TRANSLOCATING ADULT PACIFIC LAMPREY WITHIN THE COLUMBIA RIVER BASIN: STATE OF THE SCIENCE

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INTRODUCTION

Lampreys, jawless fishes of the family Petromyzontidae, are among the oldest existing vertebrates, having changed little since emerging about 530 million years ago (Dawkins 2004). The Pacific lamprey *Entosphenus tridentatus* (formerly *Lampetra tridentata*) is an anadromous species native to the north Pacific Rim (Scott and Crossman 1973) including the Columbia River Basin (Figure 1). Pacific lamprey are an important food source for marine mammal, avian, and fish predators, and may act as a predation buffer for Pacific salmon *Oncorhynchus* spp. juveniles. Moreover, they are a source of marine-derived nutrients in the upper tributaries of the Columbia and Snake rivers (Close et al. 1995). Pacific lamprey may also be a key indicator of ecological health of the Columbia River Basin. Importantly, Pacific lamprey serve a role in the culture of many Native American tribes (Close et al. 2002).

Despite their persistence through time, many lamprey populations are now believed to be declining throughout much of their distribution (e.g., see Renaud 1997). In recent decades, Pacific lamprey along the west coast of North America have experienced population declines and regional extirpations (Beamish and Northcote 1989; Kostow 2002; Moser and Close 2003). These declines parallel those of Pacific salmonids, perhaps because the two groups share widely sympatric distributions (Scott and Crossman 1973; Simpson and Wallace 1978; Moyle 2002) and similar anadromous life histories (McDowall 2001; Quinn and Myers 2004). Causes for the decline in the Columbia River Basin may include construction and operation of dams for hydropower, flood control, and irrigation, habitat degradation, poor water quality, proliferation of exotic species, and direct eradication actions.

Numerous management and research actions have been recommended to help restore Pacific lamprey in the Columbia River Basin (Nez Perce, Umatilla, Yakama, and Warm Springs Tribes 2008; Columbia Basin Fish and Wildlife Authority 2008). These actions include improving adult and juvenile passage at known and suspected obstacles, restoring degraded habitat and water quality, and implementing reintroduction methods.

Translocation of adult Pacific lamprey is a tool for reintroduction, augmentation, and as an interim measure while primary limiting factors (e.g., mainstem passage) are addressed in the longer term. In the context of this review, translocation involves collecting adult Pacific lamprey from one location (e.g., the mainstem lower Columbia River), and transporting them for release into a subbasin upstream where Pacific lamprey are severely depressed or extirpated. The resulting increase in spawning adults is intended to increase the number of larval lamprey present, which may in turn attract even more adult lamprey (if adults are attracted to pheromones produced by juveniles as described in the "Migration Behavior" section of this paper).

Our objective is to provide a thorough review of translocation programs in the Columbia River Basin to date. Summaries of the importance of Pacific lamprey to Native American tribes, important life history features, status and trends of Pacific lamprey in the Columbia River Basin, migration behavior, and factors for decline provide context for the use of translocation as a tool for reintroducing or augmenting lamprey populations. After reviewing existing translocation programs, we discuss the potential benefits and risks associated with translocation. This is a review paper and is not meant to support or refute any position regarding the use of translocation.

CULTURAL CONTEXT

Pacific lamprey are of great importance to Native American tribes for cultural, spiritual, ceremonial, medicinal, subsistence and ecological values (Close et al. 1995; 2002). The importance of the species is described through oral history, and tribal ordinances, codes and resolutions. Indigenous peoples from the coast to the interior Columbia and Snake rivers harvested lamprey for many generations (Close et al. 1995). Today these peoples have dwindling opportunities to harvest lamprey, with opportunities restricted to the lower portions of the Columbia River Basin (Close et al. 2002).

Historically, tribal people harvested adult lamprey in the mainstem Columbia and Snake rivers as well as in tributaries. Harvest occurred throughout the distribution of Pacific lamprey in the Columbia River Basin (Figure 1). Important areas used by multiple tribes prior to the treaties of 1855 included Celilo Falls on the mainstem Columbia River and Willamette Falls on the Willamette River (Figure 1). Interior Columbia River tribes typically harvested enough lamprey at these falls to feed families for an entire year. The lamprey, commonly referred to as “eels” by tribal members, were collected at night in areas where they accumulated at the falls, and were used for subsistence and trading for other food and clothing. With construction of The Dalles Dam in 1957, Celilo Falls was inundated and this culturally significant collection site was lost, forcing tribal members to harvest lamprey at other locations. In recent years, demand for lamprey from Willamette Falls has increased due to declines in lamprey abundance at other traditional harvest locations.

Individual tribes of the Columbia River Basin historically harvested lamprey at many locations within their reservations, and on ceded, aboriginal, and usual or accustomed sites. Historic stream morphology is the best indicator of where "eels" were harvested. Harvest usually occurred in rapids, crevices, and falls of rivers and streams. Harvest currently occurs only in areas not lost to anthropogenic activities or where lamprey populations can support harvest. Historical harvest methods are still in use such as scaffolds, dip nets, gaff hooks, and grabbing with hands.

In the 1970s, tribal members began noticing declines in the numbers of Pacific lamprey migrating into the interior Columbia River Basin. Tribal members identified probable causes for declines in lamprey as degraded habitat conditions, fish poisoning operations, and dams (Close et al. 2004).

From a tribal perspective, the decline of lamprey continues to have at least three negative effects: (1) loss of cultural heritage, (2) loss of fishing opportunities in traditional fishing areas, and (3) necessity to travel great distances to lower Columbia River tributaries, such as the Willamette River, for ever-decreasing lamprey harvest opportunities. As a consequence of restriction or elimination of harvest in interior Columbia River tributaries, many young tribal members have not learned how to harvest and prepare lamprey for drying. In addition, young tribal members are losing historically important legends associated with lamprey.

When the few opportunities for harvest occur, younger tribal members, with training from adult tribal members, often collect eels for tribal elders. Without lamprey to catch, prepare, and preserve, younger tribal members will lose the opportunity to gain associated technical knowledge and cultural experiences, including important connections with elders. The loss of traditional knowledge surrounding eel myths and stories threatens loss of tribal culture (Close et al. 2002). One tribal elder stated:

The eels was part of the July feast. Because along with the salmon… this is what our older people tell us… that when the time began the foods were created. The foods were here before us…and they said that the foods made a promise on how they would take care of us as Indians and the eels was one of those who made a promise to take care of us (Close and Jackson 2001).

LIFE HISTORY

Lampreys likely emerged about 530 million years ago (Dawkins 2004). Although Pacific lamprey follow a general life-history pattern (Beamish 1980; Figure 2), many details are not well known. Some between and within-basin variation may exist regarding time of spawning, metamorphosis, outmigration, ocean residency, and upstream migration.

After feeding and growing in seawater for as long as 40 months, Pacific lamprey migrate into freshwater to spawn (Beamish 1980). In the Columbia River Basin the peak of spawning migration occurs in summer (June-August) and most fish pass Bonneville Dam after water temperatures exceed 15°C (Keefer et al. 2009a). Adult Pacific lamprey may spend a winter prior to spawning becoming sexually mature in areas such as deep river pools with cover (Beamish 1980; Robinson and Bayer 2005). Recent evidence suggests that warm summer temperatures (>

20 ^{o}C) are associated with sexual maturation the following spring, whereas cooler temperatures (~13-14 ^{o}C) are associated with immaturity in adult Pacific lamprey (Clemens et al. 2009).

After over-wintering, adult lamprey have been observed spawning between March and July when the water temperature is between 10 and 15^{o}C (Beamish 1980; Beamish and Levings 1991; Close et al. 2003; Brumo 2006). Males and females cooperate to build redds (Pletcher 1963). Absolute fecundity varies between 98,300 and 238,400 eggs per female (Kan 1975). Adult lamprey die within 3-36 days after spawning (U.S. Fish and Wildlife Service 2006).

Age of Pacific lamprey at time of spawning is difficult to estimate due to their complex and variable life history, difficulties in aging ammocoetes, lack of direct information on ocean residency time, plasticity of maturation timing in relation to freshwater temperatures (Clemens et al. 2009), and migration rates. Field observations of ammocoetes and macrophthalmia suggest that freshwater age and timing of metamorphosis is diverse (McGree et al. 2008) and may vary regionally, perhaps associated with factors like water temperature and migration distance (Kostow 2002). For these reasons it is difficult to track individual year-classes throughout their life cycle, and thus modeling population dynamics is problematic. Although methods to age adult Pacific lamprey are still being explored (statoliths and length-frequency distributions have been used for sea lamprey *Petromyzon marinus*), life history characteristics indicate that some adult river migrants may be as old as eleven years (Beamish 1980).

Depending on water temperature, eggs hatch after ~15 days and ammocoetes spend another 15 days in redd gravels until they emerge and drift downstream to suitable rearing habitats (Pletcher

1963; Brumo 2006). Dispersion from redds to suitable burrowing habitat is dependent upon flow and stream gradient (Potter 1980). Ammocoetes move downstream during high flow and scouring events, generally observed during the spring and winter (Graham and Brun 2006).

In general, ammocoete habitat occurs in low velocity, low gradient areas containing soft substrate and organic materials (Pirtle et al. 2003; Graham and Brun 2006). Ammocoetes will remain burrowed in soft substrates for up to 7 years (Close et al. 1995). Although blind, and sedentary while burrowed, evidence suggests that ammocoetes from a given cohort can colonize the stream network from where they emerge down to the lower Columbia River (Jolley et al. 2010). They filter feed on diatoms and other organic material suspended in the water column (Moore and Mallatt 1980). For filter feeding, ammocoetes produce mucus from the pharynx that entraps food particles that flow over rearing beds (Moore and Mallatt 1980).

Lamprey ammocoetes experience a true metamorphosis where they undergo morphological and physiological changes to prepare for ocean life and the predatory phase of their life history (Richards 1980; Richards and Beamish 1981; McGree et al. 2008). Ammocoetes develop eyes, an oval mouth, functional teeth, and a tongue, and the size of their oral disc increases, as in sea lamprey (Youson and Potter 1979). Internal changes include foregut development for osmoregulation (Richards 1980; Richards and Beamish 1981), blood protein changes (Richards 1980), disappearance of the bile duct and gallbladder (Bond 1979), and development of a unidirectional respiratory system (Lewis 1980). Metamorphosis generally occurs between July and November (Hammong 1979; Richards and Beamish 1981; McGree et al. 2008). Once metamorphosis is complete, ammocoetes are considered macrophthalmia or juvenile lamprey.

Before outmigration, macrophthalmia appear to change their habitat preference to larger cobble-sized substrate and faster water (Beamish 1980).

Macrophthalmia migrate to the Pacific Ocean between fall and spring, coincident with periods of high river discharge (Richards and Beamish 1981; Beamish and Levings 1991; van de Wetering 1998; Graham and Brun 2006; Bleich and Moursund 2006). Pacific lamprey are thought to remain in the ocean, feeding parasitically on a variety of fish, for approximately 18–40 months before returning to freshwater as immature adults (Kan 1975; Beamish 1980). Pacific lamprey use olfactory perception, vision, and electroreception to choose their prey (Close et al. 1995). Feeding occurs when an adult lamprey attaches itself onto prey using its oral disc, rasps through prey tissue, injects anticoagulant, and feeds upon blood and fluids. Beamish (1980) found that walleye pollock *Theragra chalcrogramma* and Pacific hake *Merluccius productus* were the major prey of Pacific lamprey. However, Pacific lamprey have also been observed feeding on a wide variety of fish species and marine mammals (Scott and Crossman 1973).

STATUS AND TRENDS

Distribution

Pacific lamprey were widely distributed in the Columbia River Basin according to historic collection records (Lee et al. 1980; Kostow 2002; Oregon State University, cited in Kostow 2002; University of Washington fish collection records; University of British Columbia fish collection records). The largest concentration of observations has occurred in the lower Columbia Basin, including the Willamette River (Kostow 2002). Historic observations of adults also occurred upriver into Columbia River head waters in Canada, including Kootenay Lake and the Okanogan Subbasin, and up the Snake River to Shoshone Falls and into the upper Salmon River Subbasin (College of Idaho fish collection records; Figure 1).

Collections and historic observations of Pacific lamprey are common from the Columbia River below the mouth of the Deschutes River, and include numerous small tributaries, the entire Willamette River Subbasin, and numerous areas around the Columbia River estuary. Lamprey likely used all accessible watersheds in the Lower Columbia, including mainstem and slough habitats. A comparison of counts at Bonneville Dam to harvest at Willamette Falls during the 1940s indicates that Pacific lamprey were probably more abundant in the Willamette Subbasin at that time than they were anywhere upriver of the Columbia River Gorge (Kostow 2002).

Watersheds upstream of the Columbia River Gorge specifically noted in historic collections and observations include the Deschutes extending into the Crooked River above Pelton/Round Butte Dam, John Day, Umatilla, Walla Walla, Yakima, Entiat, Okanogan and Kootenay Lake. In the Snake River Basin, collections and historic observations have been made in the lower Palouse, Clearwater, Salmon, Grande Ronde, Imnaha, and upstream to at least the Powder River. Historic records are too sparse to determine the full extent of historic occupation of these basins.

The current distribution of Pacific lamprey is severely reduced from the historic pattern and anadromous lamprey have been lost from all areas that are blocked by impassible barriers. These barriers include the Willamette Subbasin dams, and other high-elevation dams such as the Pelton/Round Butte complex (Deschutes), Dworshak (Clearwater), Hells Canyon complex (Snake), and Chief Joseph/Grand Coulee (Columbia). Lesser barriers that may pass salmonids also can block passage by lamprey, including small water diversion dams, culverts, tide gates and other structures.

Abundance

Count data that have been collected intermittently and opportunistically as part of intensive salmonid monitoring programs at Columbia and Snake River dams for several decades (Starke and Dalen 1995; U. S. Army Corps of Engineers 2007) provide one of the few time series of Pacific lamprey abundance. However, count data can only serve as a relative index of adult population size because most adult lamprey pass at night when counting is not conducted, and numerous routes are available for lamprey to pass dams without being detected (Moser and Close 2003; Robinson and Bayer 2005). Nevertheless, counts indicate order-of-magnitude reductions in the number of Pacific lamprey spawners that return to the interior Columbia River Basin (Close et al. 2002). For example, annual counts at Bonneville Dam averaged approximately 110,000 from 1950-69, and peaked at over 350,000, but have exceeded 100,000 only twice in the last decade and have been below 20,000 in most recent years (Figure 3).

Another example of decline of Pacific lamprey in the Columbia River Basin is represented by estimated harvest at Willamette Falls, which may have approached 500,000 animals in a single year during the 1940s (Kostow 2002). The last available estimates from 1990s and early 2000s were a fraction of this number (Figure 4). Declines may be most dramatic for interior populations such as in the upper Snake River, where counts at Lower Granite Dam have ranged from 282 to a low of 12 over the last decade (Fish Passage Center 2010).

The ratio of Pacific lamprey escapement at dams (upstream count divided by downstream count) has been consistently low between Bonneville and The Dalles dams from 2000 through 2009 (mean = 0.29) and between John Day and McNary dams (mean = 0.45), whereas counts at John

Day Dam are relatively high (mean = 0.90) compared to The Dalles Dam (Figure 5). These data may not accurately reflect abundance however, because counts at John Day Dam can be higher than those at The Dalles Dam during some years. From 2006-08, lamprey escapement was estimated at 52-67% (mean 61%) between Bonneville and The Dalles dams and 52-69% (mean 62%) between The Dalles and John Day dams, but only 21-27% (mean 25%) between the John Day and McNary dams (Keefer et al. 2009a; 2009b).

Population Structure

A central unresolved question is whether Pacific lamprey exhibit stock structure resulting from natal homing or some other mechanism. Pacific lamprey may be panmictic, or may have genetically distinct, temporally- or geographically-separated populations. Three recent genetic studies provide results that may lead to different interpretations. Goodman et al. (2008) analyzed mitochondrial DNA from 81 Pacific lamprey along the Pacific Ocean coastline of North America and found that less than 2% of the genetic variation they observed was associated with differences among regions or among drainages within regions sampled. Lin et al. (2008) analyzed polymorphic loci of Pacific lamprey from seven different Northwest rivers including four in the Columbia Basin. While they, like Goodman et al. (2008), found no statistically significant differences between the Columbia and Klamath basins, they did find statistically significant differences among samples within those basins. Lin et al. (2008) concluded that Pacific lamprey showed a geographical divergence pattern across a range of Pacific Northwest samples, but with no clear pattern of geographical structure.

In the most recent study, Docker (2010) used nine newly-developed microsatellite markers to evaluate broad-scale population structure of Pacific lamprey along the west coast of North

America. A total of 965 Pacific lamprey from 21 sites throughout California, Oregon, Washington, and British Columbia were genotyped. Four sites were within the Columbia Basin. Levels of genetic differentiation were low, providing support for lack of natal homing. Docker (2010) concludes that most Pacific lamprey can be managed as one unit, but that future investigations are needed to indicate if this is true for all areas.

Keefer et al. (2009b) found evidence for possible population-based differences in run timing and body size in Columbia Basin adult Pacific lamprey, with Snake River fish migrating earlier and at a larger body size than the run at large. Although there is little evidence for population differentiation, this line of study is in its early stages and more genetic, physiological, and demographic information are needed.

MIGRATION BEHAVIOR

Understanding the cues that Pacific lamprey use to orient and navigate is an important element of planning for lamprey restoration and management. Adult Pacific lamprey are known to participate in migrations over hundreds of kilometers to reach spawning locations. The orientation and navigation cues that Pacific lamprey use during migration are largely unknown, particularly during marine and estuarine phases. However, recent research has provided some insight regarding mechanisms of orientation and run timing during the freshwater phase of migration.

After adult lamprey enter fresh water, temperature is clearly an important factor in regulation of run timing. Using visual count data from the Columbia River hydropower dams, Keefer et al.

(2009a) determined that lamprey migration was earliest in warm, low-discharge years and later in years when water temperature was cooler and discharge was high. This trend was quite stable over the 40 year period of record, with few fish passing Bonneville Dam before temperatures reached 15°C. On average, about half of all lamprey counted at Bonneville Dam passed by the time water temperatures reached 19°C. Relatively few lamprey are counted after the water temperature peaks in summer (21-23°C; Keefer et al. 2009a).

River discharge is closely correlated with temperature and likely plays an important role in both migration timing and fine-scale responses to currents and olfactory cues. Research at large hydropower dams in the Columbia River Basin has indicated that adult lamprey seek areas of relatively high flow when approaching a dam (Moser et al. 2002a; Johnson et al. 2005; Mesa et al. 2009; Moser and Mesa in press). Also, in behavioral assays conducted in the laboratory, migratory lamprey consistently chose flowing water over no flow (Moser et al. unpublished data; Keefer et al. 2010).

River discharge also has important consequences for dispersal of olfactory cues. It is unknown whether, like salmonids, Pacific lamprey use olfactory cues to home to their natal stream. However, recent research has indicated that sea lamprey and Pacific lamprey are both sensitive to olfactory signals from conspecifics. Research using sea lamprey first documented adult lamprey detection and responses to a bile acid pheromone produced by larvae (Vrieze and Sorenson 2001; Sorenson et al. 2003; reviewed in Dittman 2005). Later work indicated that in addition to this “migratory pheromone”, female lamprey are sensitive to a “sex pheromone” produced on the spawning grounds by spermiating males (reviewed in Dittman 2005; Johnson et al. 2005). A number of other lamprey species, including Pacific lamprey, have now been shown to produce these bile acids and/or respond to them (Gaudron and Lucas 2006; Yun et al. 2003; Fine et al. 2004; Robinson et al. 2009; Moser et al. unpublished data).

FACTORS FOR DECLINE

Many factors have likely contributed to the decline of Pacific lamprey in the Columbia River Basin, including impassable barriers that completely block passage to large areas, poor passage efficiency at dams and other barriers designed for passage of salmonids, degradation of remaining habitat, decreased water quality, predation, and harvest. The relative impacts of these factors vary geographically, are difficult to quantify and are difficult to prioritize over broad geographic areas; however, improving passage of both adult and juvenile Pacific lamprey at dams has been considered a high priority (Columbia Basin Fish and Wildlife Authority 2008; Nez Perce, Umatilla, Yakama, and Warm Springs Tribes 2008). Hydroelectric development in the Columbia and Snake rivers is implicated as the predominant source of Pacific lamprey decline in the Columbia River Basin (Jackson et al. 1997). Mortality of downstream-migrating ammocoetes and macrophthalmia, and impediments to upstream adult migration are suspected as the primary hydroelectric factors contributing to Pacific lamprey decline (Clair 2004). Passage of adult lamprey at dams is measurable, and the benefits to lamprey of improving passage may be more easily quantified than efforts to address other limiting factors. Most work to enhance Pacific lamprey to date has focused on evaluating and improving hydrosystem passage but recently other potentially limiting factors such as tributary passage, toxins, predation, and habitat have been considered (ISAB 2009; CRITFC 2010).

Radio-telemetry work from 1997 to 2002 at Bonneville Dam indicated that adult Pacific lamprey passage efficiency (the percentage of lamprey that successfully passed over the dam of those that approached the dam base) was less than 50% in all years (Moser et al. 2002b; Moser et al. 2005; Figure 6). Based on 2000-2002 radio-telemetry research, passage efficiencies at Bonneville, The Dalles, and John Day dams averaged only 47%, 74%, and 53%, respectively.

Studies on downstream passage of larval and juvenile lamprey have been limited. Most juvenile lamprey are believed to swim under the turbine intake screens of bypass systems installed for salmonids at mainstem dams. This would result in the majority of juvenile lamprey passing large hydropower dams through the turbines when they encounter a powerhouse. One study found that juvenile lamprey may be less likely than salmonids to be harmed by changes in pressure and shear conditions (Moursund et al. 2001); however, actual direct or indirect effects of dam passage on juvenile lamprey have not been evaluated. Juveniles that remain higher in the water column are vulnerable to impingement and mortality on surface-mounted turbine intake screens.

Evaluation and mitigation of additional factors limiting Pacific lamprey will be critical to conservation efforts. Although not as well understood as the direct effects of passage impediments, efforts currently focused on salmonids to restore habitats and natural processes should also help lamprey. Some lamprey-specific restoration projects may also be needed. The relative impact of predation on juvenile Pacific lamprey by birds and both native and non-native fish species is another potential limiting factor that is not completely understood. Predation on adult Pacific lamprey by marine mammals may also be substantial. Consequently, an assessment of the potential limiting effect from predation for Pacific lamprey conservation is confounded by their long-standing intrinsic ecological role as a widely sought prey species.

The cumulative impacts of these limiting factors likely led to the widespread decline of Pacific lamprey, and the need for expedited action is clear. Although recent actions have led to passage improvements at specific structures (Moser et al. 2003; 2005; Keefer et al. 2010), a great deal of work still remains throughout the Columbia River Basin, especially in the mainstem. Work also remains to understand and address additional limiting factors.

TRANSLOCATION PROGRAMS

Translocation of adults could potentially be used under a number of differing scenarios in an attempt to reintroduce or augment Pacific lamprey. For example, the removal of barriers such as Powerdale Dam on the Hood River and Condit Dam on the White Salmon River will allow access to habitat once used by Pacific lamprey. If other critical factors such as water quality are not limiting, then increasing access to spawning and rearing habitat in this manner could be important to the restoration of Pacific lamprey. Translocation of adult lamprey to these areas may be necessary to start the restoration process.

A specific objective of the draft Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin (Nez Perce, Umatilla, Yakama, and Warm Springs Tribes 2008) is to "Supplement lamprey by reintroduction and translocation in areas where they are severely depressed or extirpated". To date, translocation programs have been implemented by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and the Nez Perce Tribe (NPT). The Confederated

Tribes of the Yakama Nation is also considering implementation of a pilot adult Pacific lamprey translocation program from mainstem Columbia River hydropower projects into various subbasins, including an evaluation of methodology and potential biological benefits and risks (Confederated Tribes of the Yakama Nation 2008).

Guidelines for Translocation

Guidelines for Pacific lamprey translocation were first drafted by the CTUIR when the Northwest Power and Conservation Council required a Umatilla Lamprey Restoration Plan prior to initiation of translocation actions in the Umatilla Subbasin. These guidelines were also adopted for the Columbia Basin Fish and Wildlife Authority by the Columbia River Basin Lamprey Technical Work Group (1999) as part of a plan for Pacific lamprey projects and needs. This was one of the first collaborative efforts to coordinate work and define future needs for Pacific lamprey in the Columbia River Basin. The guidelines have been further revised and adopted by the Nez Perce, Umatilla, Yakama, and Warm Springs Tribes for inclusion into the Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin (Nez Perce, Umatilla, Yakama, and Warm Springs Tribes 2008). The revised guidelines include:

(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) Implement the following to minimize impacts on donor populations:

  a. Collection of donor lamprey for translocation/artificial propagation should occur at mainstem dam locations which are as near as possible to receiving tributary locations.

b. Maximize the opportunities to collect lamprey at current specific locations within mainstem dams which have reduced likelihood of resulting in successful migration thorough the dams (e.g. behind picketed areas or “pockets” where lamprey migration may be delayed or blocked).

c. Total collection of adult lamprey during the active migration at Columbia River dams by the CRITFC tribes shall not exceed 4% of the two-year running average of the total adjusted count of upriver annual adult lamprey population based on total counts past Bonneville Dam (1% per tribe per year). Should additional adult lamprey be available from dewatering dam passage facilities, these may be in addition to the 4% collection rate.

d. At any project other than Bonneville Dam (because the 4% applies to Bonneville Dam), the total collection of adult lamprey during the active migration at any Columbia River dam by the CRITFC tribes shall not exceed 10% of the two-year running average of the total estimated upriver annual adult lamprey population based on total estimated counts past that dam. Should additional adult lamprey be available from dewatering dam passage facilities, these may be in addition to the 10% collection rate.

e. If Columbia River mainstem lamprey counts continue to decline, tribes implementing translocation may collect at least 100 lamprey each to maintain programs as long as the sum of the annual tribal proposals reviewed by the CRITFC Commission does not exceed the 4% guideline in 4.c. above.

f. If the sum of the annual tribal proposals reviewed by the CRITFC Commission exceeds the 4% guideline 4.e. above (translocation programs cannot receive a 100 lamprey minimum), the CRITFC Commission will convene a discussion to consider use of the Willamette River as a source for lamprey translocation above Bonneville Dam.

g. The CRITFC Lamprey Task Force will review Bonneville Dam counts for an in-season run size update. Collection levels might be adjusted if historic data indicates that the actual returns will significantly more or less than the 2-year average on July

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

(6) Regulatory requirements have been addressed (NEPA, ESA, fish collection permits, Corps FPOM, etc.) - if applicable.

The revised guidelines correspond well with rules for propagation and translocation recently published by the American Fisheries Society (George et al. 2009). These rules include:

(1) Determine that propagation and translocation is necessary - corresponds to (1) and (3) above.

(2) Get approval and advice - corresponds to (5), and (6).

(3) Choose the source wisely - corresponds to (4) and (5).

(4) Propagate naturally and carefully - not relevant to translocation of Pacific lamprey.

(5) Prepare for release – corresponds to (2) and (5).

(6) Evaluate and adapt – corresponds to parts of (4).

(7) The public needs to know – not addressed in current translocation guidelines.

(8) Record it and share it – implicit in all current guidelines.

The current guidelines also correspond well with guidelines established for translocation of living organisms by the International Union for Conservation of Nature (IUCN 1998). The IUCN position statement includes:

(1) A feasibility study - corresponds to guidelines (1) (3), and (4).

(2) A preparation phase - corresponds to (5), and (6).

(3) Release or introduction phase – corresponds to (2) and (5).

(4) Follow up phase – corresponds to parts of (4).

Case Study: Confederated Tribes of the Umatilla Indian Reservation Translocation Program

Background

In a 1995 report for the CTUIR, Close et al. (1995) evaluated the status of Pacific lamprey as directed by the Northwest Power and Conservation Council. The report identified measures that needed immediate implementation for reintroduction of lamprey as well as recommendations for research and data gathering. Among these were recommendations to determine current abundance and distribution, and to identify potential applications of translocation. The anticipated results were identification of translocation actions including methodology, source/donor stocks, target locations, and follow-up monitoring and evaluation needs.

In 1998 the CTUIR completed an electrofishing survey for juvenile lamprey in northeast Oregon and southeast Washington to document abundance and distribution in the CTUIR ceded lands. The Umatilla, Walla Walla, Tucannon, and Grande Ronde rivers had negligible lamprey presence suggesting either extremely low abundance or extirpation of Pacific lamprey. The John Day River had the best lamprey production of the rivers sampled, with juvenile lamprey documented throughout the subbasin.

In 1999, the CTUIR developed a peer-reviewed restoration plan for Pacific lamprey in the Umatilla River. The Umatilla River was chosen for reintroduction because it once supported a large number of Pacific lamprey and a traditional lamprey fishery, and donor stocks for translocation were geographically close. In addition, numerous habitat improvements in the Umatilla River subbasin had been completed for salmonids. The restoration plan called for 1) locating an appropriate donor stock for translocation, 2) identifying suitable and sustainable habitat within the subbasin for spawning and rearing, 3) translocation of up to 500 adult lampreys annually, and 4) long-term monitoring of spawning success, changes in larval density and distribution, juvenile growth and outmigration, and adult returns.

In 1999 and 2000, the CTUIR began implementing the restoration plan (Tables 1 and 2). Lamprey used for this program were initially collected during winter lamprey salvage operations at John Day Dam, the first Columbia River hydropower dam downstream from the mouth of the Umatilla River (Figure 1). In later years, collections were augmented with fish collected during summer at Bonneville and The Dalles dams.

Tasks required to implement the Umatilla translocation plan include:

- Coordinating with U.S. Army Corps of Engineers mainstem dam fishway dewatering activities for the salvage and collection of adult lamprey
- Establishing adult collection facilities at select mainstem projects to facilitate the translocation effort
- Targeting 500 adult Pacific lamprey to be moved from mainstem dams to the Umatilla River subbasin annually
- Holding transported adults for over-wintering at the South Fork Walla Walla River Adult Lamprey Holding facility and Minthorn Springs Adult Lamprey Holding facility
- Releasing over-wintered adults in the spring into the Umatilla River subbasin
- Long-term monitoring of translocation success

Results

The use of translocation in the Umatilla Subbasin has created a lamprey presence and therefore an opportunity to collect lamprey population data to further our understanding of various life history stages. The summary of findings below is reported in Close et al. (2009) and from continuing CTUIR studies since that time:

- Adult collection, transport, holding and outplanting: 10-year survival average = 96 %.
- Redds: 2000 (n=81), 2001 (n=49), 2002 (n=67), 2009 (n=81)
- Egg viability: 81-93% mean egg viability per redd
- Larval densities: Pre-translocation = 0.08 ±0.05 larvae/m^2, Post –translocation = 5.23 ±1.73 larvae/m^2 to 6.56 ± 2.44 larvae/m^2

- Larval Distribution: Pre-translocation, larvae virtually absent. Post-translocation, larvae are present from headwaters to mouth of the Umatilla River, Rkm 0 to 144

- Outmigration: Recently metamorphosed juvenile outmigration estimates range from ~3,500 to ~240,000 / year. Estimates difficult due to size selectivity of trap.

- Returns: Only preliminary data available at this time - annual adult returns ranged from 0-17. A new ladder was installed in late 2009 so improved information on numbers returning are expected beginning in 2010.

Spawning Success

Translocated lamprey were successful in depositing fertilized eggs in redds and producing viable eggs in the Umatilla River and Meacham Creek. In 2001, 19 viable redds were found in the mainstem Umatilla River and 30 in Meacham Creek. In 2002, 21 viable redds were found in the Umatilla River and 46 in Meacham Creek. The mean percent egg viability per redd was 93.4% (± 3.6%) in the Umatilla River (N = 4) and 81.4% (± 5.1%) in Meacham Creek (N = 12). Egg viability ranged from 57.8 % to 100.0 % in the 16 redds studied, with viability over 99% in seven redds. Seventy-five percent of the unviable eggs were covered by fungus and 25.0 % were deformed.

Larval Density and Distribution

Larval abundance in index plots sharply increased one year after translocation of adult lamprey to the Umatilla River (Figure 7). Mean density levels of larvae were 0.08 ± 0.05 larvae/m^2 in 2000. Mean density levels significantly increased to 5.23 ± 1.73 larvae/m^2 and 6.56 ± 2.44 larvae/m^2, ($P < 0.01$) in 2001 and 2002. Mean densities remained elevated through 2007 ($P < 0.001$).

Larval distribution increased through time in the upper mainstem Umatilla River (Figure 8). In the years prior to translocation of adults, no larvae were found in the upper Umatilla River. However, one year after translocation of adults, larval densities increased and the distribution of larvae moved downstream. By 2007, the larval distribution extended downstream to the middle reaches of the Umatilla River, with little change in larval densities in the lower river.

Juvenile Growth and Outmigration

Recently metamorphosed lamprey abundance sharply increased during the 2000-01 outmigration (Figure 9). Abundance returned to low levels and then sharply increased again in 2005-06. The 2000-01 peak was likely due to natural production that occurred before the translocation study began. However, based on larvae densities measured at index sample sites, the 2005-06 peak likely included progeny from the translocation of adult lamprey.

During 2005-06, the median length of recently metamorphosed lamprey was 143 mm (range, 113-180; Figure 10). During the same trapping, the median length of larval lamprey was 145 mm (range, 52-182; Figure 10). This indicates that the rotary screw trap may be selective for larger sized lampreys.

Adult Returns

Prior to translocation, numbers of adult Pacific lamprey in the Umatilla River Basin were very low (Close et al. 2008). The number of adults has increased over time (Figure 11), but the total number of individuals entering the Umatilla River is still low. This is due at least in part to the long freshwater residence time of juvenile Pacific lamprey. Other contributing factors may include 1) low adult returns in the mainstem Columbia River, 2) adult lamprey may not return to their “natal” stream to spawn, 3) low instream flows that may fail to attract adult lamprey, and 4) passage barriers that block adult migration (Jackson and Moser, unpublished data).

Case Study: Nez Perce Tribe Pacific Lamprey Translocation Program

Background

Numbers of Pacific lamprey returning to the Snake River, as estimated by daytime counts at Lower Granite Dam, have been reduced to double digits in recent years (Fish Passage Center 2009). Although absolute numbers escaping to the Snake River are unknown, it is obvious that populations are precariously low and have declined dramatically. The potential loss of Pacific lamprey to the Snake River has significant ecological and cultural ramifications, especially for Native American Tribes. Since 2006, biologists with the Nez Perce Tribe have conducted a trial translocation program to augment natural lamprey production in the Snake River. Adult lamprey salvaged from John Day Dam and The Dalles adult fishways during the annual winter dewatering period are held through the winter at the Nez Perce Tribal Hatchery on the Clearwater River. In May they are released into four Snake River tributaries: Asotin Creek in Washington, and Lolo, Newsome, and Orofino creeks in Idaho (Figure12).

To document the effectiveness of the program, a sub-sample of 30 fish per year have been outfitted with radio transmitters and released into 3 of the 4 streams, ten fish per stream. Radio-tagged fish were not released into Asotin Creek during 2007 or into Orofino Creek during 2008 and 2009. Systematic (mostly weekly) surveys using a truck-mounted and hand-held receiver were conducted to determine the movements of translocated lamprey following release. Limited spawner surveys were made by foot to locate lamprey redds and, if possible, verify spawning activity.

During the summer of 2009, surveys to search for juvenile lamprey were initiated in Newsome and Lolo creeks. A specialized backpack electrofisher, designed for use with lamprey ammocoetes, was used to systematically survey 15-km reaches of the two streams, encompassing areas where radio-tagged adult lamprey had been located. Starting at locations where adult lamprey were released, sites up- and downstream at approximately 1 km intervals were surveyed until juvenile lamprey were no longer found or until the mouth of the study stream was attained. At each site, approximately 50 m of stream was surveyed, or until 20 to 30 ammocoetes were collected. Lengths (mm) and weights (nearest 0.1 g) of collected fish were measured, and all fish were then returned to the collection site.

Results

Over three years (2006, 2007, and 2008), a total of 391 adult lamprey have been collected for this trial translocation effort. All but two of these fish survived to release the following spring (Table 3); one fish each died after radio-tagging in 2007 and 2009. Lamprey were released at river miles 8.9 in Asotin Creek, 31.4 and 34.3 in Lolo Creek, 3.9 and 8.2 in Newsome Creek, and 30.0 in Orofino Creek.

For the most part, radio-tagged lamprey remained in the release streams. The exceptions occurred in Newsome Creek where 8 of 29 lamprey moved downstream to the South Fork Clearwater River. Five of 20 may have also left Asotin Creek, although only one fish was confirmed to be in the Snake River. Fish that remained in release streams generally moved an average of 1 to 2 miles from release sites, mostly downstream.

Spawning occurred during June and early July in 2007 and 2008, and late July to early August in 2009. Lamprey redds were observed in all release streams where surveys were conducted except for Asotin Creek in 2009. Surveys were conducted as time permitted and so numbers reported were not indicative of actual spawning success in release streams. Nonetheless, the presence of redds, some with adult lamprey residing, indicated that released fish were able to exhibit spawning behavior following translocation.

During the September 2009 electrofishing surveys, juvenile lamprey were observed within an 8.6 mile segment of Lolo Creek (from the upper release site down to the mouth of Eldorado Creek), and in an 8 mile segment of Newsome Creek (from the upper release site down to the confluence with the South Fork Clearwater River). No ammocoetes were observed in either creek upstream from the upper release sites. Sizes of fish collected ranged from around 30 to 100 mm (Figure 13). The range of sizes found suggests that multiple age classes were present, but the size frequency distributions did not help delineate age groupings. Spot checks in the lower segments of Eldorado and Musshell creeks (tributaries of Lolo Creek) and the Red and American rivers (tributaries of South Fork Clearwater River approximately 10 miles upstream of Newsome Creek) did not reveal any lamprey larvae. While not conclusive, the indication is that larval lamprey observed in Lolo and Newsome creeks were primarily the progeny of the translocated adults.

POTENTIAL BENEFITS, RISKS, AND UNCERTAINTIES

The ideas covered in this section on potential benefits and risks associated with translocation of lamprey from the lower mainstem Columbia River into upstream subbasins stem from two sources: 1) direct observations on actual benefits; and 2) logic extended from untested hypotheses on potential benefits and risks. As previously mentioned, the purposes of Pacific lamprey translocation programs are for reintroduction, augmentation, and as an interim measure while primary limiting factors (e.g., mainstem passage) are addressed in the longer term. Translocation targets portions of the Columbia River Basin where lamprey were once abundant but where numbers are now depressed. Translocation programs are essentially attempting to mitigate for the lack of spawning stock in these reaches of the basin by bypassing the upriver migration that would otherwise include passing several dams en route to spawning areas. The discussion of benefits and risks associated with translocation is not intended to be a comparison of the benefits and risks among various management options.

Benefits of Lamprey Translocation

Reintroduction and augmentation of Pacific lamprey through translocation programs has direct cultural benefits to tribal members. This is an actual benefit wherein tribal members directly view more ammocoetes in the subbasins into which these fish have been reintroduced, thus renewing the close relationship between indigenous tribes and lamprey. Moreover, introduction of lamprey in areas where they have been extirpated raises awareness of these fish and their role in the ecosystems among tribal members and managers alike. This increased awareness stimulates efforts to improve habitats for lamprey, provide access to spawning areas, and examine limitations to lamprey production.

Beyond awareness, the long term goal of rebuilding of lamprey to harvestable levels will provide cultural, spiritual, ceremonial, medicinal, and subsistence values to tribes. Due to the poor status and trends of Columbia Basin lamprey populations discussed above, the only consistent current location where tribes can harvest lamprey within the basin is at Willamette Falls (Figure 1).

Another likely direct benefit of translocation may be a resulting wider distribution of Pacific lamprey, through occupation of subbasins where they have been severely depressed or extirpated. Based on passage efficiencies noted previously under "Factors for Decline", total estimated passage success rate for lamprey destined above John Day Dam (Figure 1) would be about 18% and an estimated total success rate above eight dams may be an alarming 1%. Until passage survival is better understood and improved at mainstem dams, translocation from lower dams may actually produce a survival benefit for lamprey otherwise destined to interior areas. This wider distribution should help decrease the risk of lamprey extinction by decreasing the overall impact of catastrophic events within a subbasin, or even within a larger portion of the Columbia River Basin. For example, the Nez Perce program of outplanting 100 adults in Snake River tributaries would increase the entire Snake River spawner population above Lower Granite Dam by 235% (based on 2005-2008 counts) or 800% (based on 2009 counts).

As the above example illustrates, a related benefit of translocation is that population increases in target areas are immediate. This immediate result may then serve as an interim measure while mainstem passage improvements and other limiting factors are addressed. The adult-to-adult generation span for Pacific lamprey requires about a 10 year period; therefore, translocation may be a practical investment to seed selected habitats prior to passage work being completed. An aggressive program by the U.S. Army Corps of Engineers to improve adult passage is currently underway, but will take 10+ years to implement and likely another 10 years to monitor and make necessary adjustments. Juvenile passage improvements are more complicated and will likely take longer to implement and adapt. As limiting factors are addressed and lamprey survival increases, translocation efforts could be downsized or phased as judged appropriate.

A key potential benefit of translocation efforts is that the resulting augmented juvenile lamprey abundance will increase pheromone cues that may attract more adults into the Columbia River Basin as a whole and to translocated streams in particular if, as has been speculated, this in fact is a primary cue to orientation of adult migrants. Translocation and other restoration programs may therefore have a synergistic effect that could help break the downward cycle of Pacific lamprey recruitment and abundance. A significant weakness in our ability to more effectively manage Pacific lamprey populations in this region is the lack of understanding on the navigational/guidance cues used during the spawning migration. There is an immediate need for research in this area.

Lamprey translocation may also result in benefits to the ecosystem. Because ammocoetes are filter feeders, the increased production of ammocoetes may facilitate nutrient cycling in the rivers where adult lamprey have been reintroduced. Other potential benefits include increased connectivity of marine with freshwater ecosystems, and delivery of marine-derived nutrients into upper reaches of the Columbia River Basin. Outside of a lack of a sufficient spawning stock in the upper basin, delivery of marine-derived nutrients may be a limiting factor to the production of ammocoetes, as well as other fish and the freshwater ecosystems in general. In essence, potential benefits of translocation may include a realization of the unique attributes that Pacific lamprey provide for the freshwater ecosystems they use to complete their life cycles (e.g., see Close et al. 2002).

Increasing the number of juvenile lamprey through translocation or other management options may also result in direct benefits to other native species. Lamprey restoration will increase the prey base available to a number of native predators. In addition, increases in the number of juvenile lamprey may serve as a predation “buffer” to other species such as juvenile salmonids.

Although secondary to the reintroduction and augmentation of Pacific lamprey, translocation may allow collection of data that would have otherwise not been feasible. The use of translocation in the Umatilla Subbasin has created a lamprey presence and therefore an opportunity to collect lamprey population data to further our understanding of various life history stages. For example, collecting information on adult passage (considered a critical uncertainty) via radio tracking individuals over low-elevation diversion dams has been possible. The first Columbia Basin tributary adult lamprey passage structure was completed at Threemile Dam in 2009. Findings will have broad application in addressing similar tributary limiting factors throughout the Columbia Basin.

Risks of Lamprey Translocation

Potential risks of lamprey translocation are unknown, but may include disruption of any connection between stock structure and particular watersheds, if one exists, moving fish to areas with substantial limiting factors, introduction of pathogens and disease from the lower reaches of the Columbia River Basin into the upper reaches (when such pathogens and disease may be "weeded out" or selected against over the long journey upstream to the upper subbasins), decreases in abundance from donor areas, and a "tragedy of the commons" effect (e.g., see Hardin 1968). For example, removing broodstock from existing functional systems to augment other subbasins may result in loss from the remaining functional (e.g. donor) systems. The LTWG has indicated sensitivity to these potential risks as noted by inclusion of lamprey translocation guideline numbers 4 and 5 that address these issues.

As previously described, the connection between stock, or population structure, and particular watersheds within the Columbia River Basin is unclear. Any risk of disruption is contingent upon potential temporal or geographical differentiation in stock structure, including genetic, morphological, behavioral and/or physiological differences among Pacific lamprey in the Columbia River Basin. One morphological/physiological characteristic of Pacific lamprey, body size, may be associated with the distance of upstream migration and with swimming ability (Clemens et al. 2010; Keefer et al. 2009b). If body size is an inherited characteristic, then translocation may select for a different genetic architecture than selected for by evolution. Genetic risk may be somewhat immaterial in areas currently targeted for translocation, however, because lamprey abundance in these areas is extremely low or nonexistent.

The potential use of pheromones by adult Pacific lamprey for orientation and navigation has important implications for lamprey management. If lamprey migration behavior is indeed influenced by the presence of larval bile acids, changes in juvenile lamprey abundance and their pheromone output could have important consequences for adults. For example, larval lamprey extirpation or reduction in a tributary could result in lack of adult colonization due to insufficient pheromone production. Alternatively, artificially adding juvenile lamprey to a subbasin could result in attraction of adults to areas with inadequate spawning habitat, poor water quality conditions, or lack of access to suitable spawning substrates. While our understanding of Pacific lamprey use of pheromones is in its infancy, the misuse of this potentially powerful migration cue could conceivably alter spawning distributions of entire year classes of migrating lamprey. Again, the LTWG has indicated sensitivity to this potential risk which is addressed by lamprey translocation guideline number 2.

Although disease transmission is a potential risk, it appears unlikely based on recent evaluations. Oregon Department of Fish and Wildlife Fish Health Services personnel have used standard fish health diagnostic methods to test Pacific lamprey for pathogens. All examinations have been at the adult stage (N=85) with the exception of lamprey larvae (N=21) submitted in 1999 from the middle fork of the John Day River. Results to date have shown the primary pathogen of concern to be a bacterium, *Aeromonas salmonicida*, the causative agent of furunculosis. Nine of 106 (8.5%) lamprey were found to have systemic *A. salmonicida* infections over the past decade. All nine of these were mortalities from a loss situation at the South Fork Walla Walla adult facility following collection and transfer in June 2005. Since this event, oxytetracycline injections (10 mg/kg) have routinely been implemented to prevent losses due to furunculosis and this has been successful. Because *Renibacterium salmoninarum,* the causative agent of bacterial kidney disease, has been shown to reside in sea lamprey (Faisal et al. 2006), tests for this bacterium have begun as well. No viral pathogens or parasites have been detected in any lamprey examined to date.

The collection of adult lamprey for use in translocation programs poses a potential risk to the donor subbasins from which the adults are removed. Lamprey adults that would have spawned in a subbasin are removed for transfer elsewhere; however, the consequences of this action for lamprey are largely unknown. Critical uncertainties include the population structure of lamprey, lamprey distributions and abundances in currently occupied areas, the minimum demographic requirements necessary to maintain stable and viable lamprey abundances, and the potential that some threshold abundances are needed to continue attracting lamprey into subbasins. As a minimum guideline, lamprey translocation programs should not cause a substantial decrease in abundance in any currently occupied subbasin, a concern previously identified and included as lamprey translocation guideline number 4.

Examination of the largest ongoing single translocation program (the Umatilla Subbasin) provides insight as to current levels of broodstock collection. From 2000 to 2010, mainstem Columbia River lamprey collection for this program ranged from 0.1% to 2.0% of the total estimated returns to Bonneville Dam, with a 10-year average of 0.43% (Table 1). To minimize the chances of causing any substantial decreases in abundance, the four treaty tribes are discussing levels of broodstock collection for translocation of adult Pacific lamprey. The tribes agreed to a “not-to exceed” 4% removal of the running 2 year average return to Bonneville Dam for translocation.

A "tragedy of the commons" may or may not become an issue with translocation, dependent in part on success of mainstem passage improvements, adherence to guidelines discussed above and whether the fish re-colonize relatively quickly into the rivers in which they are reintroduced (thus eliminating the need for continued translocation). However, as the abundance of Pacific lamprey languishes, the urge to translocate an ever-increasing number of lamprey to a particular watershed may compete with other interests in maintaining or increasing numbers in different parts of the Columbia River Basin.

Uncertainties

A more rigorous and definitive risk-benefit analysis of adult Pacific lamprey translocation would be feasible with the following:

- Comprehensive determination of lamprey population structure
- Documentation of migration guidance mechanisms
- Accurate assessment of lamprey abundance

The first bullet highlights the primary uncertainty associated with translocation programs; a lack of understanding how inter-basin transfers of lamprey may potentially affect the natural population structure for Columbia River Pacific lamprey. Preliminary information (cited elsewhere in this document) suggests that Pacific lamprey may not exhibit a strict geospatial population. Our nescient understanding of lamprey genetics and mechanisms that guide lamprey recruitment, however, does not preclude the existence of an organization to lamprey sub-populations that may be revealed with future investigations.

Regardless of the benefits, risks, and uncertainties associated with translocation and management of Pacific lamprey in general, it is evident that substantive on-the-ground action is needed to halt the declining trends in lamprey numbers across the Columbia River Basin. Continued translocation of adult Pacific lamprey, along with continued improvement of adult and juvenile passage at known and suspected obstacles and continued habitat restoration, will likely be among those on-the-ground actions. An additional tool not yet utilized may be artificial propagation. It is important that the uncertainties associated with actions be considered in a risk-management context, however, it is imperative that significant and aggressive actions be taken immediately to begin the recovery of this culturally important and ecologically significant species.

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Table 1. Number of adult Pacific lamprey collected, radiotagged, and translocated by year into the Umatilla River Subbasin. Minthorn Springs and South Fork Walla Walla are fish holding facilities in the Umatilla and Walla Walla subbasins. Specific release locations are provided in Table 2. BD=Bonneville Dam; CRRL=Columbia River Research Laboratory, Cook, WA; JDD=John Day Dam; MSHF=Minthorn Springs Holding Facility; SFWW=South Fork Walla Walla; TDD=The Dalles Dam; TMFD=Three Mile Falls Dam.

Year collected	Collection location	Number Collected	Holding location	Number Radiotagged	Year translocated	Number translocated	% Mortality
1999	JDD	611	CRRL; TMFD	0	2000	600	1.8
2000-01	JDD	249	TMFD	0	2001	244	0
2002	JDD	510	TMFD	0	2002	491	0
2002-03	JDD	484	MSHF	0	2003	484	1.3
2003	BD	133	CRRL; TMFD	0	2004	133	1.1
2004	JDD; TDD	120	SFWW; MSHF	0	2005	120	0
2005	BD	409	SFWW; MSHF	92	2006	198	29.0[/1]
2006	BD	394	SFWW; MSHF	76	2007	394	0
2007-08	TDD, JDD	477	SFWW; MSHF	30	2008	405	0
2008	BD, JDD	483	SFWW; MSHF	80	2009	337	13.6[/2]
2009	JDD	402[/3]	SFWW; MSHF	30	2010	291	2.2

Average Annual Survival 96%

/1 Holding pump failure, N=119 mortalities
/2 Ice event, N=66 mortalities
/3 Brood transfer to Nez Perce Tribe, N=72

Table 2. Specific release locations of adult Pacific lamprey translocated into the Umatilla River Subbasin. Collection and holding information is provided in Table 1.

Year released	Umatilla River			Iskúulktpe Creek	Meacham Creek	South Fork Umatilla River
	Rkm 98.8	Rkm 118.4	Rkm 139.9			
2000	--	150	300	--	150	--
2001	--	82	81	--	81	--
2002	150	100	141	--	100	--
2003	--	90	110	54	230	--
2004	--	--	63	--	70	--
2005	--	--	50	15	55	--
2006	--	--	90	21	87	--
2007	--	--	200	25	169	--
2008	--	--	26	--	42	--
2009	--	--	100	25	150	62
2010	--	--	128	13	150	--

Table 3. Number of adult Pacific lamprey released into four study streams, mean movement (miles) from release sites (excluding fish that exited streams), and numbers of lamprey spawning redds observed in the study streams during 2007, 2008, and 2009. Specific release locations are shown in Figure 12.

Release location	Released			Mean movement			Redds counted		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Lolo Creek	50	27	28	2.0	1.1	2.1	8	3	6
Newsome Creek	50	25	25	1.9	0.8	1.2	6	8	4
Orofino Creek	49	27	26	2.0	--	--	2	--	--
Asotin Creek	28	27	27	--	1.5	1.5	--	5	0
Total	177	106	106	--	--	--	--	--	--

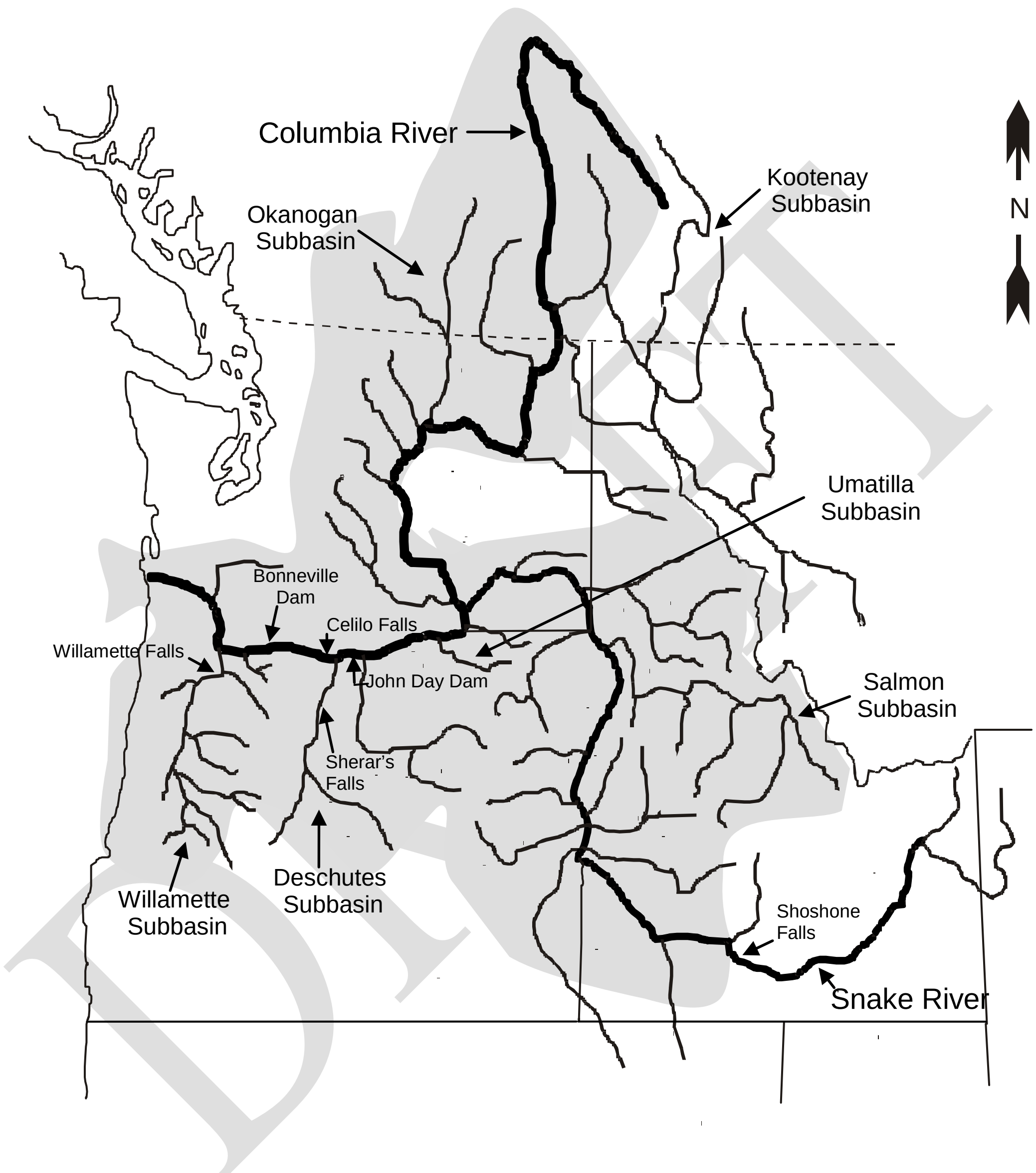


Figure 1. Map of the Columbia River Basin showing historic Pacific lamprey distribution (shaded) and some historically important tribal fishing areas (falls). Some subbasins and dams are labeled for reference.

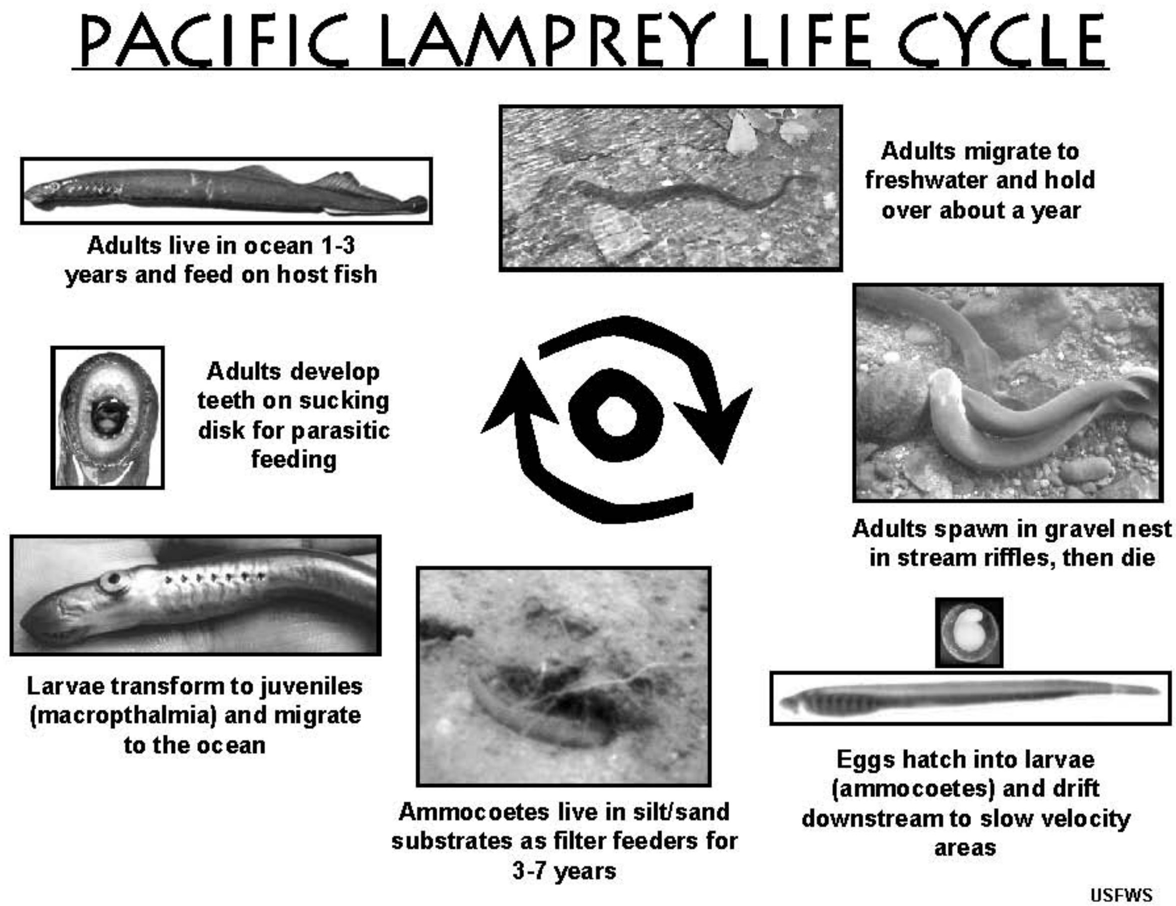


Figure 2. Pacific lamprey life cycle illustrating the duration and morphological characteristics of its life history stages (From USFWS 2010).

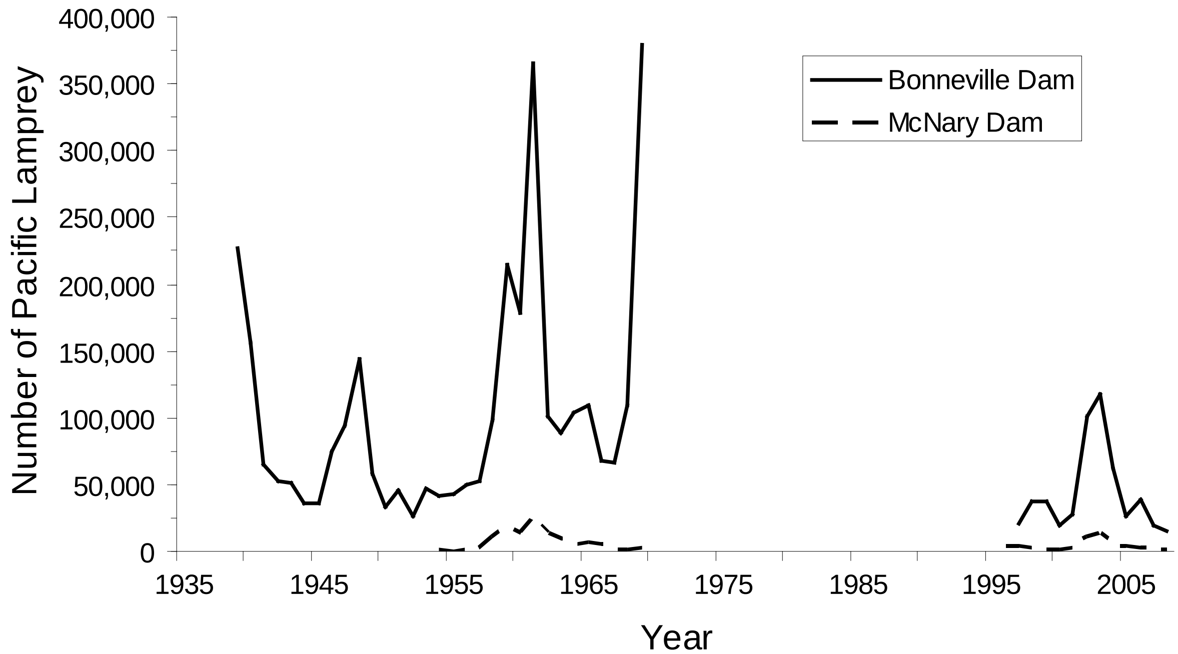


Figure 3. Counts of adult Pacific lamprey reported for Bonneville and McNary dams (Fish Passage Center 2009). Counts were not made from 1970 to 1995.

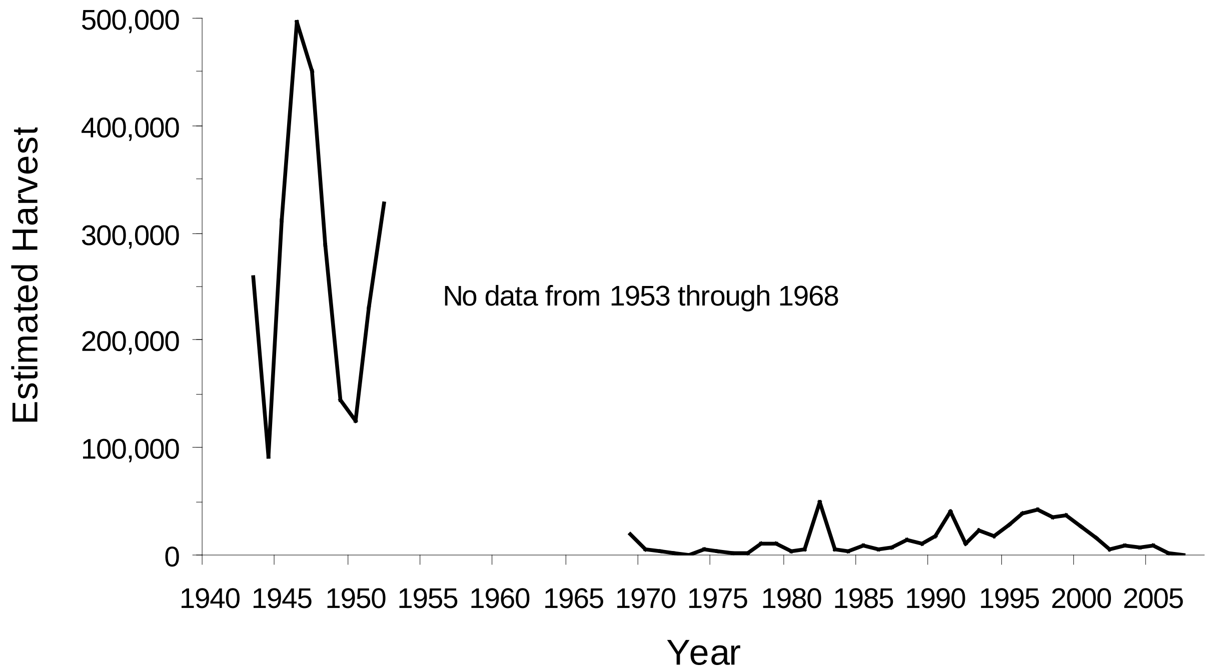


Figure 4. Estimated number of Pacific lamprey harvested at Willamette Falls, 1943-2007 (Kostow 2002; Oregon Department of Fish and Wildlife, unpublished data).

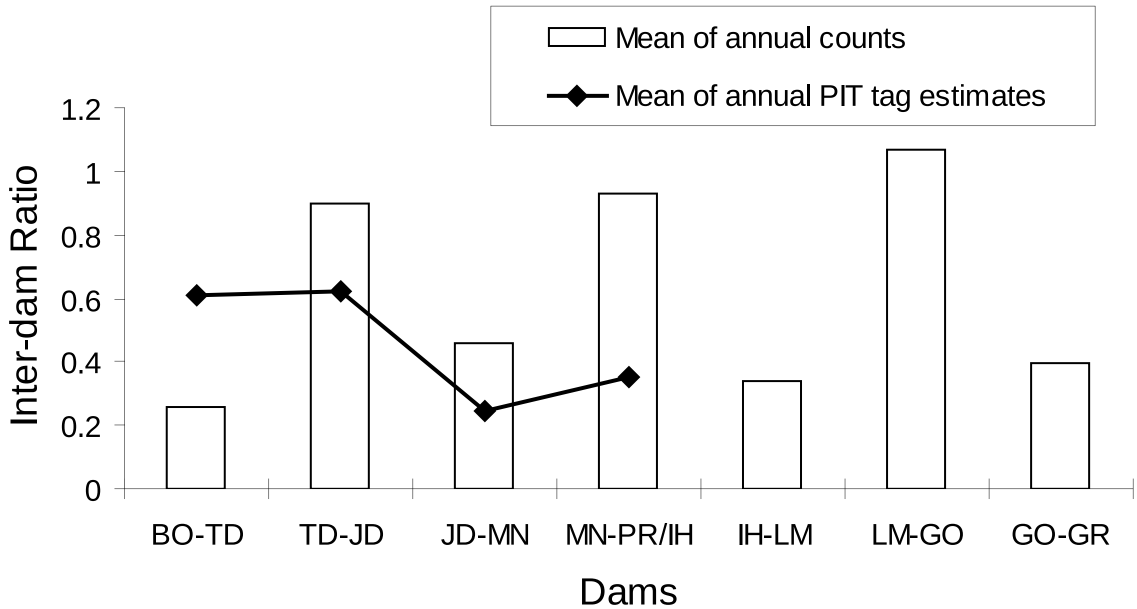


Figure 5. Mean inter-dam escapement ratios for adult Pacific lamprey between dams of the Columbia and Snake rivers based on 2000-09 averages of total annual daytime counts (bars) and from 2006-2008 PIT tag records (DART 2009; Keefer at al. 2009a; 2009b*)*. BO = Bonneville, TD = The Dalles, JD = John Day, MN = McNary, IH = Ice Harbor, PR = Priest Rapids, LM = Lower Monumental, GO = Little Goose, and GR = Lower Granite.

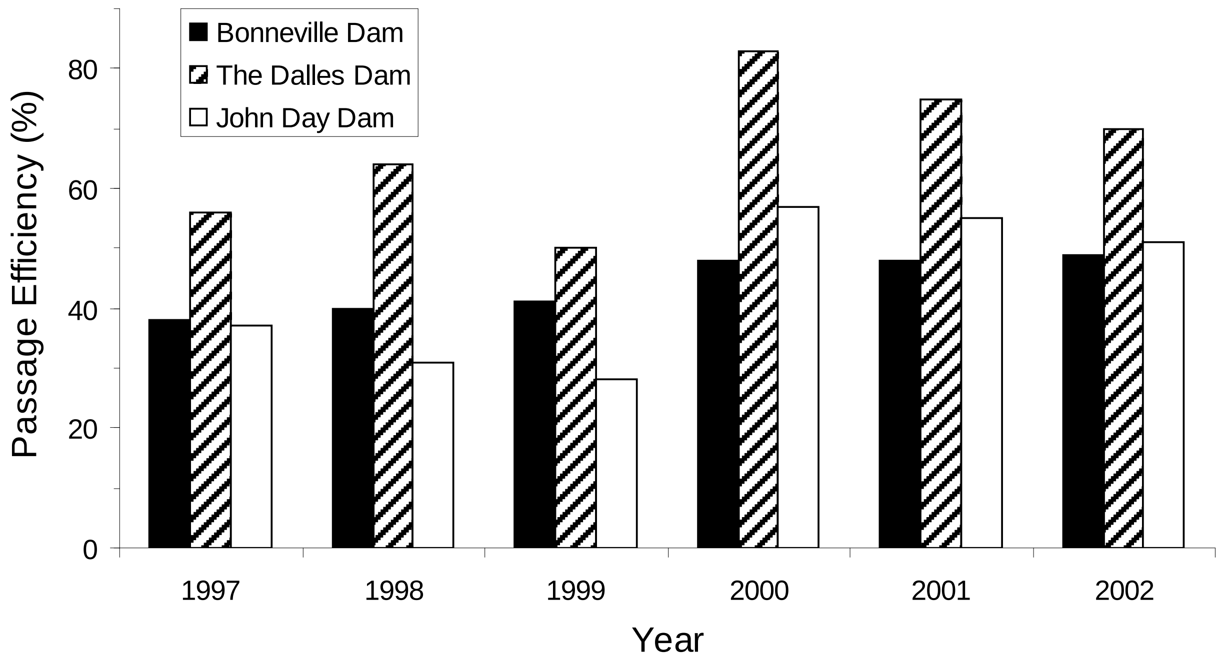


Figure 6. Overall passage efficiency (percent of lamprey that passed over each dam of those that approached each dam) for Bonneville, The Dalles, and John Day dams from 1997-2002.

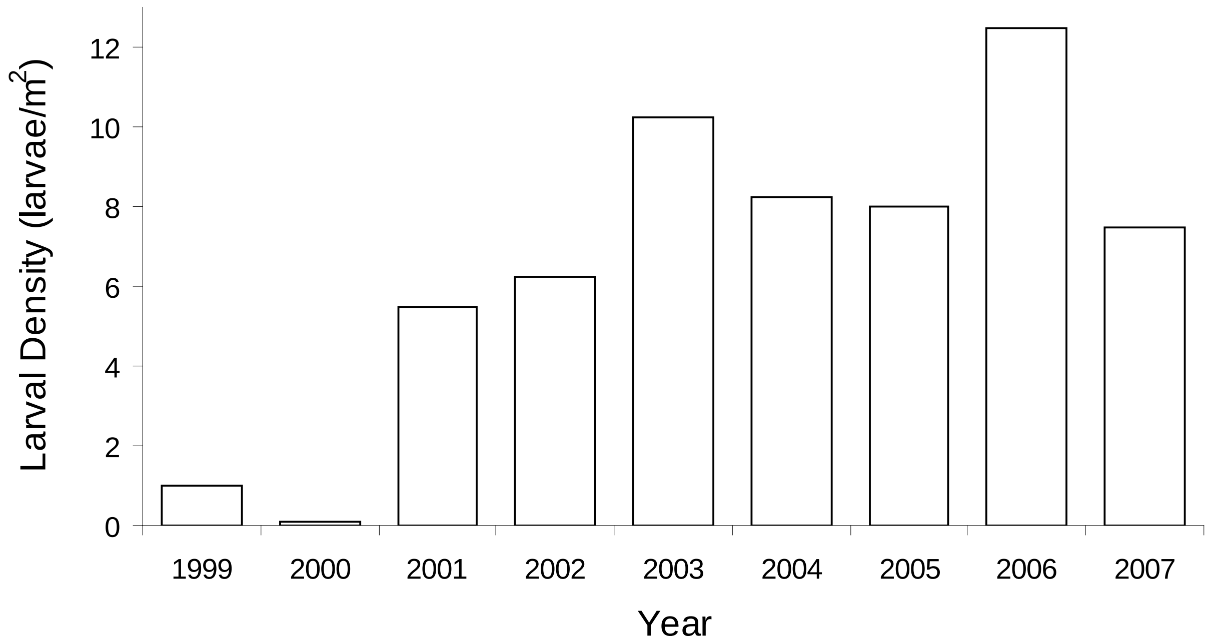


Figure 7. Changes in larval densities (mean of 30 index sites) after translocating adult Pacific lamprey to the Umatilla River, 1998-2007.

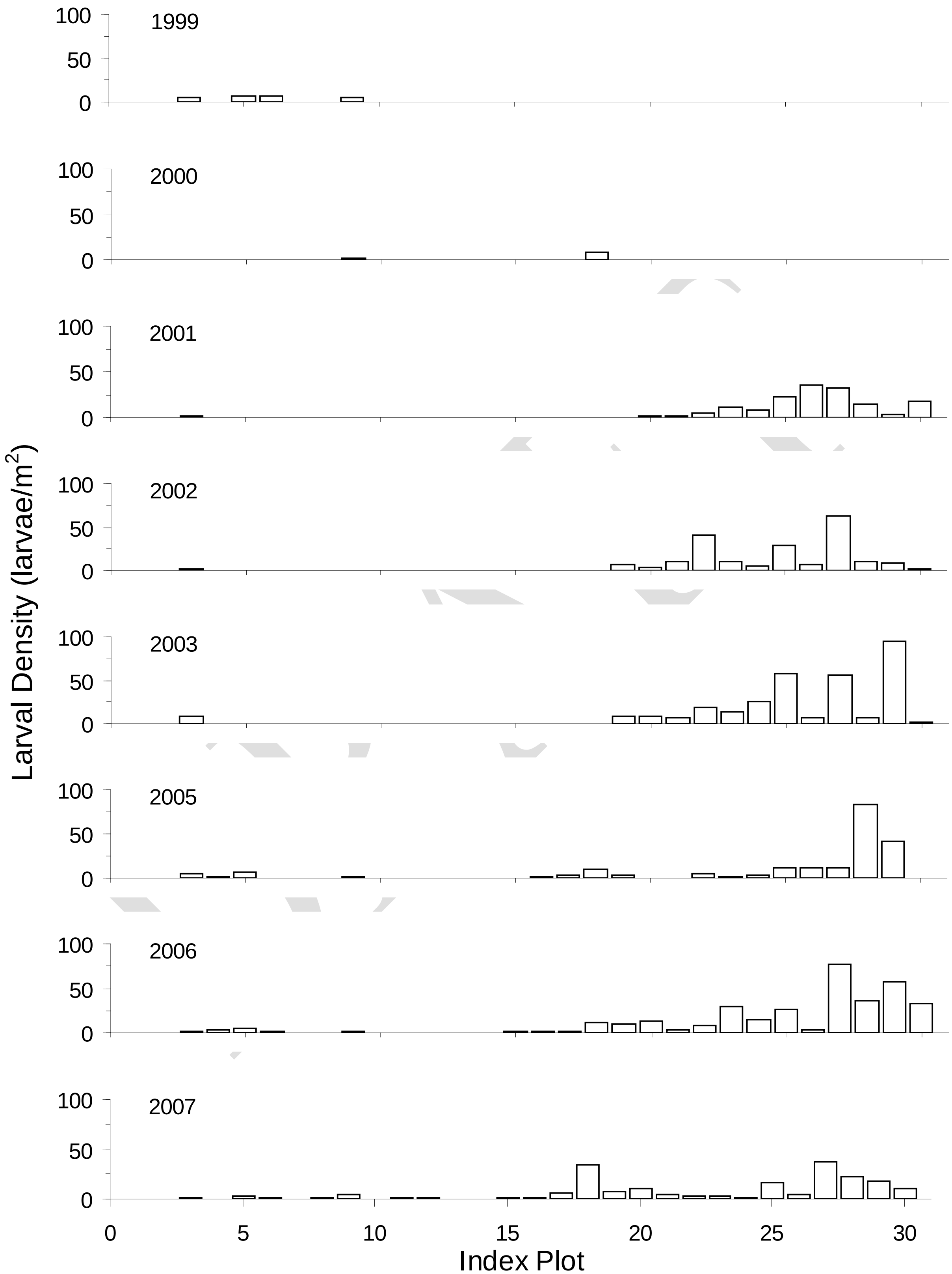


Figure 8. Density of larval lamprey in the Umatilla River, 1999-2007. Index plot zero is near the mouth and index plot 30 is in the upper Umatilla River.

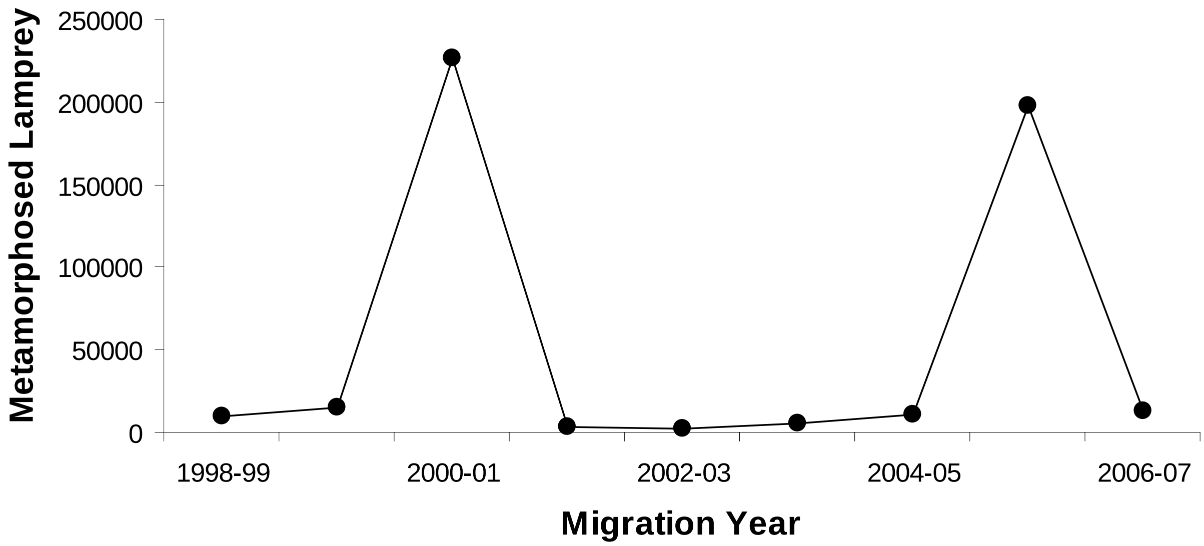
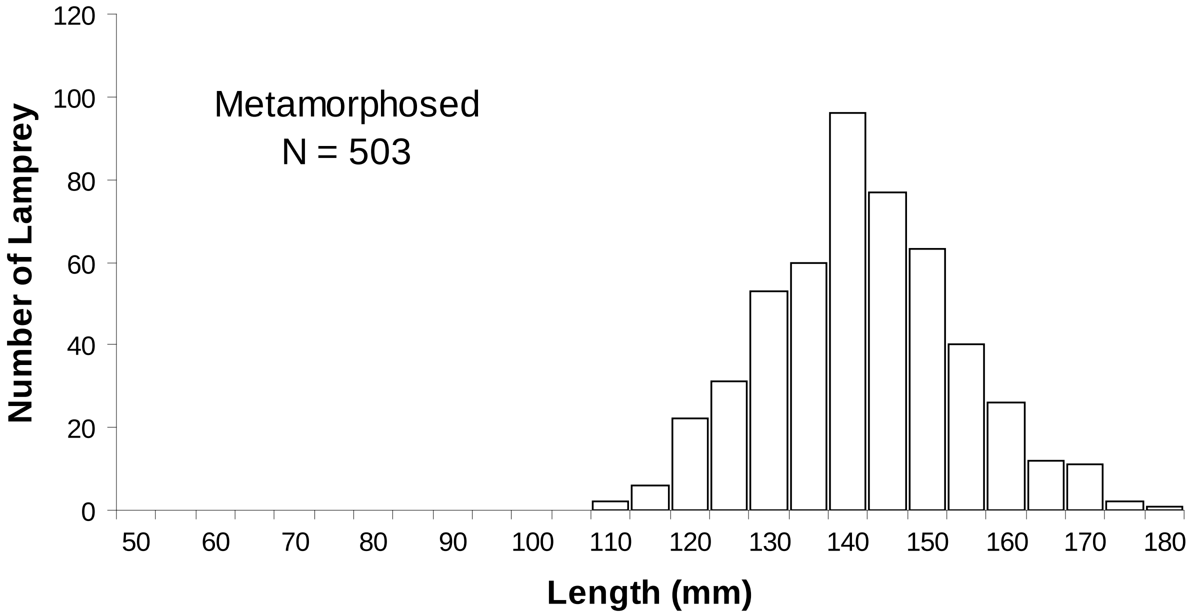


Figure 9. Yearly estimates of the number out-migrant lamprey macrophthalmia near the mouth (river kilometer 1.9) of the Umatilla River.



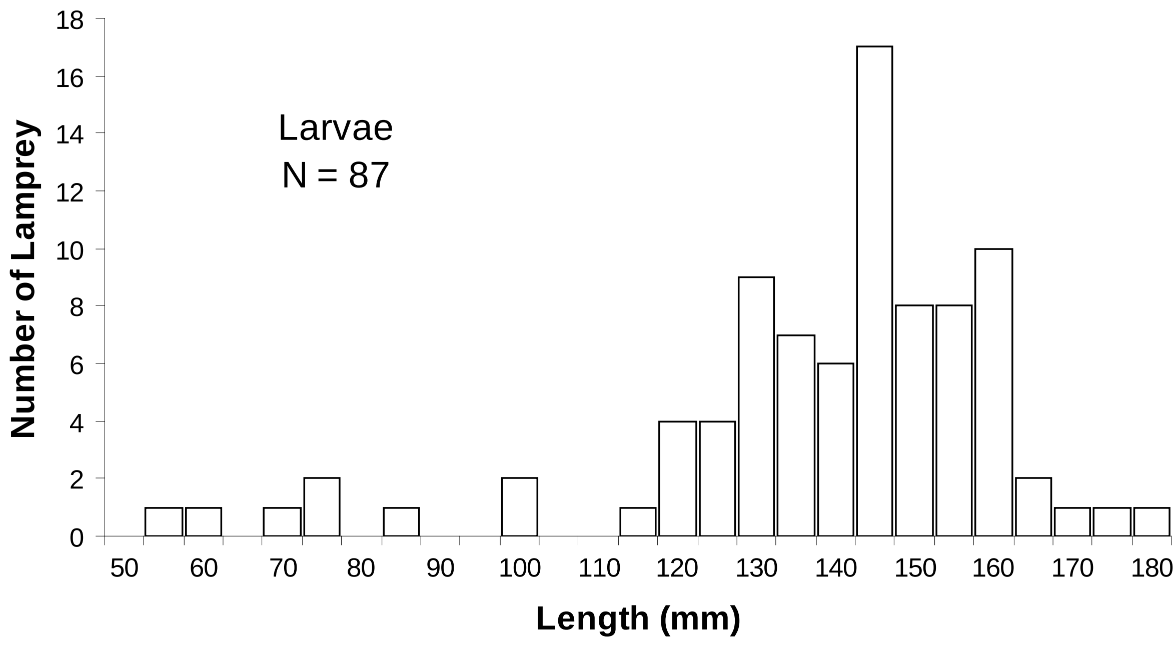


Figure 10. Length-frequency distribution of metamorphosed and larval lamprey captured in a rotary screw trap near the mouth of the Umatilla River in 2005-2006.

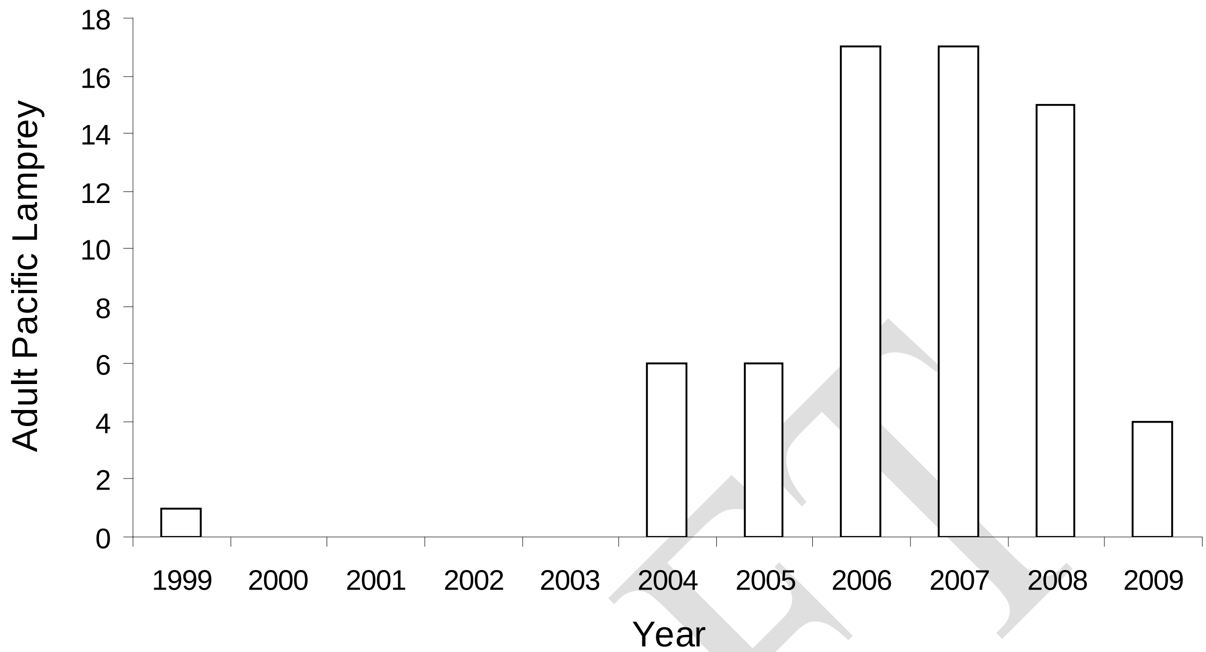


Figure 11. Number of adult lamprey trapped at Three Mile Falls Dam on the Umatilla River, 1999-2009. In 2009 the trapping period was substantially reduced while a new adult passage structure for lamprey was installed.

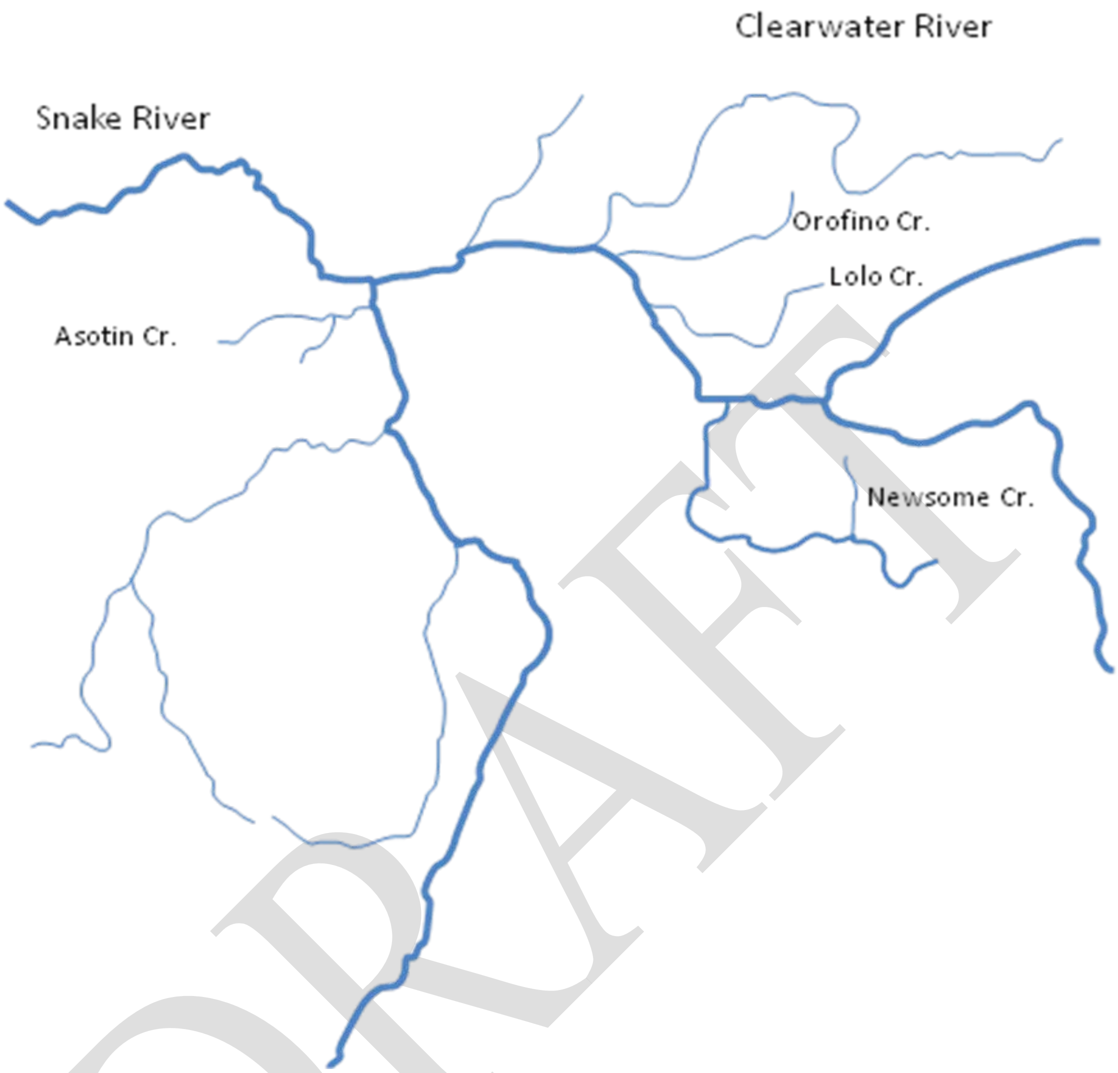


Figure 12. Map of lower Clearwater River Subbasin, showing streams utilized in Nez Perce Tribe translocation program.

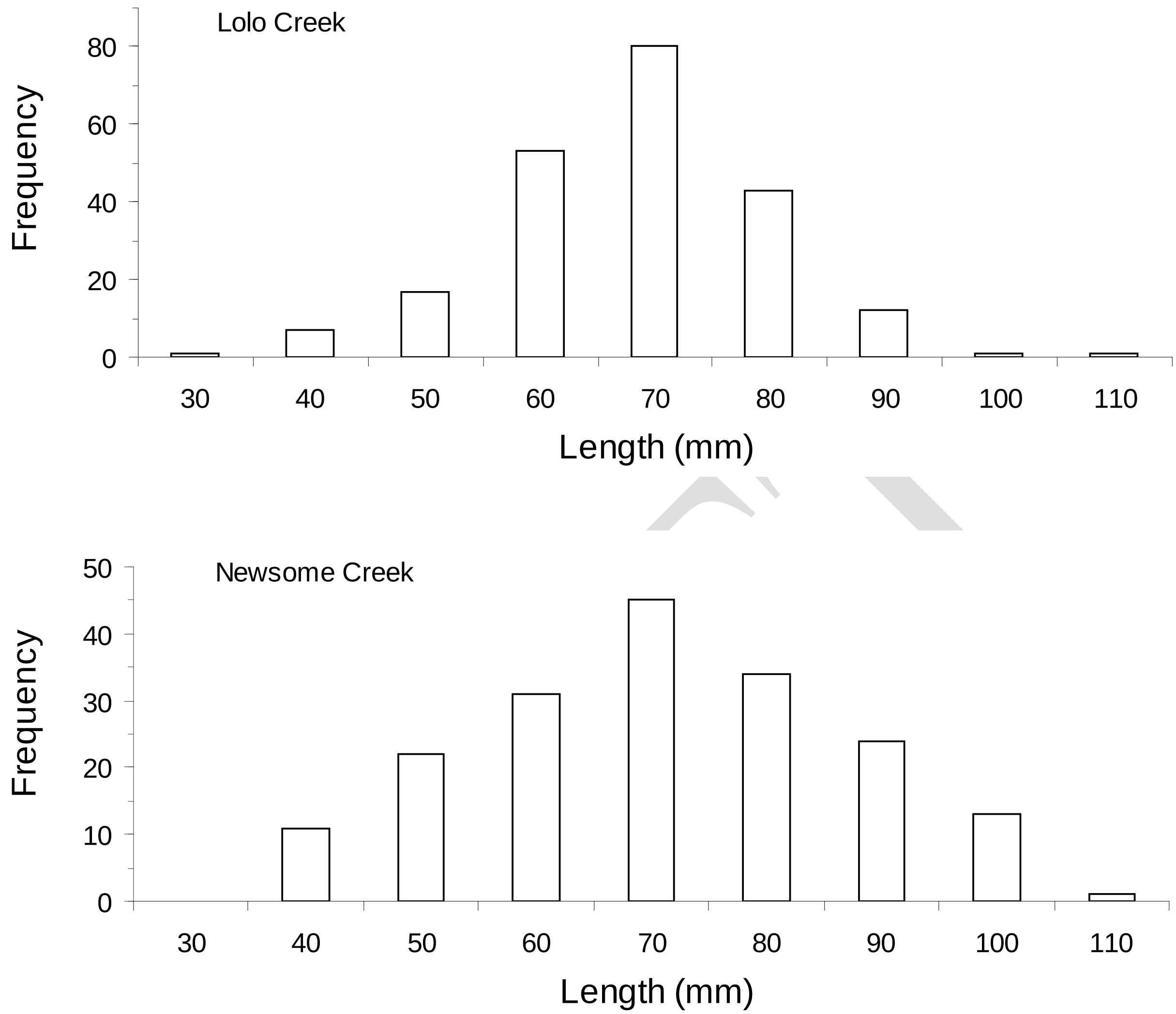


Figure 13. Length frequency of larval lamprey collected in Lolo (N = 215) and Newsome (N = 181) creeks, summer of 2009.