerselius et al. 2000). The sea lamprey pheromone is presently thought not to be species-specific (Sorensen, unpublished). Our objectives were to: (1) determine if Pacific lamprey larvae produce similar bile acids found in sea lamprey larvae; (2) determine if migratory adult Pacific lampreys can detect the same bile acids as migratory adult sea lampreys.

Methods

Larval bile acid production

To determine if Pacific lamprey larvae produce similar bile acids found in sea lamprey larvae, larval gall bladders (n=3) were collected, extracted, and analyzed by high performance liquid chromatography (HPLC). Larvae were collected by electrical shocking in the Middle Fork John Day River, Oregon and shipped by air to St. Paul, Minnesota. Larvae were killed by a high dose of tricaine methanesufonate (MS222), and gall bladders removed. Gall bladders were stored at -20°C until analysis. The extraction and characterization of bile acids protocol was developed by Locket and Gallaher (1989); Gallaher et al. (1992) and were employed by Li et al. (1995) and Polkinghorne et al. (2000). A brief summary of this procedure follows.

Gall bladders were excised from larval lamprey, sonicated, and then placed in a heating block and refluxed at 100^{o}C for one hour, after which time they were centrifuged at 1000 x g for 10 min. The supernatant was then removed and saved, and this extraction process successively repeated using 80% methanol and 50/50 methanol/ chloroform (twice), sonicating, and refluxing between each step. The pooled supernatant was dried under a stream of nitrogen and further purified by re-dissolving it in water, and passing this solution through methanol-activated reversed-phase C18 bonded-phase cartridges (Sep-pak Plus, Waters Corp., Milford, MA). The loaded column was washed with 12 mL 20% methanol, 6 mL water, 6 mL hexane and eluted with 5 mL methanol. The methanol eluant was dried and reconstituted for injection onto the HPLC. This procedure has a recovery efficiency of over 95% (Locket and Gallaher 1989).

Samples were analyzed by HPLC using established protocols (Gallaher et al. 1992). Two internal standards, HCA (α-hyocholic acid, 3α,6α,7α-trihydroxy-5β-cholan-24-oic-acid) and LCA (lithocholic acid, 3α-hydroxy-5β-cholan-24-oic-acid), were added to all samples immediately prior to injection to allow direct comparison of retention times from one chromatogram to another, as well as to ensure accurate quantification of bile acids. HCA and LCA were chosen as standards because they elute early and late in the run, respectively, and are not produced by lampreys.

Our HPLC system (Gilson Medical Electronics, Middleton, WI) employed a reverse-phase Nova-Pak C_{18} 4-μm column (4mmx10cm) housed in a radial compression module (Waters Chromatography Division, Milford, MA). We used a step-wise gradient of acetonitrile and ammonium dihydrogen phosphate (25mM, pH 7.8) which ran from a mixture of 18% acetonitrile to 35% acetonitrile over the course of a 160 minute run (Gallaher et al. 1992). Bile acids were detected by passing the eluent through a second column (34 mm x 3.9 mm i.d., Alltech, Deerfield, IL) containing 3α-hydroxysteroid dehydrogenase (EC 1.1.1.50, 50 U, Sigma Chemical Co.) mounted on glutaraldehyde-treated aminopropyl glass beads (Sigma Chemical Co.). A buffer containing NAD (0.1M Tris-HCl, pH 8.5, 2.7 mM EDTA, 1.63 mM dithiothreitol and 0.01 mM NAD) was introduced at a constant rate of 1 mL/min through a tee between the first and second columns. The 3α-hydroxysteroid dehydrogenase served to oxidize 3α-hydroxyl bile acids to 3α-keto bile acids, liberating H^+, reducing NAD to NADH. NADH production was then detected by a fluorescence detector (model 121, Gilson Medical Electronics) equipped with a narrow band excitation filter of 340 nm and wide band emission filter with a range of 420-650 nm.

Bile acids were tentatively identified and quantified by comparing their retention times with those of bile acid standards. Synthetic ACA, PS and P, obtained from Toronto Research Chemicals (Toronto, Canada), were used as standards. Standards were analyzed at the beginning of each HPLC run to create a calibration curve from which bile acid amounts were calculated. Standards were run every 24 h (after every eight samples). All chromatograms were reviewed by the Gilson software and checked by us to determine whether sample peaks occurred within 2 min of our standards. If a peak did not fall within that range it was not identified as that standard. In several instances we added standard to aliquots of sample to confirm identification by looking for co-elution. Quantification of peaks was achieved by using a ratio of the peak area of a standard peak to a sample peak with internal standard ratio comparisons used as a correction factor for instrumentation variances. Although the detection threshold of our technique is about 0.01μg bile acid in a ‘clean’ background, in most biological extracts it is about 0.2 μg bile acid.

Electro-olfactogram (EOG) recording

To determine if migratory adult Pacific lampreys can detect the same bile acids as migratory adult sea lampreys, EOG responses to compounds tested for sea lampreys were recorded. Adult Pacific lampreys (n=7) were captured in December in the John Day Dam fishway and transferred to Abernathy Salmon Technology Center, Longview, Washington and held in well water at 12.5°C. Animals were then shipped by air to St. Paul, Minnesota in May to be tested. Table 1 lists the bile acids tested on the Pacific lamprey adults. These compounds were chosen because sensitivity to them is well understood in the sea lamprey (Li et al. 1995; Sorensen, unpublished).

EOG recordings were performed as described in previous experiments (Li and Sorensen, 1997; Li *et al*. 1995). Briefly, lamprey were immobilized with an intramuscular injection of Flaxedil (gallamine triethiodide; Sigma, 150 mg kg^{-1} body weight), and secured to a stand where the gills were continually perfused with well water at 11° C containing anaesthetic (~ 0.02 2-phenoxy-ethanol; Sigma). To expose the olfactory epithelium, the dorsal portion of the cartilaginous nasal cavity was surgically removed (Li and Sorensen, 1997). An odor dripper was immediately positioned to deliver 11 ° C well water to the epithelium at a rate of 4 ml/min (Li and Sorensen, 1997). Recording apparatus and electrode preparation was the same as that described by Li and Sorensen (1997). The reference electrode was placed on the head of the fish, and the recording electrode was placed deeply between two ventral lamellae, close to the bases. Since the lamprey had initiated migration at the time of capture, olfactory responses to test odors had begun to deteriorate, making it difficult to obtain a good recording. A maximum of 2 hours was spent on each lamprey searching for a spot that would yield the maximum EOG response to the standard L-Arginine -5 Molar. Recording only began when a sufficient response to L-Arginine was obtained (> 1 mV) or the experiment was terminated. L-Arginine -5 M was presented at least once every 15 minutes to monitor the stability of the recording and the response to the most recent arginine exposure was used as a standard. Blank controls, where only well water was presented to the naris, were tested as well as methanol (MeOH) controls which contained the same amount of methanol as a test odor with a MeOH solvent. Test odors were presented to the naris twice only when there was enough testing odor available, and were tested with at least 3 minutes between exposure. The reported EOG response to an odorant was the average of the two exposures which were measured as a change in voltage (mV) from the baseline to the peak (phasic), with the response to blank control (if any) subtracted. An assessment of reproductive maturity (gonadosomatic index) was conducted on adults following EOG recording. After lampreys were killed, measurements of body weights (g) and gonads (g) were recorded.

Table 1. Compounds tested. All compounds tested at –8 Molar except for L-arginine, our standard which was tested at –5 Molar.

Common name	Chemical name
Petromyzonol sulfate	3α, 7α, 12α, 24-Tetrahydroxy-5α-cholan-24-sulfate
Petromyzonol	3α, 7α, 12α, 24- Tetrahydroxy-5α-cholan
5β-Petromyzonol	3α, 7α, 12α, 24- Tetrahydroxy-5β-cholan
Allocholic acid	3α, 7α, 12α-Trihydroxy-5α-cholan-24-oic-acid
Cholic acid	3α, 7α, 12α-Trihydroxy-5β-cholan-24-oic-acid
Cholic acid 3-sulphate	3α, 7α, 12α-Trihydroxy-5β-cholan-24-oic-acid-3-sulfate
Taurolithocholic acid 3-sulfate	3α-Hydoxy-5β-cholan-24-oic-acid N-(2-sulfoethyl)-amide 3-sulfate
Taurocholic acid	3α, 7α, 12α-Trihydroxy-5β-cholan-24-oic-acid N-(2-sulfoethyl)-amide
Tauroursodeoxycholic acid	3α, 7β-Dihydroxy-5β-cholan-24-oic-acid N-(2-sulfoethyl)-amide
Hyodeoxycholic acid	3α, 6α-Dihydroxy-5β-cholan-24-oic-acid
Cyprinol sulfate	
Δ4-Petromyzonol	
Δ4-Petromyzonol 24-phosphate	
5α-Petromyzonol multiply sulfated	
5-βPetromyzonol multiply sulfated	

Results

Larval bile acid production

The gall bladders of Pacific lamprey larvae contained large quantities of petromyzonol sulfate, similar to sea lamprey larvae (Fig. 1). However, allocholic acid and petromyzonol previously found in sea lamprey larvae (Li et al. 1995; Polkinghorne 2000), were not found in the Pacific lamprey larvae gall bladder samples.

Electro-olfactogram (EOG) recording

One out of seven Pacific lamprey adults detected similar compounds as sea lampreys. Detection levels were very similar to early migrating sea lampreys (Table 2). Petromyzonol sulfate, the bile acid found in Pacific lamrpey larvae, elicited a strong response in the Pacific lamprey adult similar to earlier studies conducted with sea lampreys.

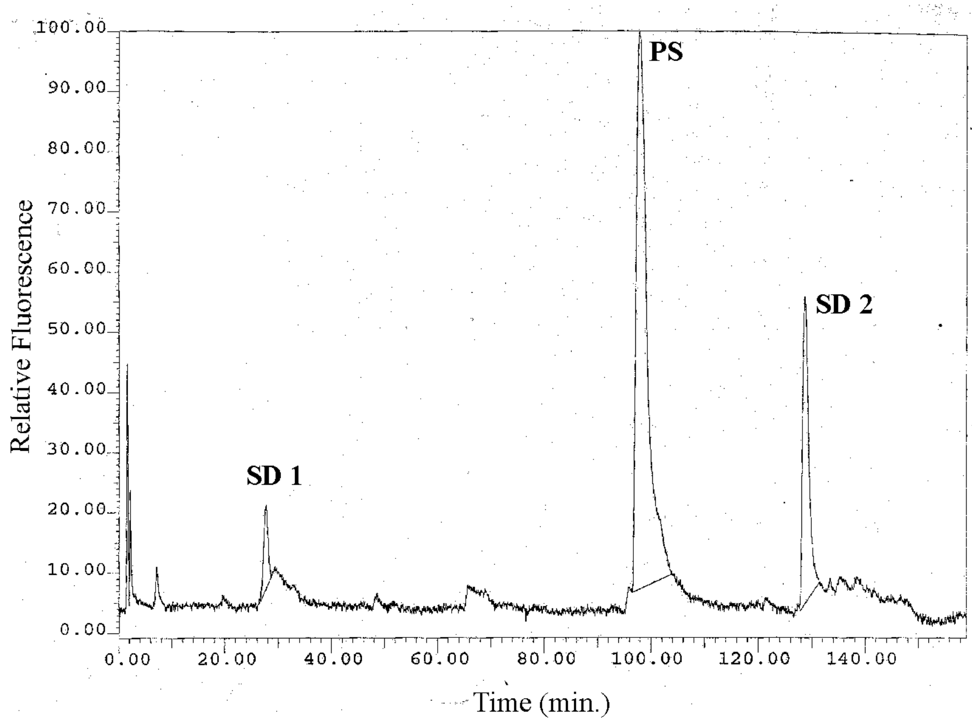

Figure 1. High performance liquid chromatography (HPLC) chromatogram of extract of larval Pacific lamprey gall bladder fluid (n=3). SD1 and SD2=standards; PS=Petromyzonol sulfate.

Table 2. Electro-olfactogram (EOG) recording results for Pacific *lamprey Lampetra tridentata* (n=1) and sea lamprey *Petromyzon marinus* (n=7). NR= no measurable; response; D= detected but response was small (<10% standard.)

Compound	Responsiveness of *L. tridentata* (% Arg)	Response of *P. marinus* (Li et al., 1995 and Sorensen, unpublished)
Arginine –5M	0.599 mV	2.84 mV
Petromyzonol sulfate	232%	240%
Petromyzonol	73%	10%
5β-Petromyzonol	55%	D
Allocholic acid	53%	65%
Cholic acid	32%	30%
Cholic acid 3-sulphate	35%	Detected
Taurolithocholic acid 3-sulfate	123%	49%
Taurocholic acid	45%	15%
Tauroursodeoxycholic acid	NR	NR
Hyodeoxycholic acid	NR	NR
Cyprinol sulfate	197%	D
Δ4-Petromyzonol	NR	NR
Δ4-Petromyzonol 24-phosphate	NR	NR
5α-Petromyzonol multiply sulfated	NR	NR
5-βPetromyzonol multiply sulfated	NR	NR

The one adult we were able to record EOG responses from had a gonadosomatic index (GSI) of 1.43. This was the lowest GSI of the seven lampreys measured (Table 3). The olfactory epithelium appeared old, unhealthy, and degenerated.

Table 3. GSI of adult Pacific lampreys.

Male	Female
1.43	2.84
2.05	11.48
2.16	7.32
	32.19

Discussion

Analysis of Pacific lamprey larval gall bladders suggests that they produce large amounts of petromyzonol sulfate. No other bile acids were evident, unlike sea lamprey larvae which also contain allocholic acid and petromyzonol (Li et al. 1995). It is notable that recent analyses suggest that several other species of lampreys also lack allocholic acid. Further where studied, all of these species have been found to release high concentrations of petromyzonol sulfate to the water soon after feeding. In all instances their odor has been found to be capable of attracting adult sea lamprey, thus petromyzonol sulfate is thought to be the primary component of the sea lamprey pheromone (Sorensen, unpublished results).

Although we were only able to record from a single adult Pacific lamprey, the sensitivity of their olfactory system appears to closely resemble that of sea lampreys. They detect petromyzonol sulfate, a unique bile acid found only in lampreys (and now Pacific lampreys) extremely well. Also, notable is the fact that they detect few compounds other than conspecific bile acids except for taurolithocholic acid sulfate. This extremely restricted and specialized range of sensitivity is identical to that of the adult sea lamprey, which of course are using conspecific bile acids as a pheromone. Because sea and Pacific lampreys are separated by great geographic distances and pheromone usage appears to be a conserved feature of most fishes, there is good reason to suggest that petromyzonol sulfate is also a ‘special’ compound for Pacific lampreys. The possible significance of taurolithocholic acid is unclear as it is for sea lampreys.

Our failure to record strong EOG responses from 6 of the 7 adult Pacific lampreys also parallels findings in the sea lamprey whose olfactory system has been found to deteriorate rapidly after they enter freshwater and start to mature (Sorensen et al. 1995, unpublished). This is thought to reflect the fact that sea lamprey no longer need an extremely sensitive olfactory system once they have chosen and entered a spawning stream (Sorensen and Gallaher 1995). It is possible that an extremely sensitive olfactory system would work to the detriment of these stream-resident animals whose behavior might be confused by inappropriate responses to migratory cues when they should be entering a sexually-active phase. Although the life history of Pacific lampreys are poorly understood, it is thought that they spend up to one year in freshwater before spawning

(Beamish 1980). In contrast, adult sea lampreys are only in freshwater streams for a few weeks prior to spawning and death. The adult Pacific lampreys tested in this study had already been in freshwater for approximately one year before testing. Our data suggests then that this species and their sensitivity to petromyzonol sulfate may be relatively long compared to the sea lamprey. It is impossible to conclude anything from a single sample of 7 fish, however. Clearly, the role of the potent odorant, and putative pheromone, petromyzonol sulfate needs to be carefully examined using both electrophysiological and behavioral means. An extended detection time may have management implications for recovery efforts currently underway in the Columbia River basin.

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CHAPTER THREE

Abundance monitoring, homing, and stock structure of Pacific lamprey (*Lampetra tridentata*) in the Columbia River Basin.

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Abstract

In 1996, a field study was begun to investigate the declining population of Pacific lamprey *Lampetra tridentata* and develop appropriate restoration programs for stocks in the Columbia River. The study was headed by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) in cooperation with the Columbia River Inter-Tribal Fish Commission (CRITFC) and Oregon State University (OSU). In 1998, the CRITFC objectives included 1.) estimating the current abundance and passage trends of adult lamprey crossing mainstem Columbia and Snake River dams; 2.) determining if adult Pacific lamprey captured at Willamette Falls and at Bonneville Dam would home back to these locations; 3.) assess the genetic variation among Columbia and Willamette Basin lamprey; 4.) review literature of related species with particular attention paid to stock transfer and restoration efforts including passage, production, genetics, life history, and management case histories; and, 5.) develop a genetic database for determination of lamprey population structure in the Columbia Basin. Pacific lamprey abundance as indexed by fish ladder counts in 1998 was 37,478; 7,665; 12,579; 3,393; 763; 69; 90; 110; 1,410; 819 for Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, Rock Island, and Rocky Reach dams, respectively. Enumerating Pacific lamprey at counting stations remained extremely problematic. Excessive up- and downstream movement at the counting windows reduces the confidence in fish ladder passage estimates. This may be an indication of severe passage problems encountered by Pacific lamprey. A displacement type homing study was initiated using radio telemetry to investigate the homing fidelity of Pacific lamprey to capture sites. An alternative approach using mtDNA analysis was also initiated. Results will be presented in next year’s report. We collected lamprey tissues to develop a genetic database to use for determination of population structure. Analysis of these data will be presented in next year’s report. Finally, we present an annotated bibliography of relevant lamprey literature.

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Introduction

Pacific lamprey *Lampetra tridentata* is an anadromous fish endemic to the Columbia River Basin. This fish is highly prized by Native Americans as a ceremonial and subsistence food item. Often found in sympatry with native anadromous salmonids (*Oncorhyncus sps*.), the Pacific lamprey shares similar life history needs that include relatively pristine freshwater spawning and rearing habitat, mainstem passage corridors to the ocean and back, and productive ocean rearing habitat.

The only living representatives of the most primitive vertebrates are the lampreys. Their ancestors can be traced back some 400 to 450 million years (Bardack and Zangerl 1971). This compares to a mere 6 million years for Oncorhyncus sp. (Nelson 1994). As a result of these basic differences we should be very careful applying knowledge derived from salmon directly to lampreys. A true ecosystem approach to aquatic resource restoration should include lamprey investigations.

Unlike anadromous salmonids, the Pacific lamprey is not highly prized or utilized by non-Indians, consequently, recent declines in Pacific lamprey abundance and distribution had gone largely unnoticed by regional fishery managers. Diligent efforts by Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and Columbia River Inter-Tribal Fish Commission (CRITFC) staff secured funding and support to investigate the declines in distribution and abundance of Pacific lamprey. The CTUIR in cooperation with the CRITFC and Oregon State University (OSU) initiated a multi-faceted, multi-year approach to investigate and determine the mechanisms behind the declines and subsequent strategies for recovery. This report covers the third year of the CRITFC portion of this study. The main emphasis will be data summary and reporting for this third year. Detailed analysis will be completed in years when sufficient data exist for analysis. Our objectives for this project include:

1. Determine the current abundance, passage trends of adult lamprey crossing mainstem Columbia and Snake River dams;

2. Determine if adult Pacific lamprey captured at Willamette Falls and at Bonneville Dam will home back to these locations;

3. Assessment of genetic variation among Columbia and Willamette Basin lamprey;

4. Review literature of related species with particular attention paid to stock transfer and restoration efforts including passage, production, genetics, life history, and management case histories; and,

5. Develop a genetic database for determination of lamprey population structure in the Columbia Basin.

Methods

Study Area

Data on adult Pacific lamprey fish ladder passage were obtained from all mainstem Columbia and Snake river hydroprojects that are equipped with fish counting stations. These include Bonneville, The Dalles, John Day, McNary, Rock Island, Rocky Reach, Wells, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams (Figure 1). These hydroelectric projects were chosen because fish passage is recorded on videotape at these sites and/or on-site lamprey counts are made there.

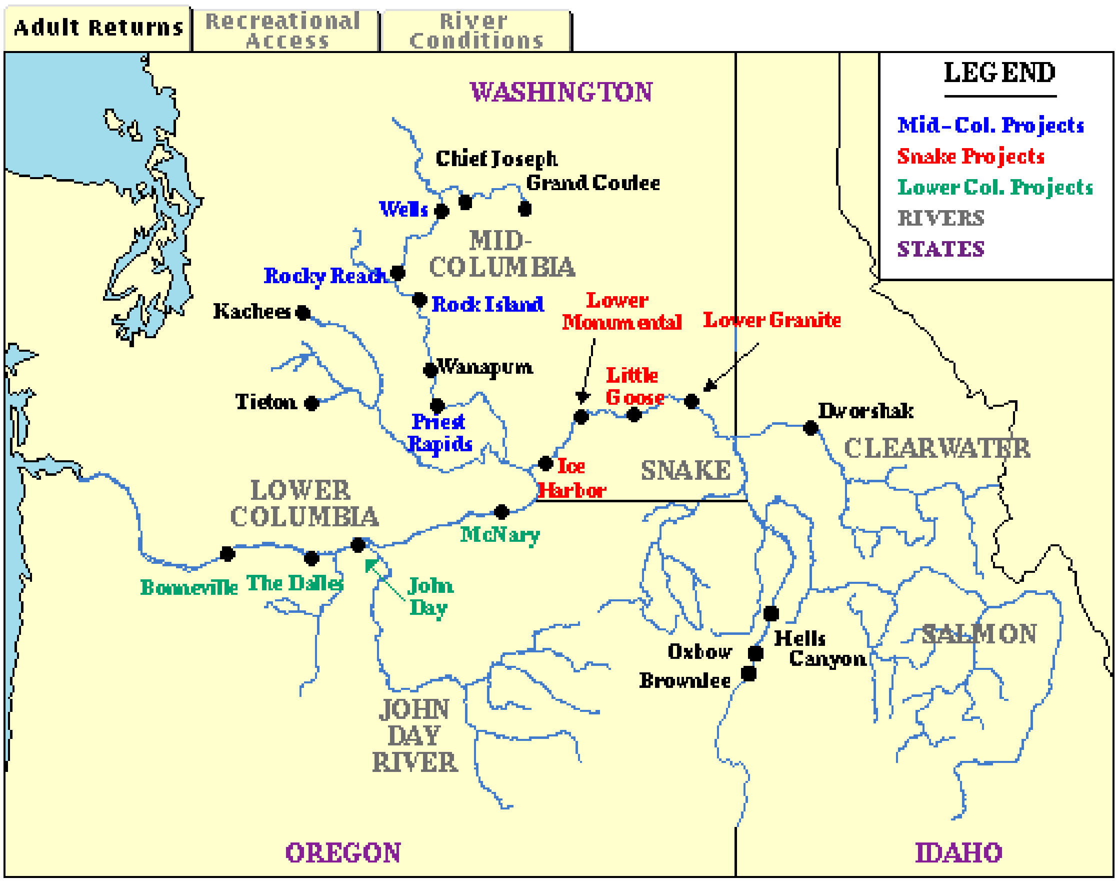

Figure 1. Map of the Columbia River Basin. The dams that are labeled are locations of adult lamprey count data.

Abundance and Passage Trends

Abundance Estimates

Fish ladder counts of adult lamprey were used as an index of abundance. Fish ladder counts were obtained by reviewing time-lapse recorded videotape, or from on-site counts. On-site lamprey counts were available for the four lower Snake River dams as well as McNary, John Day, The Dalles, and Bonneville dams. Lamprey counts from video records were available from Wells, Rocky Reach, and Rock Island dams. Additionally, CTUIR performed some nighttime on-site lamprey counting from May through August at Bonneville Dam.

The on-site lamprey counting at Bonneville Dam conducted by the U.S. Army Corps of Engineers (COE) was based on “daytime” (between 0400 and 2000 hrs) counts. The on-site lamprey counting conducted by the CTUIR was based on a sampling scheme where lamprey passage was enumerated during many (range 16 to 70) 12 minute periods selected within each stratum (1/2 month units). This counting was performed during nighttime periods. Passage estimates and 95% bounds were made using stratified random sampling (Scheaffer et al. 1990).

Similar to conditions observed in previous years (Starke and Dalen 1995; Jackson et al. 1997; Jackson et al. 1998), a tremendous amount of lamprey movement (upstream and downstream) at the count station windows was observed in 1998. Therefore for statistical comparisons, we treated upstream and downstream estimates independently.

To compare overall success of Pacific lamprey ascending the two fish ladders at Bonneville Dam in 1997 we calculated local efficiency (*E*) values for each count station using (Haro and Kynard 1997):

$$E = \frac{Nu - Nd}{Nu} \times 100$$

where: *Nu* = number of fish passed upstream; and,
Nd = number of fish passed downstream.

Local efficiency values were calculated using data from the CTUIR on-site observations for nighttime periods within two-week periods (equal to the strata used for estimating abundance above). These values were compared between fish ladders using a two sample Wilcoxon test.

Homing Fidelity

Recent discussions in the Lamprey Technical Work Group have centered on the subject of homing in Pacific lamprey. Research on sea lamprey in the Great Lakes (Bergstedt and Seelye 1995) and European river lamprey (*Lampetra fluviatilis*) in Finland (Tuunainen et. al. 1980) indicates that they may not home. A lack of homing affinity could have a tremendous effect on future restoration efforts. Positive results from restoration efforts in a particular basin or stream may be hampered if lamprey do not imprint and return to natal streams with a high degree of affinity. We used a two pronged approach to investigating homing fidelity: 1.) a field study; and, 2.) mtDNA analysis of fish collected at Bonneville Dam and Willamette Falls.

Lamprey collections

We collected adult Pacific lamprey at Bonneville Dam and Willamette Falls. Fish at Bonneville Dam were collected with an adult lamprey trap at the Washington Shore Adult Fish Facility. We collected Willamette River fish by dip-net at the Willamette Falls fish ladder while the ladder was in operation and by hand from Willamette Falls after the ladder was de-watered. We immediately transported captured fish to the Abernathy Technology center in Abernathy, WA and held them until tagging.

Surgical implantation of radio tags

We surgically implanted 50 Pacific lamprey (25 from each collection site) with Lotek MCFT-3BM radio tags. The tags have an air weight of 7.7g and a water weight of 3.7g. The water weight of the tag was less than 1% of the weight of the fish as recommended by Winter et al. (1978). Fish weights were estimated from the length-weight relationship ($W = aL^b$) calculated from a 1997 data, and a minimum length was set at 620mm.

An effort was made to maintain clean, but not aseptic conditions. All utensils and the transmitters were thoroughly washed in a betadine solution and surgical gloves were worn during surgeries. To ensure the quality of sutures and speed of tagging all surgeries were conducted by a licensed veterinarian and assisted by a fisheries technician.

The adult lamprey were anesthetized in a 150 mg/l solution of MS222 (Methane-tricaine sulfonate). Anesthetized fish were measured and placed on the surgery table. Throughout the tagging process, the gills were irrigated with a continuous flow of 75 mg/l solution of MS222, however, a 150 mg/l solution and freshwater were used to maintain a suitable level of anesthesia as needed. A 3-4 cm incision was made just anterior to the second dorsal fin of the lamprey ventrally and slightly lateral. Approximately 10 cm posterior to the incision a 16-gauge hypodermic needle was inserted and fed through to the incised area. The whip antenna of the transmitter was inserted through the needle and the needle was removed. The transmitter was then placed into the coelem through the incision, and the incision was sutured closed with 3/0 nonabsorbable nylon suture. No topical anaesthetic was applied because of risk of damage to epithelial cells (Klontz and Smith 1968, Herwig 1979). A small fin clip was taken from the second dorsal for genetic analysis and the fish was returned to freshwater for recovery.

We held the tagged lamprey for 3-5 days before release to monitor the surgeries for healing and to allow stress levels of the fish to return to pre-tagging levels (Close et al. 1996).

Releases Sites

All Pacific lampreys from the study were released near St. Helens, OR on the downstream end of Sand Island (Rkm 137).

Tracking Methods

Fixed receiver stations

The study area (figure 2) ranged from Columbia City, Oregon (RM 85) upstream to Bonneville Dam (RM 148) in the Columbia River and up to Willamette Falls (RM 28)

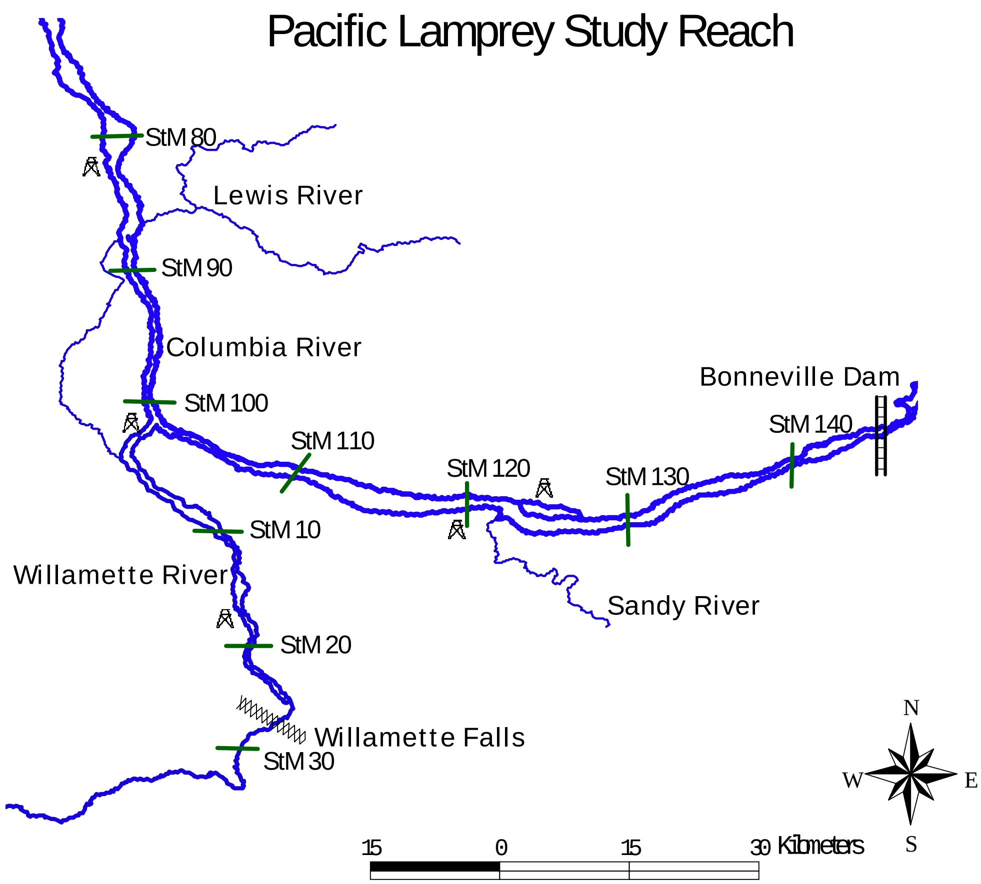

FIGURE 2. MAP OF RADIO TELEMETRY STUDY AREA.

in the Willamette River. Fixed receiver sites were selected based on the following criteria: usefulness to the study, security from vandals, ambient noise levels, and elevation. Fixed receiver site locations are marked in figure 2. We fitted each fixed receiver site with a Lotek SRX-400 radio telemetry receiver, a nine-element Yagi antenna, and a deep cycle battery. The SRX-400 receivers ran the Code-Log software that allows data to be stored in permanent memory (Lotek Engineering 1994) and were set to scan only channel 16 (149.960 MHz). Since all of our tags were on a single channel, scanning for tagged fish was continuous. We set the gain levels at each site as high as possible while trying to minimize the number of false codes received.

A total of five fixed-receiver sites were set up in the study area. One site was located below the release site to monitor for fish moving downstream out of the study area. One receiver site was set up on the Columbia River shore of Sauvie's Island about a mile below the confluence of the Columbia and Willamette Rivers. We set up two upstream receiver sites in the Columbia and one in the Willamette. One Columbia River site was at the Port of Camas-Washougal marina on the North Shore of the Columbia River, and one was at Chinook Landing on the South shore of the Columbia. Due to the large width of the Columbia River, we believed that having receiver sites on both sides of the river would increase the probability of detecting passing fish. The upstream receiver site on the Willamette River was located at the Staff-Jennings Marina (RM 16.5) just below the Sellwood Bridge (Fig. 2)

Mobile Tracking

We mobile tracked tagged lamprey by plane and boat. Boat tracking was accomplished in an 18' jet sled fitted with two five-element yagi antennas mounted on ten foot masts. The antennas were pointed forward and 45° to the side on both sides of the boat. This orientation allowed for picking up signals as the boat approached tagged lamprey while allowing fish on either side to be picked up on a single pass. Airplane tracking was done in a Cessna aircraft with a two-element yagi mounted on each wing pointing down and to the side of the aircraft. Boat tracking was primarily limited to the study area; aerial tracking was conducted within the study area, upstream and downstream of the study area, and in tributaries flowing into the Columbia or Willamette rivers within the study area. Our mobile tracking receiver had the W-5 firmware that does not allow data records to be stored (Lotek Engineering Inc.) in permanent memory. The Scan-Log program, which displays the code of a detected fish for the operator to record, was run while searching for tagged fish.

When tracking by boat, we made 2 to 4 passes through the river reach depending on width and the number of islands and side channels present. Both antennas were active when cruising to maximize coverage. When a fish was heard on the receiver, we disconnected one antenna to determine the direction of the signal and moved closer to the signal until we could record the transmitter code and determine the fish's location. Each transmitter detection recorded was coded a minimum of three times. The transmitter code, date, latitude and longitude, determined with a handheld GPS unit, and the nearest landmark or channel marker were recorded for each tag logged.

When aerial tracking on the Willamette and Columbia Rivers, upstream and downstream passes were made. When aerial tracking on smaller tributaries, a single pass was sufficient to cover the entire river. When a signal was heard, the technician attempted to code out the signal immediately, but normally the pilot would need to circle a few times to determine the direction of the signal and to allow the technician to record the transmitter code. When tracking in flight restricted zones like the Portland Airport and downtown Portland, only a single pass was allowed. If the technician heard a signal but was unable to record the transmitter code, the location was noted to return later with the boat to try to code out the fish.

Data collection from stationary receivers

Data downloads

The SRX-400 receivers at each fixed receiver station were downloaded multiple times per week during the lamprey run and every two –three weeks in the later stages of the study. Downloading was accomplished by connecting the receiver to a notebook computer with a serial link. The HOST software (Lotek Engineering) program was used to facilitate transferring of data from the receivers to the computer and the subsequent transforming of the data to a text file.

Since our study area was in close proximity to the Portland Metropolitan area and along the shipping channels of Columbia and Willamette rivers, we encountered variable radio noise patterns. We wanted to keep our receiver functioning at a high enough gain to detect fish as they passed, so we had to deal with false codes and collision codes in our download data. Most false codes that are received by the SRX-400 receiver are coded as 255 or 0; neither of these numbers represent an actual tag code and are easily filtered out. False codes are also recorded that represent actual tag numbers from passing boats, automobiles, or other noise; the same false codes tend to appear often in the data. The simplest way we found to filter out actual codes from false codes was to go through the all of the transmitter codes released using the data filter function in Excel and look for a reasonable pattern. Since all of our tags were on three second burst rates, we would see code records for an individual fish that consisted of a series of codes coded every three seconds. Since it is possible for the receiver to not code every signal, we looked for a minimum of three codes every fifteen seconds for several minutes. False codes tend to appear as a single code at irregular intervals in the code record. This method was used for all of our code numbers even prior to their release. No recorded hits fit the required pattern for tag numbers that were not present in the study area. Since no code records fit this pattern for codes until they were released, or for codes that were not in our sample, we are confident that no false hits were recorded using this methodology. We used Microsoft EXCEL for all data filtering and sorting.

mtDNA Analysis of Fish Collected at Bonneville Dam and Willamette Falls

The purpose of this subproject is to assess the inter- and intra-population genetic variation among lamprey populations from the Columbia and Willamette Basins. The design will fully complement and support the goals of Objective 2.

The genetic stock structure of Pacific lampreys populations within the Columbia Basin are totally unknown. There are no published genetic assessments of lamprey populations in the Columbia using any analytical method (gel electrophoresis, mtDNA, nuclear DNA). Beamish and Whitler (1986) demonstrated that there is sufficient allozyme variability in Pacific lampreys to investigate population structure using gel electrophoresis. Due to the nature of the techniques, it is therefore likely that sufficient variability in D-loop mitochondrial DNA fragment length to estimate genetic variability. Results of this objective will be used to test the more general hypothesis that lampreys home to their watershed of origin. Determination that lamprey which home to a specific basin are also genetically unique will greatly strengthen the conclusions of the tagging subproject. This project will employ mitochondrial DNA analyses to test the null hypothesis; Pacific lamprey populations in the Columbia Basin represent a single gene pool. Falsification of this hypothesis will critically effect the management of lamprey populations within the studied watersheds. Conclusions from this analysis will serve to support the results of the tagging study.

Annotated Bibliography

To insure that all available Pacific lamprey literature has been collected and reviewed. Literature of related species was reviewed with particular attention paid to stock transfer and restoration efforts including passage, production, genetics, life history, and management case histories.

Population Structure

The genetic consequences of supplementing natural lamprey populations with lamprey from different drainages are not known. Baseline data regarding variation among populations and within basin stock identity does not exist. Indeed, very little is known about the stock structure of Pacific lampreys in general. Life history information collected in the previous phases of this work suggests that the stock structure of lampreys is of lower geographic resolution than found in other anadromous fishes, but this remains to be confirmed quantitatively. This issue can be addressed by a survey that focuses on the variation in allozyme frequency and occurrence among populations. The purpose of this study is to quantify genetic differences/similarities between selected natural populations within the Columbia River Basin (CRB), to scale the genetic variance among populations to the greater geographic distribution of the species (e.g. selected Pacific Coast drainages), and to quantify temporal variation. The technique employed is gel electrophoresis of protein allozymes.

A genetic monitoring and evaluation program is essential for an adaptive management approach to restoration of lamprey. Testing for among-population variability will be hierarchical. Variation in the frequency of allozymes among sites will be used as a baseline indicator of stock structure. Since significant differences among populations can be attributed to a number of natural causes, such as homing, natural selection, and genetic drift, a positive result (i.e. stock identity) will indicate a need for a life history comparison study to ascertain stock compatibility. No difference among selected watersheds will indicate genetic compatibility with regard to restoration measures.

To minimize species identification problems, sampling will target juvenile lampreys of length greater than 60 mm. A variety of standard statistical analyses will be performed on the data, including indices of genetic variability, tests of conformance to Hardy-Weinberg genetic equilibrium, contingency chi-square tests, genetic distance, F-statistics, and hierarchical gene diversity analysis, as required.

Results and Interpretation

Abundance and Passage Trends

Abundance Estimates

At Bonneville Dam, Pacific lamprey counts were made during daytime periods by the USACOE observers. Pacific lamprey counts were also made by a CTUIR on-site observer between May and August 1998. The CTUIR counts were based on 12-minute observation periods during nighttime periods. The total abundance estimate from the CTUIR on-site counting had a lower confidence limit of 11,963 and an upper confidence limit of 25,205 (Table 1). Adding these nighttime estimates to the daytime counts (Table 2) would increase the ladder passage estimate by 50%. More activity, upstream and downstream counts, was observed in the Washington Shore ladder, however, greater net passage was recorded in the Bradford Island ladder.

Table 1. Pacific lamprey passage estimates (95% bound) derived from CTUIR on-site observations at Bonneville Dam in 1998.

Strata	n	Bradford Island	(+/-)	n	Washington Shore	(+/-)
5/16-31	30	1,579	588	31	3,881	1,586
6/1-15	20	2,910	1,168	16	1,800	1,873
6/16-30	25	14,448	1,934	30	4,780	1,651
7/1-15	31	10,471	1,477	35	6,771	1,437
7/16-31	68	1,628	646	70	-5,001	789
8/1-15	50	888	484	48	-538	1,041
8/16-31	31	1,755	593	35	3,401	1,017
Total		33,679	2,939		15,095	3,682

Table 2. Estimated total adult Pacific lamprey passage by month at Columbia and Snake river dams in 1998. Counts for Lower Granite and Ice Harbor are based on 24 h observation, all other counts are based in general on 16 h observation periods.

	Bonneville	The Dalles	John Day	McNary	Ice Harbor	Lower Monumental	Little Goose	Lower Granite	Rock Island	Rocky Reach	Wells
January											
February											
March											
April	103	0	53	1	10	0	0	0	0	0	
May	2213	10	313	0	17	1	0	1	0	0	
June	12851	936	251	30	19	10	5	4	5	0	
July	14548	4183	3273	1166	212	33	20	44	46	23	
August	5183	1714	6626	1664	451	24	56	29	846	515	
September	2295	717	1752	488	49	1	9	31	465	263	
October	285	105	311	44	5	0	0	1	44	18	
November	0	0	0						4	0	
December											
Total	37478	7665	12579	3393	763	69	90	110	1410	819	

Monthly fish ladder passage counts at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, Rock Island, Rocky Reach and Wells dams for 1998 are presented in Table (2). Counts from the lower Columbia River projects, Bonneville through McNary dams, were based on 16 h counts. Counts from all other projects were based on 24 h enumeration.

Based on USACOE fish ladder passage estimates there appears to be an 80% drop in Pacific lamprey abundance between Bonneville and The Dalles dams. This compares to a 65% drop in 1997 and is compatible with radio telemetry studies that reported a 66% drop in abundance (Vella and Stuehrenberg 1997).

These data support the contention that the upstream migration of Pacific lamprey is severely impacted by hydroelectric projects. Preliminary investigations correlating Pacific lamprey swimming ability and water velocity in fish ladder weir orifices revealed that lamprey had extreme difficulty negotiating the orifices (T. Bjornn Personal Communication). Additionally, these data indicated that Pacific lamprey preferred to migrate through the orifices instead of over the weir crests. Research needs to be directed toward further assessing these impacts.

Difficulties with Counting Pacific Lamprey

Fish count stations have been designed for salmonid passage and enumeration. Lamprey requirements could be very different. Up- and downstream movement creates problems for enumerating Pacific lamprey. For example, at the Washington Shore Count Station the upstream lamprey detection's were estimated at 576,542 and downstream estimate was 542,330 for the nighttime period between July 1 and September 30, 1998, based on counts from 283 12-minute observation periods. This demonstrates that Pacific lamprey were detected and counted a total of 1,118,872 times and these detection's resulted in a net passage estimate of 34,065 fish. Based on these data, for every Pacific lamprey observation there is only a 3% chance that it will result in a net upstream count. Lamprey movement at the Bonneville count stations appears to be the most extreme, however, this phenomena is observed elsewhere. Clearly, work needs to be done at Bonneville Dam to try to

Table 3. Mean local efficiency (LE) estimates of Pacific lamprey passing the Bradford Island and Washington Shore counting stations in Bonneville Dam during 1998.

	Bradford Island		Washington Shore	
Date	n	LE	n	LE
5/16-31	29	5.6	30	10.1
6/1-15	19	6.1	15	2.6
6/16-30	24	18.1	29	6.6
7/1-15	30	18.3	34	13.1
7/16-31	67	9.2	69	-15.4
8/1-15	49	8.1	47	-1.5
8/16-31	30	21.5	34	10.1

correct this problem to allow more precise passage estimates to be made. The cumulative of effect of passing 8 to 9 hydroelectric projects in this manner could be devastating to the fat reserves of individual lamprey and lead to a reduction in reproductive success.

Mean local efficiency of Pacific lamprey using the Bradford Island ladder (12.4%, SE = 6.643, N = 7) was significantly higher than Washington Shore (3.7 %, SE = 9.762; Wilcoxon Test P = 0.043). With the exception of the first estimate, all local efficiency estimates for Bradford Island were significantly higher than Washington Shore (Table 3). This is similar to 1997 where local efficiency calculated for Bradford Island was higher than that calculated for Washington Shore. The local efficiency estimates for Bonneville Dam are much lower than those reported for sea lamprey *Petromyzon marinus* (35.4%, SE = 7.94) crossing a modified Ice Harbor-type fishway (Haro and Kynard 1997). Haro and Kynard (1997) cited high water velocity, air entrainment, and turbulence within the fishway as factors inhibiting sea lamprey passage by disrupting upstream migratory motivation and visual and rheotactic orientation. Starke and Dalen (1995) also noted a lot of back and fore movement of Pacific lamprey at the fish counting stations. This phenomenon needs to be further addressed and actions must be taken to reduce it. Vella and Stuehrenberg (1997) provide further insight into the difficulty that Pacific lamprey have negotiating fish ladders. They observed that less than 50% of the Pacific lamprey, with implanted radio transmitters, that entered fish ladders actually exited the ladders. Observations were repeated over Bonneville, The Dalles, and John Day dams, and among three years. It is easy to speculate that the cumulative effect of fish ladder passage difficulties severely impacts the migration of Pacific lamprey.

Homing Fidelity

We used a two pronged approach to investigate homing fidelity: 1.) a field study; and, 2.) an analysis of mtDNA from two presumed distinct stocks. The literature states that adult Pacific lamprey tend to migrate directly to the upper reaches of the stream or small lake, then over-winter (Beamish 1980). Therefore, we assumed that Pacific lamprey should quickly move through our study area. We also assumed that the fish collection sites were located upstream enough to preclude most “explorers” from capture. Kan (1975) estimated migration rates in the Columbia River at 4.5 km/day. The two collections sites were Willamette Falls and Bonneville Dam. These collection sites are located 45 km and 70 km from the confluence of the Willamette River, which was the decision point for determining homing affinity. The study design was very similar to the classic homing study conducted by Wisby and Hassler (1954), which has since been repeated more than 20 times with various fish species, (Harden-Jones 1968; Tuunainen et al. 1980, Hasler and Scholz 1983; Halvorsen and Stabell 1990).

Between June 8 and September 24, 1998, we collected and implanted radio transmitters in 50 Pacific lamprey (25 from each capture location).

Currently, we are still collecting data on instrumented Pacific lamprey and will present a full analysis of this component of the project in next year's annual report.

mtDNA Analysis of Fish Collected at Bonneville Dam and Willamette Falls

The mtDNA analysis allows non-lethal genetic sampling of fish used in the tagging study. By testing the same fish with two methods (tracking and mtDNA) we increase the amount of evidence to generate conclusions. Mitochondrial DNA has been used to determine homing fidelity in several species (Avise and Hamrick 1996) but its use in sea turtles *Chelonia* sp. is the most documented (Meylan et al. 1990).

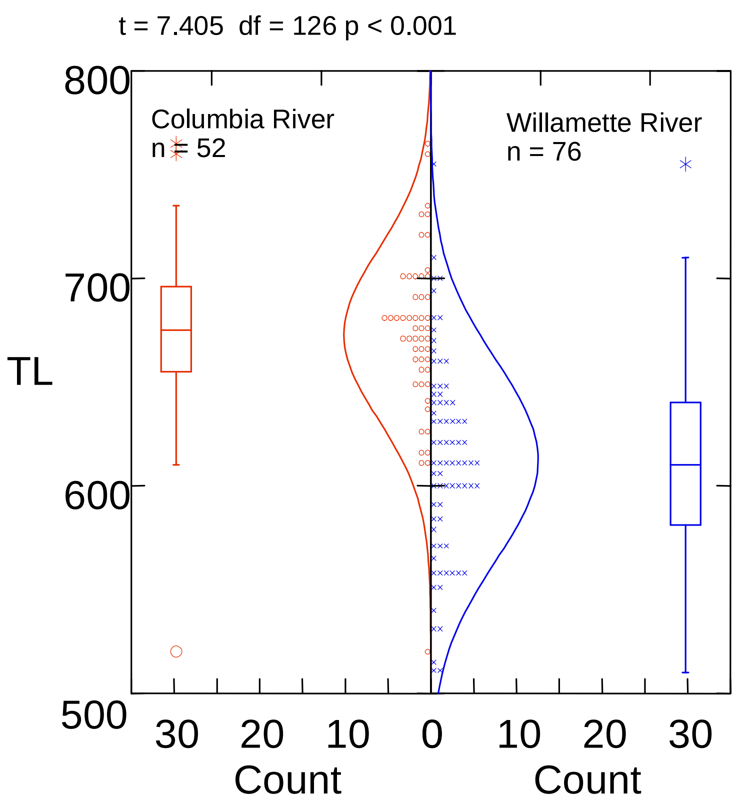

Figure 3. Length frequency plots and significance test of Pacific lamprey captured at Bonneville Dam and Willamette Falls in 1998.

We collected tissue samples from each Pacific lamprey that were implanted with radio transmitters and tissue samples from an additional 27 fish at Bonneville Dam and 51 from Willamette Falls. Therefore, total samples sizes were 52 and 76 for Bonneville and Willamette Falls. Figure (3) gives length frequency plots for collections from Bonneville Dam and Willamette Falls. These genetic samples are being processed and analyzed by the University of Idaho and a complete analysis and reporting will occur in next years annual report.

Annotated Bibliography

In appendix (A) we provide an annotated bibliography of lamprey work. Annotation includes the citation, general description of the work, species of interest, keywords, abstract, and notes.

Population Structure

To develop a genetic database for Pacific lamprey in the Columbia River Basin, we collected samples from 12 streams within the basin and from 4 streams outside of the basin (Table 4). Some of these collections had been made in previous years. In those cases, we tried to collect additional samples to permit temporal comparisons. These samples are being processed and analyzed by the University of Idaho. A complete analysis and reporting will occur in next year's annual report.

Table 4. Sites where lampreys were collected for genetic analysis.

Date	SubBasin	Site & RM	Number Collected	Mean length	Life History Stage	Genetic Analysis
8/25/98	John Day	Camas Cr. RM 10.2	20	--	ammocoete	Protein electrophoresis
8/25/98	John Day	Middle Fork	50	--	ammocoete	Protein electrophoresis
9/3/98	John Day	North Fork RM 58.5; 67.2	23	--	ammocoete	Protein electrophoresis
9/3/98	Fifteen Mile Cr	15 Mile Cr	127	108 mm	ammocoete	Protein electrophoresis
9/2/98 9/25/98	Lower Columbia	Milton Cr	89 40	106 mm 94 mm	ammocoete	Protein electrophoresis
10/7/98	Chehalis	Chehalis River	100	88 mm	Ammocoete & macrophathalmia	Protein electrophoresis
3/27/98 3/28/98 3/29/98	Snake	Lower Granite Dam	8 61 29	-- -- --	Ammocoete & macrophathalmia	Protein electrophoresis
6/11/98 thru 9/24/98	Lower Columbia	Bonneville	52	673 mm	adult	Protein electrophoresis mtDNA
6/11/98 thru 9/3/98	Willamette	Willamette Falls	76	612 mm	adult	Protein electrophoresis & mtDNA
	Sacramento		100		Ammocoete & macrophathalmia	Protein electrophoresis
	Deschutes	Shearars Falls			Adult	Protein electrophoresis
	Lewis	Cedar Creek			Adults	DNA
	Clearwater	Red River	26		Ammocoete	
	Nass River	Nass River	12		Ammocoete	
	Cowlitz	Toutle River			Adult	
	Rogue	Rogue River			Adult	

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APPENDIX A. PLANNING OF THE COLUMBIA BASIN PACIFIC LAMPREY PROJECTS AND NEEDS.

A Report to

The Northwest Power Planning Council

and

Bonneville Power Administration

Prepared by

Columbia Basin Pacific Lamprey
Technical Work Group

for

Columbia Basin Fish and Wildlife Authority

JULY 1999

Planning of Columbia Basin Pacific Lamprey Projects and Needs

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PLANNING OF COLUMBIA BASIN PACIFIC LAMPREY PROJECTS AND NEEDS
A REPORT TO THE NORTHWEST POWER PLANNING COUNCIL – JULY 1999

Background

Severely declining Pacific lamprey populations throughout the Columbia River Basin has recently elevated the interest and concern of various entities. The tribes have expressed the most concern due to the cultural significance and lost traditional fishing opportunities.

In 1994, the Northwest Power Planning Council approved the first lamprey project in the Fish and Wildlife Program. The project proposed by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR), called for research and restoration of Pacific lamprey throughout tribal ceded lands. In 1995, an initial product (Status Report of the Pacific Lamprey in the Columbia River Basin) was completed. Since that time, the CTUIR has continued the lamprey project with efforts directed at mainstem abundance monitoring, NE Oregon tributary population abundance documentation (past and present), development of genetic baseline information, basic migratory behavior, and artificial propagation techniques (capture, transport, holding, spawning). This information has been essential for development of a pilot pacific lamprey restoration plan in the Umatilla Basin. CTUIR hopes the plan, to be completed in 1999, will lead to lamprey restoration in the Umatilla and ultimately other subbasins.

Additional lamprey studies have been proposed creating uncertainty regarding priority lamprey needs and projects. The NPPC approved FY 99 funding for the ongoing CTUIR project but not others that were proposed, due to these uncertainties and also due to potential project duplication. This document is intended to help clarify the various lamprey project purposes and needs and assist the NPPC in making FY 2000 funding decisions.

Since the initiation of the CTUIR lamprey research and restoration project, a Columbia Basin Pacific lamprey technical work group (Table 4.) has been formed to discuss current issues and findings, coordinate ongoing project efforts, and define future project needs as requested by the NPPC. Numerous state, federal, university, and tribal entities have met approximately twice a year for the last three years. The most recent meeting (entitled "Columbia Basin Pacific Lamprey Workshop") took place in Mission, Oregon on October 22 and 23, 1998. This report will utilize information resulting from the work groups meetings and information from FY 2000 proposals to discuss all ongoing and proposed Pacific lamprey research and restoration efforts and will identify what are believed to be priority needs.

Brief historical facts

- The Pacific lamprey are native to the Pacific Northwest and are believed to have inhabited most tributaries throughout the Columbia River Basin.
- The overall distribution of Pacific lamprey is from southern California to the Gulf of Alaska and inland to central Idaho.
- Former distribution was likely broader than anadromous salmonids due to the ability of lamprey to cling to rocks and pass around slides or falls.
- Pacific lamprey were and still are highly regarded culturally and religiously by Native American tribes. Former lamprey abundance provided tribal fishing opportunities throughout Columbia River Basin tributaries.

- Significant non-Indian lamprey collection at Willamette Falls for fish food processing in 1913 was documented at 27 tons. Commercial fishermen in the 1940's harvested 40 to 185 tons annually (100,000 to 500,000 adults) at Willamette Falls for use as vitamin oil, protein food for livestock, poultry, and fish meal.

Current status of populations and fisheries

- The current potential distribution of Pacific lamprey in the Columbia River and tributaries extends to Chief Joseph Dam and to Hells Canyon Dam on the Snake River.
- Although adult lamprey counting at mainstem Columbia and Snake River dams is not standardized and was sometimes restricted to certain hours, population trends indicate precipitous declines.

Pacific lamprey counts at Columbia and Snake River dams

Dam	Former counts	1997 counts
Bonneville	350,000 in early 60's	22,830
The Dalles	300,000 in early 60's	14,835
John Day	----	14,845
McNary	25,000 in early 60's	4,213
Ice Harbor	50,000 in early 60's	1,454
Lower Monumental	----	217
Little Goose	----	245
Lower Granite	----	1,274
Rock Island	----	2,321
Rocky Reach	17,500 twice in 60's	1,405
Wells	----	773

- Based on 1997 COE fish ladder passage estimates, there appears to be a 65% drop in Pacific lamprey abundance between Bonneville and The Dalles Dams which suggests a substantial portion of the lamprey run spawn in the following tributaries - Wind, Little White Salmon, White Salmon, Klickitat, and Hood rivers.
- Based on 1997 COE fish ladder passage estimates, there appears to be another large drop (72%) between John Day and McNary Dam counts which suggests that the John Day River may support a run of approximately 10,000 Pacific lamprey. Sampling of juvenile lamprey by CTUIR in NE Oregon streams has shown that the John Day basin has the highest juvenile densities relative to other subbasins.
- In the mid-Columbia, there is approximately a 40% drop in counts between Rock Island and Rocky Reach Dams indicating that a sizable Pacific lamprey population may persist in the Wenatchee River. However, fish counting at Tumwater Dam on the Wenatchee River during most of the last 10 years between May and September have not recorded lamprey movement. The fish could over-winter in the lower river and go upstream prior to salmon counting.

- Passage over the last dams in the Snake and Columbia rivers in 1997 appears to be seriously low. Only 3% of the Pacific lamprey that crossed Bonneville Dam were counted at Lower Granite Dam and approximately 6% crossed Wells Dam.
- Pacific lamprey population declines have reduced, eliminated, or relocated the once widespread tribal fisheries to Willamette Falls on the Willamette River. A small tribal fishery also sometimes occurs at Shears Falls on the Deschutes River, Fifteen Mile Creek and on the Klickitat River.
- ODFW currently issues permits for Indian and non-Indian subsistence and commercial fisheries at Willamette Falls
    - fishing occurs by hand-type methods only on east side of the horseshoe falls area
    - of 55 permits issued in 1997, 17 of those people (about one-half Indian and one-half non-Indian) sold fish for commercial purposes
    - a calculation of catch through buyers records indicated about 28,000 pounds of lamprey were harvested commercially at Willamette Falls in 1997
    - the average, annual commercial harvest since 1990 is 22,000 pounds
    - since recent catch is remaining stable and the fishery is closed over one-half of the falls area, ODFW has determined that current harvest is not a biological problem.

Principle problems impacting populations

Mainstem passage at dams - Similar to anadromous salmonids, hydroelectric dams along the Columbia and Snake rivers also create passage impediments for Pacific lamprey. Recent NMFS studies (funded by COE) utilizing radio telemetry in the lower Columbia River indicates that 40% of adult Pacific lamprey migrating to Bonneville Dam do not move upstream past the fishways. This problem multiplied by several dams is likely the main reason for the severe declines or possibly extirpation of Pacific lamprey in most mid to upper Columbia and Snake river tributaries. Juvenile lamprey outmigrants are also subjected to high mortality rates at hydroelectric projects. Although mortality percentages are not known, it is believed to be higher than salmonids due to lesser swimming ability of lamprey and resultant poor avoidance and increased impingement on bypass screens.

Poor habitat conditions in tributaries - Reduced instream flows in many tributaries has greatly impacted the natural production potential of Pacific lamprey. Dewatering or low flows in late spring and summer impacts adult upstream migration into tributaries. Low flows, poor riparian conditions and resultant high water temperatures have also reduced the quality and quantity of adult spawning and juvenile rearing areas.

Goals

Other than the Tribes, no entity has stated any specific lamprey restoration goals in fisheries management plans. The Wy-Kan-Ush-Mi-Wa-Kish-Wit states the goal: within 25 years, increase lamprey populations to naturally sustainable levels that also support tribal harvest opportunities. The CTUIR is utilizing the Umatilla Basin as a pilot project to test lamprey restoration techniques with the ultimate goal of reestablishing self sustaining natural producing populations which also provide for tribal fishing opportunities at traditional locations within the subbasin.

Ongoing projects
The Columbia Basin Pacific Lamprey Workshop identified the ongoing lamprey projects, sponsors, general tasks, and funding sources (see Table 1).

Proposed projects
The Columbia Basin Pacific Lamprey Workshop also identified information relevant to proposed lamprey projects. This information in addition to that provided in the FY 2000 BPA lamprey proposals is presented in Table 2.

Critical uncertainties/lamprey project needs
Attendees at the Columbia Basin Lamprey Workshop identified the following regarding Columbia Basin Pacific lamprey (all are priorities, no order identified):

I. Estimate upstream migrant abundance at mainstem dams
II. Upstream migration - mainstem passage success
III. Downstream juvenile migration - mainstem passage success
IV. Genetic database for population structure
V. Species identification techniques
VI. Juvenile and adult life histories - habitat requirements
VII. Artificial propagation success - hatchery practices
VIII. Pilot restoration actions in a tributary with associated M & E

To help assess the need for ongoing and proposed Pacific lamprey projects, a column was added in Tables 1 and 2 indicating which critical uncertainty or need listed above is addressed by each project.

Discussion of proposed project needs and priorities
If we assume that our long-range goal is to rehabilitate the population of Pacific lampreys in the Columbia River basin to self sustaining natural producing populations which also provide for fishing opportunities at traditional locations, the following general actions will need to be implemented:

1. We must identify the numbers and distributions of what we have currently.
2. We must identify the relative importance of factors limiting reproduction, primarily passage through dams (upstream and downstream) and habitat requirements of all life stages.
3. We must develop rehabilitation plans that include methods for collecting, transporting, and culturing Pacific lampreys
4. We must demonstrate rehabilitation is feasible by conducting controlled, designed studies in one stream.
5. We must initiate a long term monitoring program on the numbers of Pacific lampreys entering the Columbia River to assess our success or failure to increase the population.

The project critical uncertainties, I through VIII above, identified at the workshop are the subject of several ongoing and proposed projects. The workshop attendees agreed that all projects have a high priority considering the current status of lamprey populations.

Table 3 was developed to help the NPPC and project reviewers understand Columbia River Pacific lamprey project critical needs and ties to ongoing and proposed projects. There are more critical needs than there are approved projects. Also, one ongoing project listed does not mean it entirely meets the general objective need.

Due to the fact that Columbia Basin Pacific lamprey populations are believed to be extirpated or nearly so in many subbasins, transplantation and/or artificial propagation is expected to be necessary in many restoration efforts. The Columbia Basin Pacific lamprey technical work group developed draft ("working thoughts" – open to revision) guidelines for Pacific lamprey transplantation and/or artificial propagation (Appendix B). The first project expected to employ these guidelines is the Umatilla pilot subbasin restoration project 9402600.

Restoration of Pacific lampreys and fisheries in the Columbia River basin will require a substantial effort in terms of dollars and time. Total restoration of Pacific lampreys is probably closely linked with restoration of salmon populations and all of the complexities of habitat changes both in the rivers and in the ocean. However, if we make a few assumptions about Pacific lamprey populations based on what we know of other species, we can develop plans and implement demonstration projects where individual tributaries to the Columbia River could have rehabilitated populations of Pacific Lampreys. At the workshop, there seemed to be a consensus that priorities of future work should be based on both the information needs for large scale rehabilitation and for rehabilitation of lampreys in the Umatilla River. Conducting studies that will benefit both objectives should be given highest priority. A systematic, logical progression of studies needs to be continued to make the best use of limited research dollars leading to the most complete rehabilitation of Pacific lampreys that we can achieve.

Changes in aquatic habitats in the Columbia River Basin have resulted in declines in populations of several desirable fishes including Pacific lampreys. Because the wellbeing of Pacific lampreys is closely tied to the wellbeing of salmonids in other systems, it follows that if we improve conditions for salmonids in the Columbia River Basin, we will see an increase in the Pacific lamprey populations.

Passage of upstream migrating Pacific lampreys through fishways designed to pass salmonids is one issue that needs to be examined early in our plans. Problems encountered by downstream migrating Pacific lampreys might be similar to problems juvenile salmonids encounter.

This updated status report represents an initial assessment of what needs to be done concerning Pacific lampreys to facilitate their rehabilitation. As we conduct studies and learn more about lampreys in the Columbia River, we will likely need to modify our approach. Having a workshop periodically should allow that to happen. Having a meeting of researchers and others working on Pacific lampreys on an every other year schedule would keep the planning and evaluation process in an efficient mode. Producing list such as those in Tables 1, 2 and 3 on an annual basis will provide an index of how much progress we are making. An additional table should be included that lists reports and publications that have been produced since the Pacific lamprey rehabilitation effort was begun. Eventually this information could be set up in a WEB site that would allow frequent updating of lists.

Table 1. Ongoing Columbia Basin Pacific Lamprey projects

Sponsor	Funding	Project title	General project actions	Critical uncertainties and needs addressed
CTUIR/ CRITFC	BPA	Pacific Lamprey Research & Restoration (project #9402600)	· Monitor abundance & passage trends of adult lamprey at Columbia & Snake River dams · Develop a genetic database for determination of lamprey population structure in the Columbia Basin · Investigate adult lamprey homing fidelity back to initial capture sites · Document presence/absence and distribution of lamprey in NE Oregon & SE Washington subbasins · Develop pilot lamprey restoration plan for Umatilla subbasin · Begin initial restoration plan actions: 1) trap adults from John Day river; 2) evaluate lamprey hatchery practices while holding adults at USGS Cook, WA lab; 3) spawn adults, incubate eggs, rear & outplant prolarvea in Umatilla River; 4) monitor Umatilla River for juvenile survival and growth; 5) monitor lamprey migratory pheromone in water samples from the Umatilla & John Day rivers to better understand adult lamprey attraction into tributaries.	· Adult abundance monitoring · Adult homing behavior · Genetic database · Life histories & habitat req. · Hatchery practices · Pilot restoration actions - · M & E
NMFS/ U of Idaho	COE	Radio Telemetry of Adult Pacific Lamprey in the Lower Columbia River	· Evaluate passage of radio tagged adults below and at Bonneville Dam · Conduct laboratory evaluations of upstream movement through various augmented adult fishway structures	Adult upstream migration success
USGS CRRL	COE	Characteristics of Upstream Migration of Pacific Lamprey in the Columbia River	Evaluate adult maturation & physiology of adult lamprey collected at Bonneville Dam	Adult upstream migration success Life histories
USGS CRRL	COE	Effects of Swimming & Exhaustive Stress in Pacific Lamprey: Implications for Upstream Migration Past Dams	Evaluate swimming performance, metabolic condition, and exhaustive stress to assess efficacy of current upstream fish passage facilities at Bonneville Dam.	Adult upstream migration success
USGS CRRL	USFWS	Evaluation of Tagging Techniques for Pacific Lamprey Ammocoetes & Macropthalmia	Evaluate effectiveness (tag retention & animal survival) of visible implant (V1) & PIT tags in juvenile lamprey.	Juvenile downstream migration success

Sponsor	Funding	Project title	General project actions	Critical uncertainties and needs addressed
USGS CRRL	USFWS	Validation of Statolith - based aging Techniques for Pacific Lamprey Ammocoetes & Macropthalmia	Validate statolith-based aging techniques in laboratory & compare results to wild lamprey samples.	Life histories
U of Idaho	Misc	Genetic Analysis Pacific Lamprey	Receive tissue samples and conduct genetic analysis (generally a subcontractor under other studies)	Genetic database

Table 2. Proposed Columbia Basin Pacific Lamprey projects

Sponsor	Funding	Project title	General project actions	Critical uncertainties and needs addressed
IDFG	BPA	Evaluate Status of Lamprey in Clearwater River (#20019)	· Determine life history characteristics · Determine habitat requirements · Determine juv. & adult distribution · Develop & implement strategies to minimize impacts to habitat	Life histories & habitat req.
USFWS	BPA	Evaluate Habitat Use and Population Dynamics of Lamprey in Cedar Creek (#20121)	· Estimate adult abundance & determine migration timing · Determine larval lamprey distribution & habitat use · Determine outmigrant timing & abundance · Eval. homing fidelity, surv. rates & ocean residence with CWT's · Rear ammocoetes to verify species identifications · Evaluate effects of PIT tagging juveniles in lab · Evaluate adult spawning habitat requirements · Sample & cap redds to determine egg & larvae survival & developmental timing	· Life histories & habitat req. · Adult homing behavior · Species indentification · Juv. tagging/migration success
USGS CRRL	BPA	Identification of larval Pacific lampreys, river lampreys, and western brook lampreys and thermal requirements of early life history stages of lampreys. (#20065)	· Spawn three species in captivity & determine diagnostic characteristics of each · Collect ammocoetes and hold through metamorphosis to verify identification techniques · Evaluate temperature effects on the survival and early development of three species	· Species identification · Life histories & habitat req.
USGS CRRL	BPA	Upstream migration of Pacific lampreys in the John Day River: behavior, timing, and habitat preferences (#20064)	· Trap adults and use radio telemetry to determine lamprey movement to spawning · Describe overwintering & spawning habitat of radio tagged fish	· Adult upstream migration success · Life histories & habitat req.
Battelle PNNL	COE	Evaluate juvenile lamprey passage at John Day Dam	Assess juvenile lamprey impingement and injury during screening/bypass and turbine passage	Juvenile downstream migration success

Table 3. Critical uncertainties, goals and objectives for Columbia Basin Pacific Lamprey projects

Critical questions/uncertainties	Goal statement	General objectives	Applicable projects[1/]

Critical questions/uncertainties	Goal statement	General objectives	Applicable projects[1/]
I. Current abundance	A. Annually determine numbers & distribution of current populations	1. Coordinate with entities conducting salmonid counts at mainstem dams to expand counts for adult lamprey abundance	O: 9402600 much more needed
		2. Estimate upstream migrant abundance in major tributaries	O:9402600 P: 20121
		3. Survey ammocoete populations in major tributaries and mainstem	O: 94002600 P: 20019 P: 20121
		4. Analyze population trends and distribution and develop a long term monitoring program to assess restoration success	Needed
II. Upstream migration -passage success.	A. Provide for safe adult passage at mainstem dams	1. Evaluate passage of radio tagged adults in mainstem	O: U of I - COE
		2. Conduct laboratory evaluations of upstream movement through various augmented adult fishway structures	O: U of I - COE
		3. Evaluate swimming performance, metabolic condition, and exhaustive stress to assess efficacy of current upstream fish passage facilities	O: USGS - COE
		4. Identify upstream passage impediments at mainstem dams	O: U of I - COE more needed
		5. Determine what devices or operational procedures will allow adult migration through dams without excessive mortality	O: U of I - COE more needed
		6. Implement appropriate passage improvements at mainstem dams	Needed
	B. Provide for safe adult passage in major tributaries	1. Identify upstream passage impediments in major tributaries 2. Determine solutions for passage impediments 3. Implement passage improvements in major tributaries	O: 9402600 (Umatilla) Needed

Critical questions/uncertainties	Goal statement	General objectives	Applicable projects[1/]
III. Downstream migration - passage success	A. Provide for safe juvenile passage at mainstem dams	1. Evaluate effectiveness of various tag types in juvenile lamprey	P: 20121 O: USGS - USFWS
		2. Identify downstream passage impediments at ainstem dams	P: Battelle - COE (John Day Dam)
		3. Determine what devices or operational procedures will allow juvenile migration through dams without excessive mortality	Needed
		4. Implement appropriate passage improvements at mainstem dams	Needed
	B. Provide for safe juvenile passage in major tributaries.	1. Identify downstream passage impediments in major tributaries	Needed
		2. Determine solutions for passage impediments	Needed
		3. Implement passage improvements in major tributaries	Needed
IV. Genetic population structure	A. Develop understanding of Columbia Basin Pacific lamprey population structure.	1. Develop a genetic database for determination of lamprey population structure	O: 9402600
V. Lamprey species identification techniques.	A. Develop species identification techniques for larval lamprey (Pacific, river and western brook).	1. Spawn and hold each lamprey species in captivity through metamorphosis to verify identification techniques	P: 20065
VI. Life history, behavior and habitat requirements	A. Gain understanding of adult migration/homing behavior.	1. Determine general migration behavior through radio tagging and genetic assessment techniques	O: 9402600
		2. Investigate adult migration attractant potential of pheromones emitted by larvae	O: 9402600
		3. Conduct large scale CWT or PIT tag homing/ocean survival study.	Needed?
	B. Gain understanding of life history and habitat requirements for adult lamprey.	1. Evaluate adult migration and holding & spawning habitat requirements	P: 20064 P: 20121
		2. Sample and cap redds to determine egg & larvae survival & developmental timing	P: 20121

Critical questions/uncertainties	Goal statement	General objectives	Applicable projects[1/]
	C. Gain understanding of life history and habitat requirements for larval lampreys.	1. Validate statolith-based aging techniques	O: USGS - USFWS O: 9402600
		2. Evaluate effectiveness of various tag types in juveniles	P: 20121 O: USGS - USFWS
		3. Sample various tributaries to determine larvae distribution, life history characteristics, and habitat requirements	O: 9402600 P: 20121 P: 20019
		4. Sample juvenile outmigration in tributaries to determine timing and abundance	O: 9402600
VII. Artificial propagation and transplantation techniques & success	A. Develop transplantation and artificial propagation techniques for lamprey restoration in tributaries	1. Evaluate capture and transport techniques of adults from donor site to hatchery or recipient stream	O: 9402600
		2. Evaluate hatchery practices for adult holding, spawning, and early rearing of pro larvae	O: 9402600 P: 20065
VIII. Success of tributary restoration actions	A. Develop successful lamprey reintroduction/ restoration techniques for tributary application	1. Develop pilot restoration plan for Umatilla subbasin	O: 9402600
		2. Implement and monitor pilot restoration actions in Umatilla subbasin	O: 9402600

1/ P = proposed; O = ongoing; for BPA funded projects, the project number is given; for non BPA funded projects, the sponsor precedes the funding source.

Table 4. Columbia Basin Pacific Lamprey Technical Workgroup.

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Appendix 1. Draft Guidelines for Pacific lamprey Transplantation and/or artificial propagation actions.

1) The target or recipient subbasin formerly (or currently) sustained a pacific lamprey population.

2) The problems which lead to the reduction or demise of pacific lamprey in a recipient subbasin have been addressed (dewatering, passage barriers, chemical treatments, etc.)

3) The existing recipient subbasin Pacific lamprey population has been determined to be below a level which could recover to self-sustainability with harvest.

4) Pacific lamprey removal (defined location, life history state, and number) from a subbasin donor population is determined to have insignificant impact on that population.

5) Disease clearance or screening has been conducted on the donor population and results have been approved by fish pathologist (similar to salmonid transfers).

6) The donor population was selected based on the following: 1) results of a Columbia Basin Pacific lamprey genetic database/stock structure study (being conducted under CTUIR project 9402600); 2) geographic locations of donor vs recipient subbasins (may not be a critical factor depending on outcome of genetic database/stock structure study); and 3) availability of stocks.

7) NEPA requirements have been addressed - if applicable.

8) ESA concerns/requirements have been addressed - if applicable.

9) Proposed action includes a monitoring and evaluation plan to determine effectiveness of action.

Appendix B. Annotated bibliography of lamprey literature.

Beamish, F.W.H. 1980. Biology of the North American anadromous sea lamprey, Petromyzon marinus. Can. J. Fish. Aquat. Sci. 37:1924-1943.
General type: *Life History*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, distribution, life cycle, growth, energetics, fecundity*
Abstract: *The author provides data on marine distribution, reproduction, migration timing, ammocoete phase development/growth, juvenile feeding, and predation on and mortality of ammocoetes/juveniles/adults.*
Notes:

Beamish, R.J. 1980. Adult biology of the river lamprey (Lampetra ayresi) and the Pacific lamprey (Lampetra tridentata) from the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 37:1906-1923.
General type: *Life History*
Species: *L. tridentata, L. ayresi*
Keywords: *Pacific lamprey, river lamprey, life history, fish parasites, Pacific fishes*
Abstract: *The author provides results and conclusions of sampling both species in freshwater and saltwater (Strait of Georgia) habitats. Information on metamorphosis, migration, feeding, distribution, and spawing presents a thorough picture of each species entire life cycle.*
Notes:

Beamish, R.J. 1987. Evidence that parasitic and nonparasitic life history types are produced by one population of lamprey. Can. J. Fish. Aquat. Sci. 44:1779-1782.
General type: *Population studies, Stock Identification*
Species: *L. richordsoni, L. richardsoni var. marifuga*
Keywords: *brook lamprey, parasitic, non-parasitic, histology*
Abstract: *A population of lamprey in a small stream on Vancouver Island, British Columbia, Canada, was shown to contain the nonparasitic Lampetra richardsoni and a parasitic variety, herin named L. r. var. marifuga.*
Notes: *See Beamish and Withler 1986*

Beamish, R.J., and C.M. Neville. 1995. Pacific salmon and Pacific herring mortalities in the Fraser River plume caused by river lamprey (Lampetra ayresi). Can. J. Fish. Aquat. Sci. 52:644-650.
General type: *Life History, Ecology*

Species: *L. ayresi, Oncorhynchus sp.*
Keywords: *River Lamprey, estuary plume, feeding strategy, predation, parasitism,*
Abstract: *Estimates of lamprey predation on coho and chinook salmon in the Fraser River Plume suggest high natural mortality rates of salmon. The authors suggest that river lamprey predation is equivelent to approximately 65% of coho and 25% of chinook hatchery and wild production in Canada. Methods include abundance, gut content, feeding, and wounding studies.*
Notes:

Beamish R.J., and T.G. Northcote. 1989. Extinction of a population of anadromous parasitic lamprey, Lampetra tridentata, upstream of an impassable dam. Can. J. Fish. Aquat. Sci. 46:420-425.
General type: *Passage*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, passage barriers, extinction*
Abstract: *This study shows that despite initial evidence of attacks on resident lake trout, a landlocked population was not established after the construction of dams on the outlet of Elsie Lake, British Columbia. The inability to establish a landlocked population indicated that the transition from an anadromous parasitic life history type to a freshwater parasitic life history type did not occur as quickly or as easily as previously suggested.*
Notes:

Beamish, R.J., and C.D Levings. 1991. Abunance and freshwater migrations of the anadromous parasitic lamprey, Lampetra tridentata, in a tributary of the Fraser River, British Columbia. Can. J. Fish Aquat. Sci. 48:1250-1263.
General type: *Life History, Passage*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, ammocoetes, age determination, migration, parasitism*
Abstract: *This report presents results of monitoring ammocoete and young adult lamprey migrating out of the Nicola River, British Columbia during the four year period of 84-85 to 87-88. Young adult migration typically began in September with the largest number migrating from mid-March to mid-May. Ammocoete behaved similarily, except movements continued throughout the year. This is the first time that abundance of Pacific Lamprey in the Fraser system had been attempted, and estimates indicate that there are a larger number than previously suspected.*
Notes:

Beamish, R.J., and R.E. Withler. 1986. A polymorphic population of lampreys that may produce parasitic and a nonparasitic varieties. *In* Info-Pacific Fish Biology; Proceedings of the Second International Conference on Indo-Pacific Fishes, ed. by Uyeno et al. Icthyology Soc. of Japan, Tokyo. pp.31-49.
General type: *Life History*
Species: *L. richardsoni, L. ayresi, and L. tridentata*
Keywords: *river lamprey, trophic behavior, electrophoresis*
Abstract: *The authors provide morphometric and electrophoretic data concerning the discovery of a polymorphic population in a small creek on Vancouver Island, British Columbia, Canada. The genetic differences among populations within L. ayresi and L. richardsoni are as great as those that occur between the two species, but L. tridentata, a parasitic species, is genetically distinct.*
Notes: *closely related article – Beamish 1987*

Beamish, R.J. and J.H. Youson. 1987. Life history and abundance of young adult Lampetra ayresi in the Fraser River and their possible impacts on salmon and herring stocks in the Strait of Georgia. Can. J. Fish. Aquat. Sci. 44:525-537.
General type:*Life History*
Species: *L. ayresi*
Keywords: *River Lamprey, trophic behavior, feeding habits*
Abstract: *The authors present data on abundance, metamorphosis and migration timing, feeding habits, stage specific survival/mortality, and ultimately, indications of impact on herring and salmon populations in the Strait of Georgia.*
Notes:

Bell, G.R. and G.S. Traxler. 1986. Resistance of the Pacific lamprey, Lampetra tridentata (Gairdner), to challenge by Renibacterium salmoninarum, the causative agent of kidey disease in salmonids. J. Fish Diseases. 9:277-279.
General type: *Ecology, Pathogens*
Species: *L. tridentata, Renibacterium salmoninarum*
Keywords: *Pacific Lamprey, bacteria kidney disease (BKD), fish pathogens*
Abstract: *This report describes the results of challenging Pacific Lamprey with measured inocula of live R. salmoninarum which concurrently killed the positive control group of sockeye salmon. The sympatric resource utilization and feeding of lamprey upon salmon make them suspect vectors of the disease, yet results indicate that lamprey are unlikely to be a factor in transmitting the pathogen.*
Notes:

Bergstedt, R.A. and Seelye, J.G. 1995. Evidence for lack of homing by Sea Lampreys. Trans. Amer. Fish. Soc. 124:235-239.

General type: *Passage, Life History*

Species: *P. marinus*

Keywords: *sea lamprey, migration, homing, behavior, sensory cues, coded-wire-tags*

Abstract: *This report describes the results of a study in which 555 recently metamorphosed sea lamprey (from a tributary to L. Huron) were code wire tagged and released. After examining nearly 50,000 animals in nine tributaries of L. Huron, 41 tagged animals were recovered. Analysis of the distribution of these recoveries led the authors to the conclusion that lamprey do not home to natal streams, but rather select streams through innate attraction to other sensory cues.*

Notes:

Bodznick, D. and D.G. Preston. 1983. Physiological characterization of electroreceptors in the lampreys Ichthyomyzon unicuspis and Petromyzon marinus. J. Comp. Physiol. 152:209-217.

General type: *Life History, Physiology*

Species: *Icthyyomyzon unicuspis, Petromyzon marinus*

Keywords: *Sea Lamprey, Silver Lamprey, electroreceptors, mechanoreceptors*

Abstract: *It has been suggested that electroreceptors in fish, particularly salmon and eels, may provide explanation for their ability to migrate great distances back to natal homing streams. Results from this study indicate that electrosensory systems of lampreys and non-teleost gnathostome fishes are homologous*.

Notes:

Brussard, P.F., M.C. Hall, and J. Wright. 1981. Structure and affinities of freshwater sea lamprey (Petromyzon marinus) populations. Can. J. Fish. Aquat. Sci. 38:1708- 1714.

General type: *Genetics*

Species: *Petromyzon marinus*

Keywords: *sea lamprey, genetic variation, electrophoresis, population structuring*

Abstract*:* *This study presents evidence of sea lamprey genetic structure in Northeastern North America using gel electrophoresis. Analysis suggest that there are three genetically distinct groups in the region: (1) anadromous (plus those of L. Champlain) (2) L. Erie and upper Great Lakes Region (3) L. Ontario and three interior New York Lakes.*

Notes:

Clarke, W.C., and R.J. Beamish. 1988. Response of recently metamorphosed anadromous parasitic lamprey (Lampetra tridentata) to confinement in fresh water. Can. J. Fish. Aquat. Sci. 45:42-47.

General type: *Life History, Physiology*

Species: *L. tridentata*

Keywords: *Pacific Lamprey, osmoregulation, landlocked populations, passage*

Abstract: *Representatives of six populations of postmetamorphic lamprey from different rivers in British Columbia were collected and held in ambient fresh water laboratory conditions to observe longevity and physiological response. Between population mortality onset ranged from February to May, with a decline is plasma sodium concentrations identified as the source of mortality. A possible cause of this decline is the depletion of body lipid reserves, yet a seperate experiment shows that feeding does not prolong survival in freshwater confinement. This study was the first of its kind, and the authors conclude that confinement does not easily result in landlocked populations.*

Notes:

Close, D.A., Fitzpatrick, M., Li, H., Parker, B., Hatch, D., and James, G. 1995. Status Report of the Pacific Lamprey (Lampetra tridentata) in the Columbia River Basin. Bonneville Power Administration, Portland, Oregon. 35 pp.

General type: *Life History*

Species: *L. tridentata*

Keywords: *Pacific lamprey, life history, population declines, cultural significance*

Abstract: *The authors provide information on the cultural significance, historical/current distributions, population trends (including factors affecting declines) and general life history of Pacific Lamprey. Recommendations for research and evaluation efforts critical to the implementation of restoration actions are included.*

Notes:

Ferreri, C.P., W.W. Taylor, and J.F. Koonce. 1995. Effects of Improved Water Quality and Stream Treatment Rotation on Sea Lamprey Abundance: Implications for Lake Trout Rehabilitation in the Great Lakes. J. Great Lakes Res. 21(supp. 1):176-184.

General type: *Life History, Habitat*

Species: *P. marinus*

Keywords: *sea lamprey, water quality, Great Lakes, lake trout rehabilitation*

Abstract: *Improved water quality in streams has been linked to increased amounts of suitable sea lamprey spawning and ammocoete habitat leading to increased sea lamprey production. The authors simulate transformer*

production in a model stream to analyze effects of habitat availability and variablitity in lampricide treatment cycle lenghts. The authors suggest an increase in sea lamprey control efforts to counterbalance effects of improved water quality, in order to enable lake trout rehabilitation to succeed.
Notes:

Filosa, M.F., Sargent, P.A., and Youson, J.H. 1986. An electrophoretic and immunoelectrophoretic study of serum proteins during the life cycle of the lamprey, Petromyzon marinus L. Comp. Biochem. Physiol. 83B:1 pp. 143-149.
General type: *Genetics*
Species: *P. marinus*
Keywords: *sea lamprey, electrophoresis*
Abstract: *Electrophoretic analysis of serum proteins for upstream migrants, parasitic adults, early and late metamorphosing animals and ammocoetes were performed in this study of sea lamprey. Results showed; 1) that patterns for two proteins change during the life cycle, 2) these same two proteins measurably increase into the adult stage at which time they constitute 85% of the total serum protein.*
Notes:

Hammond, R.J. 1979. Larval biology of the Pacifc Lamprey, Entosphenus tridentatus (Gairdner), of the Potlatch River, Idaho. M.Sc. thesis. University of Idaho, Moscow, Idaho. U.S.A. 44pp.
General type: *Life History*
Species: *L. (Entosphenus) tridentata*
Keywords: *larval biology, ammocoete, metamorphosis, migration, habitat*
Abstract: *The author provides a literature review and field data from ammocete collections on tributaries of the Clearwater River, Idaho. Included are data on transformation timing, migration timing, and diet. No correlation between sediment condition or water velocity and population density was determined.*
Notes:

Hardisty, M.W. 1956. Some aspects of osmotic regulation in lampreys. J. Exp. Biol. 33:431-447.
General type: *Life History, Physiology*
Species: *L. planeri, L. fluviatilis, P. marinus*
Keywords: *lamprey, osmosis, chloride balance, saline solution, permeability*
Abstract: *The author provides a study of the problems of osmotic regulation, primarily in fresh water, of lamprey. Fasting by both ammocoetes and adults is shown to increase water content in the body and*

consequently raise Cl levels in fluids and tissues. Wide variation in Cl content of ammocoetes throughout the year emphasize the importance of Cl metabolism in osmotic regulation for lamprey in freshwater.
Notes:

Hardisty, M.W., and Potter, I.C. 1971-1983. The Biology of Lampreys. Academic Press Publishers. vol.1-4b.
General type: *General*
Species: *Petromyzonidae family*
Keywords: *life history, physiology, taxonomy, evolution*
Abstract*:*
Notes: *Out of print and difficult to find, but rich in information*

Haro, A., and B. Kynard. 1997. Video evaluation of passage efficiency of American shad and sea lamprey in a modified Ice Harbor fishway. North American Journal of Fisheries Management. 17:981-987.
General type: *Passage*
Species: *P. marinus, Alosa sapidissima*
Keywords: *sea lamprey, American Shad, weirs, diurnal movements*
Abstract: *Video evaluation reveals movement and behavior of American Shad and sea lamprey within a modified fishway. Shad primarily migrate through the fishway exclusively using surface weirs, wheras lamprey used both surface weirs and submerged orifices. High water velocity, air entrainment, and trubulence appeared to inhibit passage by disrupting upstream migratory motivation and visual and rheotactic orientation.*
Notes:

Hubbs, C.L. 1967. Occurrence of the Pacific lamprey, Entosphenus tridentatus, off Baja California and in streams of Southern California; with remarks on its nomenclature. San Diego Society of Natural History. XX:303-311.
General type: *Life History*
Species: *L. (Entosphenus) tridenatus*
Keywords: *taxonomy, distribution*
Abstract: *This reference describes a collection off the Baja coast which the author indicates as a southern range extension. The author suggests the need for a racial analysis for Pacific Lamprey and the justification for designating a northern and southern sub-species.*
Notes:

Jackson, A.D., P.D. Kissner, D.R. Hatch, B.L. Parker, M.S. Fitzpatrick, D.A. Close, and H. Li. 1998. Pacific Lamprey research and restoration. Annual Report 1996 to the Bonneville Power Administration, Project Number 94-026, Portland, Oregon.
General type: *Life History, Research and Monitoring*
Species: *L. tridentata*

Keywords: *Pacific Lamprey, abundance, freshwater distribution*
Abstract: *This annual report provides data on 1) past and present abundance/distribution of Pacific Lamprey in areas of NE Oregon and SE Washington subbasins of Columbia River, 2) monitoring efforts and abundance records of adult passage on mainstem Columbia and Snake, and 3) stress level comparisons for tagged vs. untagged fish. Methods include oral histrories and records for historical distributions, and videotaped records for mainstem passage at Bonneville Dam. Lamprey implanted with 3g transmitters show similar glucose levels (indicator of stress levels) to the untagged control group.*
Notes:

Jacobson, L.D. 1986. Temporal variation in allelic frequencies of sea lamprey ammocetes. Copeia. 1:202-207.
General type: *Genetics*
Species: *Petromyzon marinus*
Keywords*:* *sea lamprey, ammocoetes*
Abstract*:* *The author provides allelic frequency data from sea lamprey ammocoetes within the same spawning drainage to investigate temporal variation problems in identifying/classifying populations. Results indicate no significant differences from Hardy-Weinberg equilibrium values between five sites, and suggest that allelic frequencies in this drainage, when taken as a whole, are constant over time.*
Notes:

Jacobson, L.D., R.L. Torblaa, and R.H. Morman. 1984. Problems with samples of sea lamprey (Petromyzon marinus) ammocoetes used in stock identification studies. Can. J. Fish. Aquat. Sci. 41:1421-1427.
General type: *Genetics*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, ammocoetes, electrophoresis*
Abstract: *Electrophoretic evidence of ammocoetes from three Great Lake drainage basins frequently failed to conform to Hardy-Weinberg equilibrium values. Allelic frequency variation was larger among samples from the same drainage than variation among drainages. The authors argue that effective size of spawning groups contributing to progeny is often small and thus, ammocoete samples are undesirable for stock identification use.*
Notes:

Johnston, P.G., Potter, I.C., and Robinson, E.S. 1987. Electrophoretic analysis of populations of the southern hemisphere lampreys Geotria australis and Mordacia mordax. Genetica. 74:113-117.
General type: *Genetics*

Species: *G. australis, M. mordax*
Keywords: *ammocoetes, electrophoresis*
Abstract: *Electrophoretic data is provided for the first time of S. hemisphere lamprey. Of the six populations analysed, the four G. australis populations exhibit average heterozygosity to that of the work recorded on L. planeri in the British Isles (Ward et al. 1980). However, the two populations of M. mordax, which have a much more restricted distribution, exhibit a much lower level of heterozygosity.*
Notes:

Kan, T.T. 1975. Systematics, variation, distribution, and biology of lampreys of the genus Lampetra in Oregon. Doctoral Dissertation, Oregon State University, Corvallis, Oregon. 194 p.
General type: *Life History*
Species: *Lampetra spp.*
Keywords: *sea lamprey, river lamprey, brook lamprey, taxonomy, biogeography, evolution*
Abstract: *The author provides extensive information on the morphology contributing to taxonomic divisions within the genus. Also included are life history and distribution data for ammocoetes and adults; in both marine and freshwater habitats. The goes on to discuss evolutionary events and rates of speciaion concerning the historical presence of lamprey in Oregon.*
Notes:

Krueger, C.C. 1980. Detection of variability at isozyme loci in sea lamprey, Petromyzon marinus. Can. J. Fish. Aquat. Sci. 37:1630-1634.
General type: *Genetics*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, isozyme, electrophoresis, population structure, polymorphism*
Abstract: *The author uses electrophoretic methods to provide evidence of significant genetic differences between lamprey from multiple sites in Great Lakes region, suiggesting that gel resolution can be satisfactory for population studies. Results also indicate no enzyme expression differences between life stage or collection method (fresh frozen or TFM killed).*
Notes:

Krueger, C.C., and G.R. Spangler. 1981. Genetic identification of sea lamprey (Petromyzon marinus) populations from the Lake Superior basin. Can. J. Fish. Aquat. Sci. 38:1832-1837.
General type: *Genetics*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, population identification, electrophoresis*

Abstract: *This study provides electrophoretic data from 18 locations withing Lake Superior. A weak but significant correlation was detected between genetic and geographic distances. The authors conclude that multiple distinct populations exist within the lake, and provide discussion for management implications.*
Notes:

Lee, W.-J., and T.D. Kocher. 1995. Complete Sequence of a Sea Lamprey (Petromyzon marinus) mitochondrial genome: early establishment of the vertebrate genome organization. Genetics. 139:873-887.
General type: *Genetics*
Species: *Petromyzon marinus*
Keywords: *phylogeny, vertebrates, evolution*
Abstract: *The authors report the completion of the nucleotide sequence for a sea lamprey mitochondrial genome. The genome length is 16,201 bp and contains genes for 13 proteins, two rRNA's, 22 tRNA's and two major non-coding regions. The results suggest that a common mitochondrial gene organization of vertebrates was established early in vertebrate evolution.*
Notes:

Lewis, S.V. 1980. Respiration of lampreys. Can. J. Fish. Aquat. Sci. 37:1711-722.
General type: *Life History, Physiology*
Species: *E. tridentatus, L. fluviatilis, L. planeri, P. marinus*
Keywords: *lampreys, gills, morphology, oxygen consumption, ventilation rates, sexual maturity*
Abstract: *The author provides a review of lamprey branchial/gill structure, and the unique aspects of respiration. Although gross morphology and method of ventilation is radically different from that found in gnathastomes, the ultrastructure of the gills and the thickness of the water-blood barrier are similar to active teleosts. Data of oxygen consumption, ventilation and heart rates are given for all stages of development and activity, including swimming and post-spawning.*
Notes:

Long, C.W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. Fishery Bulletin 66:599-609.
General type: *Passage*
Species: *L. tridentata, Oncorhynchus sp.*
Keywords: *Pacific Lamprey, salmonids, hydroelectric dams, passage barriers, ammocoetes, diel migration*
Abstract: *This report focusses on salmonid fingerling abundance in relation to turbine intakes at The Dalles and McNary Dams. Lamprey ammocoete data is also included from The Dalles. Results indicate that*

while salmonids typically are found near the ceilings of the intakes, ammocoetes are concentrated near the center and bottom. The authors suggest that deflection and bypass techniques could be feasible and possibly successful at reducing (fingerling) mortality if placed near the intake ceilings.
Notes:

Mallatt, J. 1983. Laboratory growth of larval lampreys (Lampetra (Entosphenus) tridentata Richardson) at different food concentrations and animal densities. J. Fish Biol. 22:293-301.
General type: *Production, Rearing*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, ammocoetes, culturing, nutrition*
Abstract: *This study explores important parameters for culturing ammocoete lamprey, including; food concentration, temperature, and density effects. Both suspended yeast cells and Liquifry® were used as food sources under different density and temperature regimes. Growth rates differences were reported.*
Notes:

Michael, J.H. 1983. Additional notes on the repeat spawning by Pacific Lamprey. California Fish and Game. vol. X:186-188.
General type: *Life History*
Species: *L. tridentatus*
Keywords: *pacific lamprey, spawning, kelts*
Abstract: *This report is the authors reply to questions and concerns raised after his 1980 publication on the evidence that Lampetra tridentatus may be capable of repeat spawning.*
Notes: *see Michael, J.H., 1980. Calif. Fish Game, 66(3):186-187.*

Moore, J.W., and J.M. Mallatt. 1980. Feeding of larval lamprey. Can J. Fish. Aquat. Sci. 37:1658-1664.
General type: *Life History*
Species: *L. planeri, P. marinus*
Keywords: *European brook lamprey, ammocoetes, assimilation efficiency, bacteria, detritus, mucous complex*
Abstract: *The authors present a review and data on the feeding mechanism of larval lampreys involving mucous production, transport, and entrapment. Three factors of selective feeding are identified: 1) susceptibility to capture in the feeding-respiratory flow differs among particles, 2) filtration of long filaments by the cirri, and 3) selective agglutination at the mucous filter. Additional data is provided on size distribution of ingested particles, factors effecting feeding rates, and digestion efficiencies.*
Notes:

Morman, R.H., D.W. Cuddy, and P.C. Rugen. 1980 Factors influencing the distribution of sea lamprey (petromyzon marinus) in the Great Lakes. Can. J. Fish. Aquat. Sci. 37:1811-1826.

General type: *Life History, Ecology*

Species: *P. marinus*

Keywords: *sea lamprey, Great Lakes, distribution, parasitic, movement, ammocoetes*

Abstract: *This review explores the factors, primarily environmental and host food source dependent, which have concentrated the distribution of sea lamprey to 433 (7.5%) of the Great Lakes watersheds 5747 streams. Results indicate that stream temperature is the most important factor effecting embryo survival, and that barriers, warm water and stream flow govern larval distribution. Interconnecting waterways and attachment to fishes and boats are thought to be major factors in lake movements of parasitic phase adults.*

Notes:

Morris, K.H. 1989. A multivariate morphometric and meristic description of a population of freshwater-feeding river lampreys, Lampetra fluviatilis (L.), from Loch Lomond, Scotland. Zoological Journal of the Linnean Society. 96:357-371.

General type: *Taxonomy*

Species: *L. fluviatilis*

Keywords: *river lamprey, non-anadromous, multivariate, morphometric*

Abstract: *Genetic isolation and short feeding time are used to explain the morphometric distinction between the freshwater feeding L. fluviatilis (L.) and the larger anadromous L. fluviatilis. The author suggests that the 'dwarf' L. fluviatilis may represent the intermediate stage between the parasitic and non-parasitic forms in the L. fluviatilis/L. planeri species pair.*

Notes:

Potter, I.C. 1980. Ecology of larval and metamorphosing lampreys. Can. J. Fish. Aquat. Sci. 37:1641- 1657

General type: *Life History, Ecology*

Species: *general lamprey literature; P. marinus, L. fluviatalis, L tridentata, etc.*

Keywords: *ammocoete, habitat, growth, mortality, larvicide, metamorphosis, migration*

Abstract: *A general review of lamprey larval life history. Though primarily sedentary, movement is related to discharge, temperature, and season; and occurs predominantly downstream and at night. At the end of larval life, ammocoetes cease rapid growth rates and begin to accumulate*

lipids. Metamorphosis usually begins in summer. The time between initiation of transformation and onset of feeding is generally 4-10 months.
Notes:

Potter, I.C., B.J. Hill, and S. Gentleman. 1970. Survival and behaviour of ammocoetes at low oxygen tensions. J. Exp. Biol. 53:59-73.
General type: *Physiology*
Species: *P. marinus*
Keywords: *sea lamprey, ammocoetes*
Abstract:
Notes:

Read, L.J. 1968. A study of ammonia and urea production and excretion in the fresh- water-adapted form of the Pacific Lamprey, Entosphenus Tridentatus. Comp. Biochem. Physiol. 26:455-466..
General type: *Life History, Physiology*
Species: *L. (Entosphenus) tridentatus*
Keywords: *Pacific Lamprey, surplus nitrogen, enzymes, excretion*
Abstract: *The author provides results and discussion of enzyme activity in the liver, primary excretion of ammonia via the gills, and the resemblance of surplus nitrogen management in Entosphenus to fresh-water teleosts. Additionally, the results are related to adaptive and evolutionary implications.*
Notes:

Renaud, C.B. 1997. Conservation status of Northern Hemisphere lampreys (Petromyzontidae). J. Appl. Ichthyol. 13:143-148.
General type: *Status Report*
Species: *all Petromyzontidae*
Keywords: *Petromyzontidae, distribution, endangered species, economic/social value*
Abstract: *The author provides a review, based on distributions and conservation status, of the 34 known lamprey species in North America.. Four conservation priorities are recommended; including the need to protect permanent freshwater resident populations of anadramous species such as Entosphenous tridentatus.*
Notes:

Richards, J.E. 1980. The freshwater biology of the anadromous Pacific Lamprey (Lampetra tridentata). MSc. Thesis. University of Guelph, Canada. 99pp.
General type: *Life History*
Species: *Lampetra tridentata*
Keywords: *Pacific Lamprey, identification, metamorphosis, migration, feeding*

Abstract: *The author studied larval development, metamorphosis, habitat requirements and upstream migration in the Chemainus River of British Columbia. Valuable data includes ammocoete distribution and size composition; evidence of a size distribution gradient from river mouth (older) to upper watershed (0 year class). The author estimates larval life duration in this system to be 5-6 years. Also included is a quick method of distingushing between L. tridentata and the non-parasitic brook lamprey (L. richardsonii) based on pigmentation patterns in the caudal region.*
Notes:

Richards, J.E., and F.W.H. Beamish. 1981. Initiation of feeding and salinity tolerance in the Pacific Lamprey, Lampetra tridentata. Marine Biology. 63:73-77.
General type: *Life History (Marine)*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, metamorphosis, parasitic feeding, development*
Abstract: *The authors provide results indicating stages of development at which tolerance to salinity and ability to feed increase. Although metamorphosis phase 5 lamprey can tolerate no greater than 13.4 ppt, phase 6 survived direct transfer to sea water (30 ppt). Phase 7 of metamorphosis exhibits completion of tooth development and beginning of parasitic feeding.*
Notes:

Richards, J.E., R.J. Beamish, and F.W.H. Beamish. 1982 Descriptions and keys for ammocoetes of lampreys from British Columbia, Canada. Can. J. Fish. Aquat. Sci. 39:1484-1495.
General type: *Life History, Identification*
Species: *L. tridentata, L. richardsoni, L. ayresi, L. macrostoma*
Keywords: *ammocoetes, taxonomy*
Abstract: *The authors provide new data to compliment and update previously published diagnostics for taxonomy of four types of larval lampreys found in streams of British Columbia. Diagnostics were verified through rearing ammocoetes through metamorphosis to identifiable adults.*
Notes: *Very useful*

Roffe, T.J., and B.R. Mate. 1984. Abundances and feeding habits of pinnipeds in the Rogue River, Oregon. J. Wildl. Management. 48(4). 1262-1274.
General type: *Ecology, Predation*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, Sea Lions, Harbor Seals, mortality, gut contents*

Abstract: *Observations of pinniped feeding during seaward migration of steelhead and upriver migrating spring chinook suggest that pinnipeds do not constitute a major threat to Rogue River salmonid stocks. Based on methods of surface observations, scat collection, and gastrointestinal tract examinations, the most heavily preyed upon species appeared to be Pacific Lamprey.*
Notes: *Do low lamprey population levels result in increased predation on pinniped secondary prey, salmonids? OR, do pinnipeds feed on whatever is most abundant? No lamprey abundance data relative to salmon abundance is provided.*

Roos, J.F., P. Gilhousen, S.R. Killick, and E.R. Zyblut. 1973. Parasitism on juvenile Pacific salmon (Oncorhynchus) and Pacific herring (Clupea harengus pallasi) in the Strait of Georgia by the river lamprey (Lampetra ayresi). J. Fish. Res. Board Can. 30:565-568.
General type: *Life History, Ecology*
Species: *L. ayresi*
Keywords: *River Lamprey, feeding strategy*
Abstract: *This paper explores the extent of L. ayresi parasitism on teleost fish in the Strait of Georgia, particularly juvenile salmon. L. ayresi appear attach dorsally which contrasts the ventral attachment by other lamprey species which parasitize salmonids. About 1.9% of the young salmon sampled showed evidence of lamprey markings, most of which are in a narrow range of fork length size.*
Notes:

Russell, J.E., F.W.H. Beamish, and R.J. Beamish. 1987. Lentic spawning by the Pacific Lamprey, Lampetra tridentata. Can. J. Fish. Aquat. Sci 44:476-478.
General type: *Life History, Habitat*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, spawning habitat, lentic vs. lotic, unidirectional flow*
Abstract: *Pacific Lamprey typically construct nests and reproduce in lotic environments characterized by unidirectional flow. Field observations from the Babine Lake system, British Columbia, revealed spawning in shallow lentic waters. Although the nests were subject to wave action, there was no obvious unidirectional flow.*
Notes: *Lentic spawning by lampreys has also been reported for L. macrostoma and the now extinct L. minima, both freshwater parasitic life history types. L. macrostoma and L. minima are believed to be recent derivitives of L. tridentata.*

Sea Lamprey International Symposium (SLIS). 1980. Northern Michigan University, Marquette, Michigan. July 30-August 8, 1979. Canadian Journal of Fisheries and Aquatic Sciences. vol. 37.
General type: *General, Life History, Genetics, Management*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, Great Lakes, physiology, management*
Abstract: *The proceedings of research presented at the symposium*
Notes: *A particularly good source for general physiology information on lamprey.*

Starke, G.M., and J.T. Dalen. 1995. Pacific lamprey (Lampetra tridentata) passage patterns past Bonneville Dam and incidental observations of lamprey at the Portland district Columbia River Dams in 1993. U.S. Army Corps of Engineers. CENPP-OP-PF. Bonneville Lock and Dam, Cascade Locks, Oregon.
General type: *Passage*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, passage behavior, dam barriers, ladder construction*
Abstract: This report evaluates; 1) historic lamprey passage, 2) current estimation of lamprey passage, 3) video evaluation of nighttime passage 4) sources of mortality during passage/problems with dewatering fishways and 5)seasonal/diel patterns of passage.
In addition to these data and general life history discussions, the authors provide recommendations for adjusting structures and maintenance procedures to reduce mortality of lamprey in the fishway passage system.
Notes:

Slatick, E. and L.R. Basham. 1985. The effect of denil fishway length on passage of some nonsalmonid fishes. Marine Fisheries Review. 47(1):83-85.
General type: *Passage*
Species: *L. tridentata, other non-salmonids*
Keywords: *Pacific Lamprey, migration, fishway construction*
Abstract: *Observations at varied length/slope denil-type steep-pass fishways at Bonneville and McNary Dams suggest that while salmonids and Pacific Lamprey are able to pass the extended (20.1 m.) fishway; all other non-salmonids (ie. shad and resident freshwater fish) were not observed ascending the Denil. The authors suggest that varying fishway length could be an effective management tool for denying upstream access to certain unwanted salmonids.*
Notes:

Stock, D.W., and G.S. Whitt. 1992. Evolutionary implications of the cDNA sequence of the single lactate dehydrogenase of a lamprey. Proc. Natl. Acad. Sci. 89:1799-1803.

General type: *Genetics*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, PCR, parsimony, molecular phylogeny*
Abstract: *The study uses both distance and maximum parsimony, and evolutionary parsimony analyses to examine the relationship of the single LDH of lampreys to other vertebrate LDHs and comparisons to previously published sequences from bacteria, plants and vertebrates. While maximum parsimony analyses strongly rejects a relationship of lamprey LDH with mammalian LDH-C, evolutionary parsimony analyses suggest that lamprey LDH is related to Ldh-A.*
Notes:

Stock, D.W., and G.S. Whitt. 1992. Evidence from 18S ribosomal RNA sequences that lampreys and hagfishes form a natural group. Science. 257:787-789.
General type: *Genetics, Evolution*
Species: *Petromyzon marinus, Lampetra aepyptera*
Keywords: *Cyclostomata, gnathastomes, mononphyletic, parsimony analysis, phylogeny*
Abstract: *Recent morphological evidence had led to the conclusion that lamprey are more closely related to jawed vertebrates than hagfish. 18S ribosomal RNA sequence data reported herein support the more traditional view that lamprey and hagfish form a natural (monophyletic) group.*
Notes:

Teeter, J. 1980. Pheromone communication in sea lampreys (Petromyuzon marinus): implications for population management. Can. J. Fish. Aquat. Sci. 37:2123-2132.
General type: *Life History, Behavior*
Species: *P. marinus*
Keywords: *sea lamprey, pheromones, spawning migration, preference behavior, homing*
Abstract: *Preference tests were performed on landlocked sea lamprey to evaluate; 1) mate attraction and 2) spawning migration. Results suggest that after reaching a specific stage of sexual maturity, pheromone releases attract conspecifics of the opposite sex, and that upstream spawning migrants exhibit preference for waters in which sea lamprey larvae have been held. The authors further discuss the environmental and physiological factors that may influence pheromone communication in sea lamprey.*
Notes:

Vella, J. and L. Steuhrenberg. 1997. Migration patterns of Pacific lamprey (Lampetra tridentata) in the lower Columbia River, 1997. Annual Report

of Research to the U.S. Army Corp of Engineers, Delivery Order E9650021, Portland District, Portland, Oregon.
General type: *Passage*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, passage, behavior, swimming speeds, telemetry*
Abstract: *This report provides preliminary results of radio-tagging/telemetry studies of Pacific Lamprey migrating in the Columbia River. Objectives of the study include; 1) determine run time from release sight to Bonneville Dam, 2) determine passage routes and behavior, and 3) determine migration rates through resevoirs.*
Notes:

Vladykov, V.D. 1973. Lampetra pacifica, A new nonparasitic species of lamprey (Petromyzontidae) from Oregon and California. J. Fish. Res. Board Can. 30:205-213.
General type: *Life History*
Species: *L. pacifica L. richardsoni*
Keywords: *Brook lamprey, non-parasitic*
Abstract: *The author describes a newly catagorized non-parasitic species which has both physiological and geographical differences from its closest relative, L. richardsoni. The description is based on an examination of 233 specimens (190 ammocoetes; 43 transformed).*
Notes:

Vladykov, V.D., and Follett, W.L. 1958. Redescription of Lampetra ayresii (Gunther) of Western North America, a species of lamprey (Petromyzontidae) distinct from Lampetra fluviatilis (Linnaeus) of Europe. J. Fish. Res. Board Can. 15:1 pp. 47-77.
General type: *Taxonomy*
Species: *L. ayresii, L. fluviatilis*
Keywords: *River Lamprey, parasitic*
Abstract: *The authors provide detailed taxonomic guidelines for identifying and verifying the endemic quality of of this species in Western North America. They provide records of the first specimens categorized from Oregon, and evidence for range extension further up the Sacramento River than previously perceived.*
Notes:

Vladykov, V.D., and Kott, E. 1976. A new nonparasitic species of lamprey of the genus Entosphenus Gill, 1862, (Petromyzonidae) from South Central California. Bulletin southern California Academy of Sciences. 75:60-67.
General type: *Taxonomy, Life History*
Species: *Entosphenus hubbsi (argument for new species)*
Keywords: *Entosphenus, Lampetra, ammocoetes*

Abstract: The authors argue for the distinction of Entosphenus as a seperate genus unto its own from Lampetra. Five phenotypic observations are used to justify the distinction.
Notes:

Volk, E.C. 1986. Use of Calcareous otic elements (Statoliths) to determine age of sea lamprey ammocoetes (Petromyzon marinus). Can. J. Fish. Aquat. Sci. 43:718-722.
General type: *Production, Identification*
Species: *P. marinus*
Keywords: *sea lamprey, age estimation, ammocoetes, nonteleosts, lenght-frequency analysis*
Abstract: *The author provides the first exploration of using calcareous otic elements to determine age in nonteleost fishes. The correspondence between statolith band number and known age was very close in the first 4 yr. but less rigorous for the few 7 year-olds examined. This method will provuide greater reliability than length frequency analysis for lamprey age determination.*
Notes:

Wallace, R.L. 1978. Landlocked parasitic pacific lamprey in Dworshak Reservoir, Idaho. Copeia. 3:545-546.
General type: *Passage, Life History*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, anadromous, passage barriers*
Abstract: *This report provides evidence suggesting that dam construction resulted in this landlocked anadromous parasitic populations inability to establish a reproducing population within the resevoir. They provide evidence of rapid decline in parasitism on fish, unsuccessful attachment evidence, and lack of sightings.*
Notes:

Ward, R.D., McAndrew, B.J., and Wallis, G.P. 1981. Enzyme variation in the brook lamprey, Lampetra planeri (Bloch), a member of the vertebrate group Agnatha. Genetica. 55:66-73.
General type: *Genetics*
Species: *L. planeri*
Keywords: *brook lamprey, electrophoresis, heterozygosity*
Abstract: *Values of mean heterozygosity for this brook lamprey of the British Isles represent values similar to those recorded for other vertebrates. Although polyploidy has been invoked to explain high chromosome numbers for this and related species, results herein report that enzymes encoded by duplicate loci in other vertebrates are encoded by single loci in the lamprey.*
Notes:

Whyte, J.N.C., R.J. Beamish, N.G. Ginther, and C.-E. Neville. 1993. Nutritional condition of the Pacific lamprey (Lampetra tridentata) deprived of food for periods of up to two years. Can. J. Fish. Aquat. Sci. 50:591-599.
General type: *Life History*
Species: *L. tridentata*
Keywords: *pacific lamprey, feeding, physiology, nutrition, energy reserves*
Abstract: *This study compares the utilization of body reserves in adult lampre starved for 2 years, recently metamorphosed lamprey, and lampreys starved for 6 months. Endogenous reserve supply allows lamprey to make long spawning migrations from the ocean to the headwaters.*
Notes:

Wolf, B.O., and S.L. Jones. 1989. Great Blue Heron Deaths caused by predation on Pacific Lamprey. The Condor. 91:482-484.
General type: *Ecology*
Species: *L. tridentata*
Keywords: *Pacific Lamprey, Great Blue Heron, prey induced mortality*
Abstract: *This report documents two cases of apparent prey induced mortality of the Great Blue Heron due to its unsuccessful attempt to feed on Pacific Lamprey. Herons are known to be diverse feeders, capable of feeding on fish too large for other heron species. Investigation suggests that the herons died due to suffocation after the lamprey became lodged in the esophogus.*
Notes:

Wright, J., C.C. Krueger, P.F. Brussard, and M.C. Hall. 1985. Sea lamprey (Petromyzon marinus) populations in northeastern North America: genetic differentiation and affinities. Can. J. Fish. Aquat. Sci. 42:776-784.
General type: *Genetics, stock structure*
Species: *Petromyzon marinus*
Keywords: *sea lamprey, genetic variation, population structure, electrophoresis*
Abstract: *The authors used gel electrophoresis analyses to detect genetic variability between populations from different lakes in the Great Lake region and throughout Northeastern North America. Allozyme frequencies indicate greater genetic divergence between populations than within populations and suggest limited movement between lakes, despite canals, and an apparent reproductive isolation between L. Erie and L. Ontario.*
Notes:

Youson, J.H., and Beamish, R.J. 1991. Comparison of athe internal morphology of adults of a population of lampreys that contains a nonparasitic life-history type, Lampetra richardsoni, and a potentially parasitic form, L. richardsoni var. marifuga. Can. J. Zool. 69:628-637.

General type: *Life-History,*

Species: *L. richardsoni, L. richardsoni var. marifuga*

Keywords: *Brook lamprey, trophic interaction, taxonomy, histology, evolution*

Abstract: *Results from this study provide histological support for the view that one population in Morrison Creek, British Columbia produces two life-history varieties. Internal morphological differences imply a retarded sexual maturation in the parasitic variety which may permit the retention of a functional digestive system. The authors discuss to-date views on lamprey evolution.*

Notes: