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Translocating Adult Pacific Lamprey within the Columbia River Basin: State of the Science

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Translocating Adult Pacific Lamprey within the Columbia River Basin: State of the Science

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ABSTRACT: *The Pacific lamprey (*Entosphenus tridentatus*) is in decline in the Columbia River Basin, and translocating adult lamprey to bypass difficult migration corridors has been implemented since 2000. We describe and report results from two current translocation programs, provide context for use of translocation, and discuss potential benefits, risks, and uncertainties. Both translocation programs appear to have increased the number of spawning adults and the presence of larvae and juveniles; however, any subsequent increase in naturally spawning adults will require at least one, and likely more, generations to be realized. It was seen that the number of adults entering the Umatilla River increased beginning four years after the first translocations. Potential benefits of translocation programs are increased pheromone production by ammocoetes to attract adults, increased lamprey distribution and abundance in target areas, increased marine-derived nutrients, and promotion of tribal culture. Potential risks include disruption of population structure and associated genetic adaptations, disease transmission, and depletion of donor stocks.*

Translocación de Individuos Adultos de Lamprea del Pacífico dentro de la Cuenca del Río Columbia: Estado de la Ciencia

RESUMEN: *Las poblaciones de la lamprea del Pacífico (*Entosphenus tridentatus*) están declinando en la cuenca del Río Columbia, y desde el año 2000 se ha implementado la translocación de individuos adultos para restablecer los corredores migratorios de esta especie. Se describen y reportan los resultados de dos programas recientes de translocación, se contextualiza el uso de la translocación y se discuten sus beneficios potenciales, riesgos e incertidumbre. Ambos programas de translocación parecen haber incrementado el número de adultos desovantes y la presencia tanto de larvas como de juveniles; sin embargo, para que sea posible cualquier incremento ulterior en el stock natural de reproductores se requerirá de al menos una, aunque muy probablemente de más, generaciones. Se observó que el número de adultos que ingresó al Río Umatilla aumentó en los primeros cuatro años después de la primera translocación. Los beneficios potenciales de los programas de translocación son un aumento en la producción de feromonas por parte de larvas ammocoetes para atraer adultos, incremento en la distribución y abundancia de lampreas en áreas objetivas, incremento en la cantidad de nutrientes derivados del medio marino y la promoción de culturas tribales. Los riesgos potenciales incluyen modificación de la estructura poblacional y las adaptaciones genéticas asociadas, transmisión de enfermedades y agotamiento de los stocks donadores.*

INTRODUCTION

The Pacific lamprey (*Entosphenus tridentatus*) is an anadromous species native to the Pacific Coast of North America and northern Asia, including the Columbia River Basin (Figure 1). Descriptions of Pacific lamprey taxonomy and life history were provided by Beamish (1980), Richards (1980), and Beamish and Levings (1991) and recently summarized by Clemens et al. (2010). Pacific lamprey are an important food source for marine mammal (Roffe and Mate 1984), avian (Merrell 1959), and fish (Semakula and Larkin 1968) predators and may act as a predation buffer for Pacific salmon (*Oncorhynchus* spp.; Close et al. 1995). They are a source of marine-derived nutrients (Close et al. 1995), may be an indicator of ecological health, and serve an important role in the culture of many Native American tribes (Close et al. 2002b).

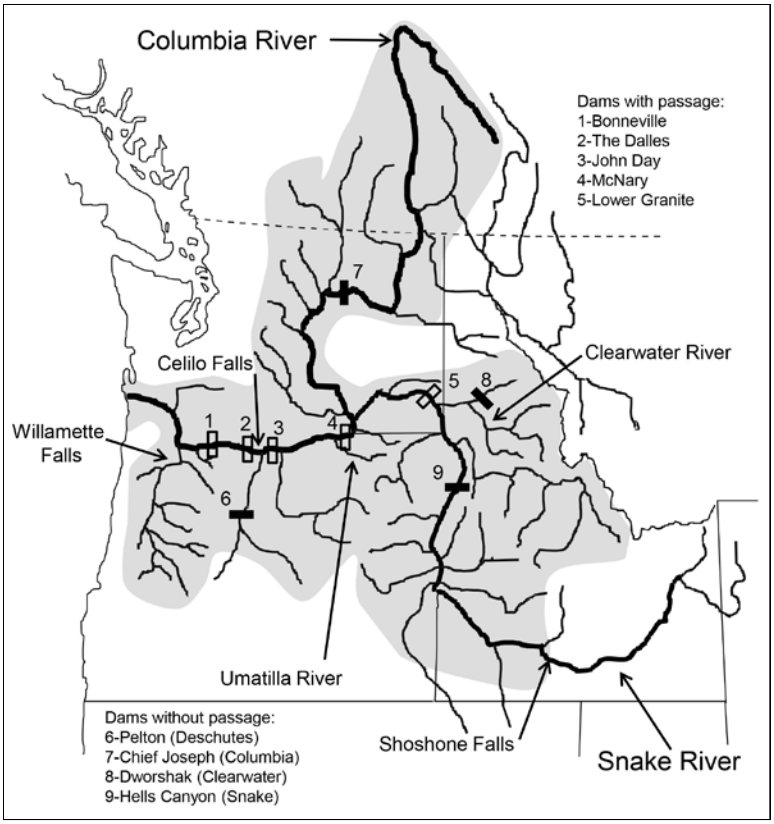

Figure 1. Historic Pacific lamprey distribution in the Columbia River Basin (shaded) and some historically important tribal fishing areas (falls). Some mainstem Columbia and Snake River dams providing passage are labeled for reference, as are some dams that block passage and therefore restrict distribution. Two subbasins with translocation programs are also labeled.

Pacific lamprey along the West Coast of North America have recently experienced declines and widespread localized extirpations (Beamish and Northcote 1989; Moser and Close 2003; Luzier et al. 2011). For example, Wallace and Ball (1978) documented the complete loss of Pacific lamprey from the North Fork Clearwater River upstream from Dworshak Dam (Figure 1) in the five years following the dam's completion in 1971. In addition to the effects of dams, causes for the decline in the Columbia River Basin may include habitat degradation, poor water quality, proliferation of exotic species, and direct eradication actions.

Indigenous peoples historically harvested lamprey throughout the Columbia River Basin (Close et al. 1995; Figure 1), but now harvest is restricted to the lower portions of the basin (Close et al. 2002b). 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 for ever-decreasing lamprey harvest opportunities. As a consequence of restriction or elimination of harvest in interior Columbia River tributaries, young tribal members are losing historically important legends associated with lamprey because they have not learned how to harvest and prepare them. Reintroduction and augmentation of Pacific lamprey in the upper reaches of the Columbia River Basin will renew the relationship and cultural identity between indigenous tribes and lamprey.

Translocation of adult Pacific lamprey is a tool for reintroduction and augmentation and an interim measure to prevent local extirpation (see George et al. 2011) while primary limiting factors (passage and degraded habitat) are addressed. Here we define "translocation" as the collection of adult Pacific lamprey from one location (the mainstem lower Columbia River) and transport for release into a subbasin upstream, where they are scarce or even extirpated. The resulting increase in spawning adults is intended to increase the number of ammocoetes present, which may in turn attract even more adult lamprey (Yun et al. 2011).

We describe and report results from two current translocation programs in the Columbia River Basin and discuss associated benefits and risks. The programs are conducted by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) in the Umatilla River Subbasin and the Nez Perce Tribe (NPT) in the Clearwater River and Asotin Creek subbasins (Figure 1). Results from the first few years of monitoring the CTUIR program have been previously provided by Close et al. (2009). Findings since 2007 are available only in agency reports, most recently in Jackson et al. (2011). The NPT program has been described only by Peery (2010). Here we present the first comprehensive summary of both programs since their inception.

Close et al. (1995) conceptualized the goal of lamprey transplantation to "begin reestablishment or supplementation of lamprey in selected tributaries above Bonneville Dam where populations have been extirpated or are at extremely low levels." The goal of the CTUIR program is to restore natural production of Pacific lamprey in the Umatilla River to self-sustaining and harvestable levels (Close et al. 2002a). The purposes of the NPT program are to (1) move adult Pacific lamprey past mainstem dams into Snake River tributary spawning habitat, (2) provide an interim measure to prevent local extirpation of Pacific lamprey in the Snake River Basin, (3) avoid loss of pheromone attractants from larval lamprey that may be key in guiding spawning adults, and (4) preserve tribal culture (Statler 2011).

This information is of worldwide import, because over half of all Northern Hemisphere lamprey species are considered to be vulnerable, endangered, or extinct (Renaud 1997). Recognizing that efforts to restore other aquatic species, notably anadromous salmonids, have been ineffective and even counterproductive at times, regional managers wish to take a thoughtful approach to develop methods to conserve and restore this unique group. We hope that information gained from this effort for Pacific lamprey can benefit other lamprey species.

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

Background

Through oral interviews with tribal members and former state and federal agency fisheries personnel, Jackson and Kissner (1997) determined that Pacific lamprey were historically abundant and that fishing occurred throughout the Umatilla Subbasin (Figure 2). No records were kept of lamprey counts, but former agency personnel noted that "there were so many adult Pacific lamprey in the Umatilla River that they were a nuisance." Tribal members and agency personnel stated that abundance decreased dramatically after rotenone treatments in 1967 and 1974. Throughout the 1990s, very few Pacific lamprey were observed, although 12 adult Pacific lamprey were found in the ladder at Three Mile Falls Dam (Figure 2) during dewatering in 1996. No Pacific lamprey were collected during numerous electroshocking surveys upstream from the dam in the 1990s. Kostow (2002) noted that lamprey production in the Umatilla appears to be restricted to the lower few miles of the subbasin and that Pacific lamprey may be gone from the upper subbasin.

In 1999, the CTUIR developed a peer-reviewed restoration plan for Pacific lamprey (Close 1999). The Umatilla Subbasin was chosen for reintroduction because it once supported a traditional lamprey fishery and donor stocks for translocation were geographically close. In addition, numerous habitat improvements in the 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) translocating 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.

Methods

In 1999 and 2000, the CTUIR began implementing the restoration plan; methods described here are summarized from a detailed account provided by Close et al. (2009). Adult lamprey used for this program were initially collected during winter lamprey salvage operations at John Day Dam (Figure 1). In later years, collections were augmented with fish collected at Bonneville and The Dalles dams. Fish were held through the winter then released the following spring to one of six locations in the Umatilla Subbasin (Table 1, Figure 2).

In 2001 and 2002, surveys were conducted by foot on the Umatilla River and Meacham Creek in June and July to locate lamprey redds. Surveyors walked downstream along the margins or in the river and traversed from bank to bank checking the tail out of each pool and above each riffle.

To study egg viability, a subsample of redds was sampled for eggs in 2001. A probe sample of 10–20 eggs was taken to determine stage of egg development. When eggs were nearing hatching, approximately 200 were taken from each redd. Viable and unviable (covered with fungus or deformed) eggs were counted using a dissecting microscope.

Thirty sites were selected in the Umatilla River for documenting larval densities. All sites were 7.5 m^2 in area with silt substrates where larvae are typically most abundant. During August and September, larvae were collected during two passes with a backpack electrofisher designed for use with lamprey ammocoetes. If no larvae were detected in the first pass, only one pass was conducted. All fish collected were measured (millimeters), a subsample was weighed (nearest 0.01 g), and then fish were returned to the collection site.

The outmigration of larval and metamorphosed lampreys was monitored each year using a rotary-screw trap located 1.9 km upriver from the mouth. The trap was checked and the catch was enumerated twice daily. Lampreys were measured (millimeters) and then returned to the river. Mark–recapture studies were conducted to calculate trapping efficiency of the rotary screw trap and to estimate the total number of outmigrants during trapping.

Adult lamprey entering the Umatilla River each year were captured in portable assessment traps placed just below the water surface on both sides of the entrance to the fish ladder at Three Mile Falls Dam. Traps were checked daily and captured lamprey were measured and released immediately upstream from the dam.

TABLE 1. Releases of adult Pacific lamprey into the Umatilla subbasin, 2000–2011, as part of a translocation program. Rkm = river kilometer. NA signifies that no fish were released. Data from Close et al. (2009) and Jackson et al. (2011).

		Umatilla River					
Year	Number Released	Rkm 98.8	Rkm 118.4	Rkm 139.9	Iskúulktpe Creek	Meacham Creek	South Fork Umatilla River
2000	600	NA	150	300	NA	150	NA
2001	244	NA	82	81	NA	81	NA
2002	491	150	100	141	NA	100	NA
2003	484	NA	90	110	54	230	NA
2004	133	NA	NA	63	NA	70	NA
2005	120	NA	NA	50	15	55	NA
2006	198	NA	NA	90	21	87	NA
2007	394	NA	NA	200	25	169	NA
2008	68	NA	NA	26	NA	42	NA
2009	337	NA	NA	100	25	150	62
2010	291	NA	NA	128	13	150	NA
2011	89	NA	NA	40	10	39	NA

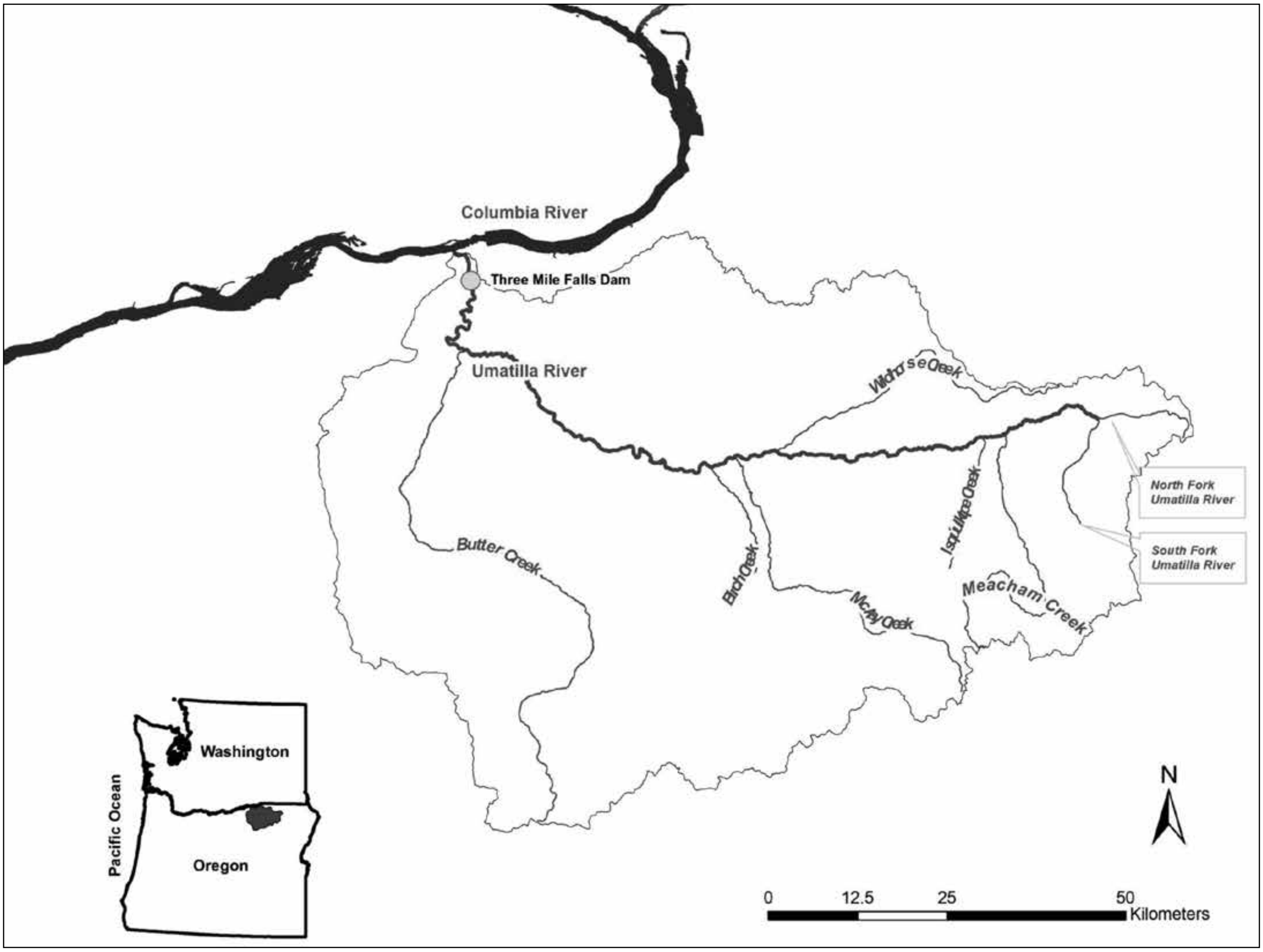

Figure 2. Map of the Umatilla River Subbasin, showing streams utilized in the Umatilla Tribe translocation program.

Results

Translocated lamprey spawned and produced viable eggs. In 2001, 19 viable redds were found in the Umatilla River and 30 in Meacham Creek. In 2002, 21 viable redds were found in the Umatilla River and 46 in Meacham Creek. Mean 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%, with viability exceeding 99% in 7 of 16 redds. Seventy-five percent of the unviable eggs were covered by fungus and 25% were deformed.

Larval abundance in index plots sharply increased one year after translocation of adult lamprey (Figure 3). Mean larval density increased from 0.08 ± 0.05 larvae/m^2 in 2000 to 5.23 ± 1.73 larvae/m^2 and 6.56 ± 2.44 larvae/m^2 in 2001 and 2002 ($P < 0.01$). Mean densities remained elevated through 2009.

Larval distribution also increased through time (Figure 4). In the years prior to translocation of adults, no larvae were found in the upper Umatilla River. One year after translocation of adults, larval densities increased and the distribution of larvae moved downstream. By 2005, larval distribution extended downstream to the middle reaches of the Umatilla River, with little change in larval densities in the lower river.

Abundance of both migrating ammocoetes and macrophthalmia sharply increased from previous low levels during 2000–2001 (Figure 5). Abundance returned to low levels and then began increasing again in 2005–2006.

The number of adults observed in the Umatilla River increased beginning 4 years after the first translocations, with a clear increase beginning after 6 years (Figure 6). The total number of individuals entering the Umatilla River remained relatively low through 2010, but a large increase was observed in 2011.

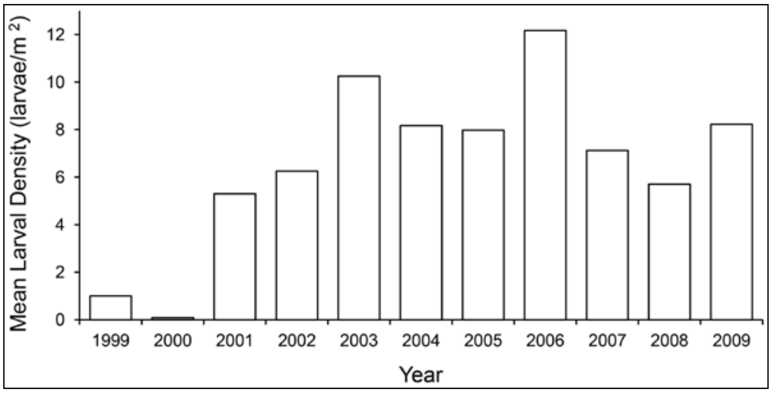

Figure 3. Changes in larval densities (mean of 30 index sites) after translocating adult Pacific lamprey to the Umatilla River, 1999–2009.

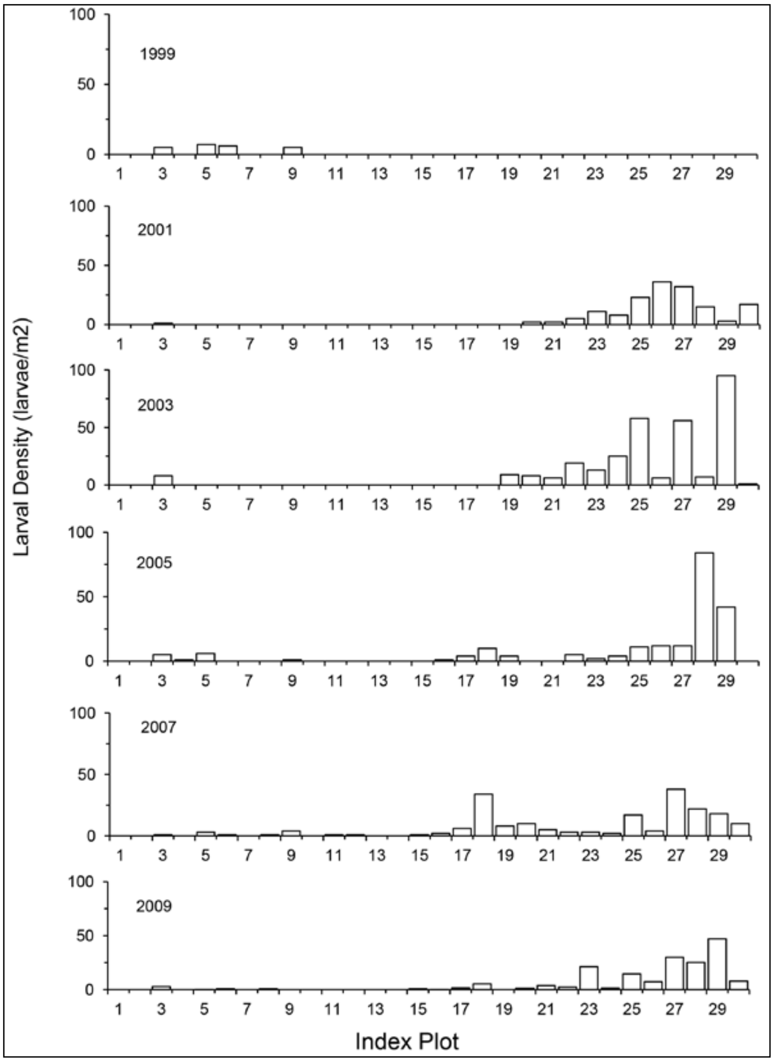

Figure 4. Density of larval Pacific lamprey in the Umatilla River, 1999–2009. Index plot 1 is near the mouth and index plot 30 is in the upper Umatilla River.

Case Study: Nez Perce Tribe Pacific Lamprey Translocation Program (Clearwater and Asotin Subbasins)

Background

Counts of adult Pacific lamprey at Snake River dams did not begin until 1996; therefore, no long-term information at these sites is available. Nevertheless, available count information indicates a decline in numbers of Pacific lamprey returning to the Snake River. Counts at Lower Granite Dam (Figure 1) were 490 in 1996 and 1,122 in 1997 but have failed to exceed 100 since 2004 (Fish Passage Center 2012).

Information summarized by Cochnauer and Claire (2009) from the Clearwater Subbasin (Figure 7) indicates a precipitous decline in lamprey abundance and distribution. The number of kilometers occupied by Pacific lamprey in the Clearwater River and six selected tributaries declined by an estimated 66% between 1960 and 2006. Counts at Lewiston Dam, near the mouth of the Clearwater River, decreased from over 5,000 in 1950 to zero by 1972, after which the dam was removed and lamprey once again had access to the upper drainage. Pacific lamprey ammocoetes and macrophthalmia were collected in Lolo Creek (Figure 7) from 1994 through 2003; however, continued sampling failed to capture any lamprey from 2004 through 2006. Since 2006, biologists with the Nez Perce Tribe have conducted a trial translocation program to augment natural lamprey production in the Clearwater and Asotin subbasins.

Methods

The methods described here are summarized from a detailed account provided by Peery (2010). Adult lamprey salvaged from John Day Dam and The Dalles Dam during the annual winter dewatering period were held through the winter at the Nez Perce Tribal Hatchery on the Clearwater River (Figure 1). In May they were released into one of four Snake River tributaries: Asotin Creek in Washington and Lolo, Newsome, and Orofino creeks (Clearwater Subbasin) in Idaho (Figure 7, Table 2).

To document the effectiveness of the Nez Perce Tribe translocation program, approximately 30 fish each year were surgically outfitted with radio transmitters and released into three of the four streams (Table 2). Lamprey were typically released at two locations in each stream at sites containing suitable spawning and rearing habitat. Weekly surveys were conducted to determine movements of translocated lamprey following release. Limited spawner surveys were made by foot to locate lamprey redds and, if possible, verify spawning activity.

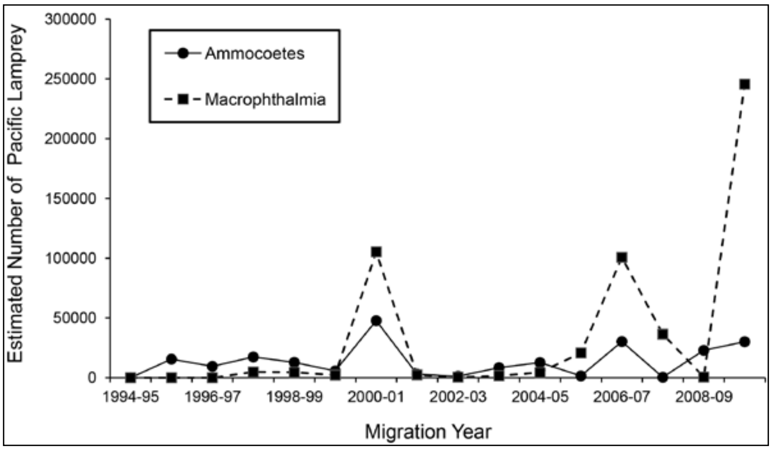

Figure 5. Yearly estimates of the number of migrating Pacific lamprey ammocoetes and macrophthalmia near the mouth (rkm 1.9) of the Umatilla River.

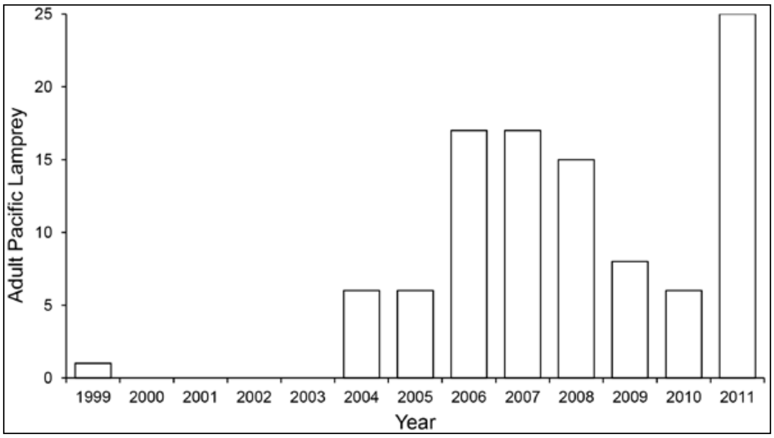

Figure 6. Number of adult Pacific lamprey trapped at Three Mile Falls Dam on the Umatilla River, 1999–2011. An additional 104 lamprey passed the dam in 2011 via a new lamprey passage structure.

During the summer of 2009, surveys to search for juvenile lamprey were initiated in Newsome and Lolo creeks. A specialized backpack electrofisher was used to systematically survey 15-km reaches of the streams, encompassing areas where radio-tagged lamprey had been located. Starting at locations where adult lamprey were released, sites up- and downstream at approximately 1-km intervals were surveyed. At each site, surveys were conducted on approximately 50 m of stream or until 20–30 ammocoetes were collected. Lengths (millimeters) and weights (nearest 0.1 g) of collected fish were measured and then fish were returned to the collection site.

Surveys were repeated in 2010 in Newsome, Lolo, and Asotin creeks. Control streams in the area were also surveyed to gauge the level of natural production: Musselshell and El Dorado creeks (tributaries of Lolo Creek); George Creek (tributary of Asotin Creek); Red, American, and Crooked rivers (tributaries of the South Fork Clearwater River near Newsome Creek); and two locations in the South Fork Clearwater River near Newsome Creek (Figure 7).

Results

From 2007 through 2010, 480 adult lamprey were released into the four study streams, of which 115 were radio-tagged (Table 2). For the first three years, all but two of these fish survived until release the following spring; in 2007 and 2009, one fish died after being radio-tagged. In 2010, 9 fish, including one radio-tagged fish, died prior to release. At release in 2010, we also determined that two radio transmitters had stopped working, one each from the Newsome Creek and Asotin Creek groups.

Following release, adult lamprey either remained near the release areas, moved moderate distances (1 to 5 km) up- and downstream, or moved downstream and out of the release watersheds (Table 3). From three years of information (2008–2010) in which the same three study streams were investigated, 30% (25 of 83 fish) remained at or near the release sites and 12% (10 of 83) left the study streams. Most that left were fish from Newsome Creek (n = 6) and Asotin Creek (n = 3). One of 30 fish released into Lolo Creek was also detected in the Clearwater River in 2010, a distance of over 50 km downstream from the release location. Of the remaining 48 fish (58%) that moved within the release streams, 69% (n = 33) moved about 4.8 km downstream, and the rest moved 1 to 3 km upstream (3.1 km in 2009, 1.3 km in 2010), on average.

Over the four years of the study, 48 redds were observed in study streams. The number of redds observed per stream each year varied from 0 to 8, with most (41 of the 48) observed in Lolo and Newsome creeks. The number of redds observed each year declined from 16 in 2007 and 2008 to 6 in 2010. Based on when redds were first observed, spawning occurred during June and early July in 2007 and 2008 and late July to early August in 2009 and 2010.

Ammocoetes were observed in the study streams but only in the mainstem South Fork Clearwater River for the control sites surveyed. Ammocoetes occurred in a 15-km segment of Lolo Creek (from the upper release to mouth of El Dorado Creek), a 14-km segment of Newsome Creek (from the upper release site to confluence with the South Fork Clearwater River), and a 15-km segment of Asotin Creek (upper release site downstream to river km 3). In 2009, we observed ammocoetes at all sites surveyed in Lolo and Newsome creeks (Figure 8). Mean length of ammocoetes per site ranged from 57 to nearly 88 mm and tended to be largest at downstream sites in Lolo Creek. Mean length per site of ammocoetes in Newsome Creek ranged from 52 to 84 mm and trended smaller at downstream sites. Length frequencies for all ammocoetes sampled produced unimodal distributions with peaks at 70 mm in both streams (Figure 9). No ammocoetes were observed at the control sites sampled in El Dorado and Musselshell creeks and American and Red rivers.

In 2010, ammocoetes were observed at one site 0.6 km upstream from the upper release point for adult lamprey; otherwise, the distribution of ammocoetes in Newsome and Lolo creeks was similar to that observed in 2009. In Asotin Creek,

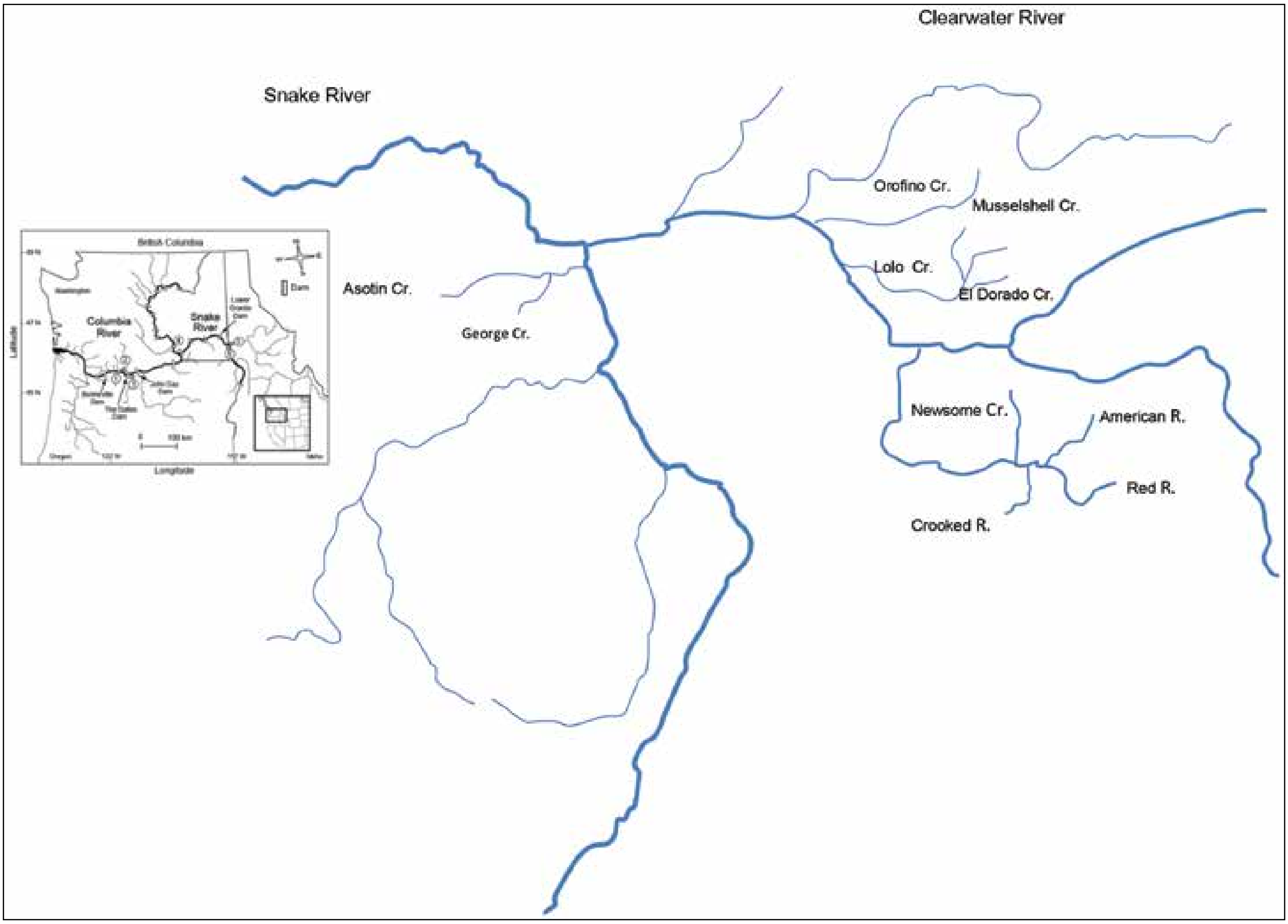

Figure 7. Map of lower Clearwater River and Asotin Creek subbasins, showing streams utilized in the Nez Perce Tribe translocation program.

ammocoetes were found in good abundance in an approximately 3-km section of stream near the adult lamprey release sites (river kilometer [rkm] 11.7 to 14.3), but few were collected in the lower 10 km of the stream (Figure 8). Mean length of ammocoetes per site ranged from 57 to 106 mm in Lolo Creek, 44 to 85 mm in Newsome Creek, and 56 to 149 mm in Asotin Creek (Figure 8). Mean lengths were greater at downstream sites in all three study streams. Length frequency plots described wider distributions for ammocoetes sampled in 2010 than in 2009 (Figure 9). Length–weight curves also suggested a wider distribution of sizes for ammocoetes in 2010 than in 2009 (Figure 10). In general, ammocoetes tended to be larger in 2010 than in 2009 in both Lolo and Newsome creeks. Ammocoetes were collected from two sites in the South Fork Clearwater River 10.1 and 2.4 km upstream from the mouth of Newsome Creek. Mean lengths of lamprey at those two sites were 123 and 139 mm, respectively. No ammocoetes were observed at sites sampled in Crooked, American, and Red rivers or in Musselshell and El Dorado creeks.

DISCUSSION

Results from both programs suggest that translocations of adult Pacific lamprey have resulted in increased spawning in the recipient subbasins, as evidenced by increases in the number and distribution of ammocoetes (and macrophthalmia in the Umatilla) from preprogram conditions. In addition, the Umatilla Subbasin experienced a small but consistent increase in the number of naturally spawning adults within four to six years of the first translocations. Increases in naturally spawning adults

TABLE 2. Releases of adult Pacific lamprey into four study streams in the Clearwater and Asotin subbasins, 2007–2010, as part of a translocation program. NA signifies that no fish were released. Data from Peery (2010).

Release Location	Total Released				Radio-Tagged Released				
	2007	2008	2009	2010	2007	2008	2009	2010	Total
Lolo Creek	50	27	28	22	10	10	10	10	40
Newsome Creek	50	25	25	22	10	9	9	9	37
Orofino Creek	49	27	26	24	10	NA	NA	NA	10
Asotin Creek	28	27	27	23	NA	10	10	8	28
Total	177	106	106	91	30	29	29	27	115

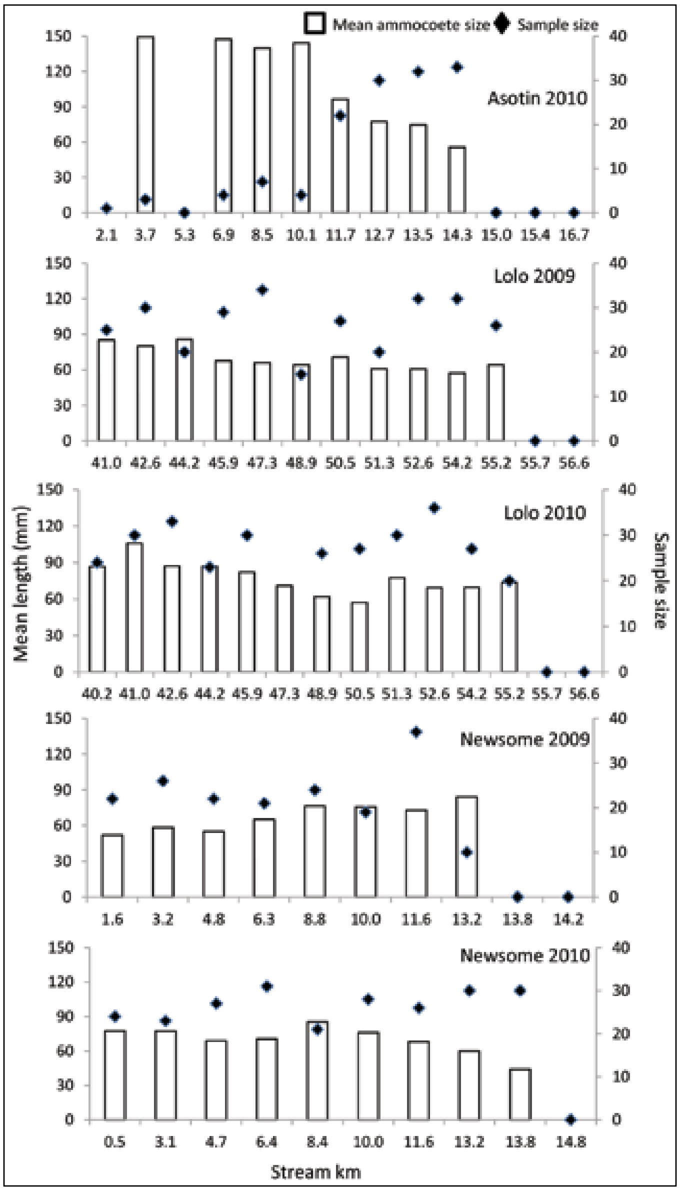

Figure 8. Numbers of juvenile Pacific lamprey ammocoetes (diamonds) and mean size of ammocoetes (millimeters; bars) collected in study streams during 2009 and 2010.

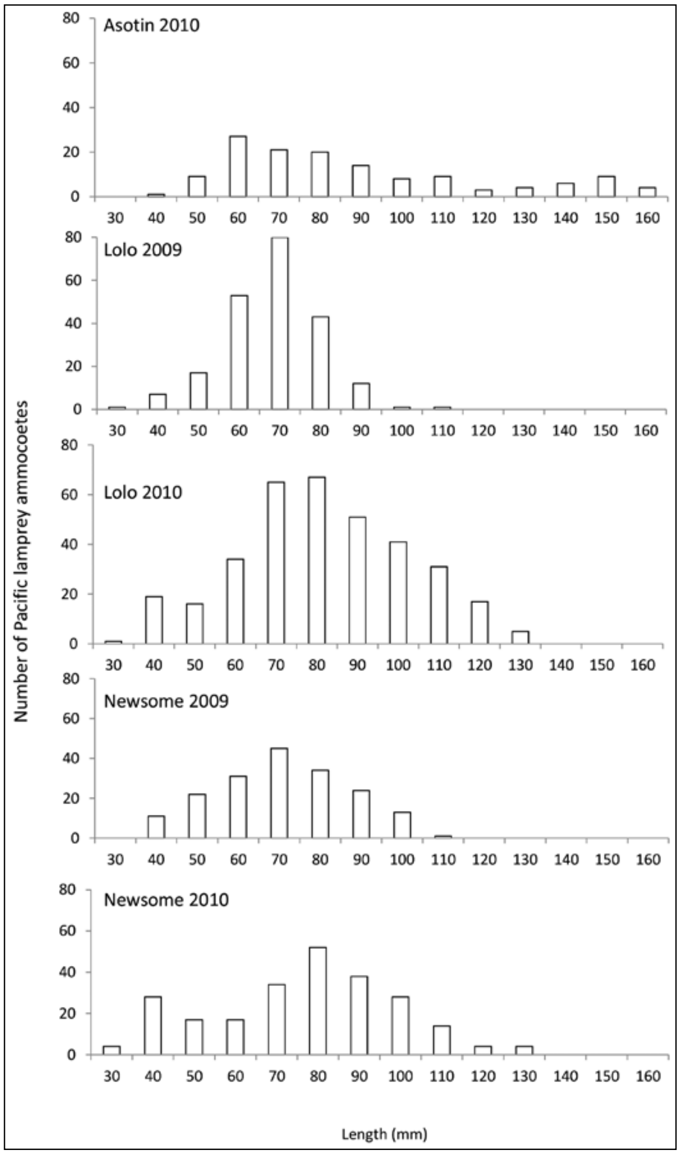

Figure 9. Length frequency distributions for juvenile Pacific lamprey ammocoetes collected from study streams during 2009 and 2010.

have not yet been documented in the Clearwater and Asotin subbasins, because this program is only four years old.

In systems with remnant lamprey populations, assessment of translocation effects can be confounded by even limited natural production. For example, the 2000–2001 increase in ammocoetes and macrophthalmia collected in the Umatilla River was likely due to natural production that occurred before the translocation program began. In subsequent years, numbers returned to low levels and then again increased. We think, based on ammocoete densities measured at index sample sites, that subsequent increases likely included progeny from the translocation of adult lamprey. This result highlights the utility of long-term sampling of index sites following lamprey translocations.

Translocation programs in areas where lamprey have been extirpated allow for direct assessment of production ascribed to specific translocations. Cochnauer and Claire (2009) reported that by 2006, Pacific lamprey no longer utilized Lolo Creek. It is therefore likely that all redds observed in Lolo Creek were from translocated lamprey. The 2009–2010 observations of ammocoetes in all streams in the Clearwater Subbasin receiving adult lamprey, combined with the absence of ammocoetes in all control streams (except for the South Fork Clearwater River), further supports the premise that most production observed was from translocated lamprey.

Assessment of translocation efforts can also be confounded by simultaneous efforts to improve access to and/or quality of lamprey spawning and rearing habitat. For example, the large increase in Umatilla River adult lamprey abundance observed in 2011 (N = 129) may be partially due to installation of a new lamprey-specific fishway at Three Mile Falls Dam (Figure 2). Nevertheless, at least 25 (19%) adults passed the dam via the

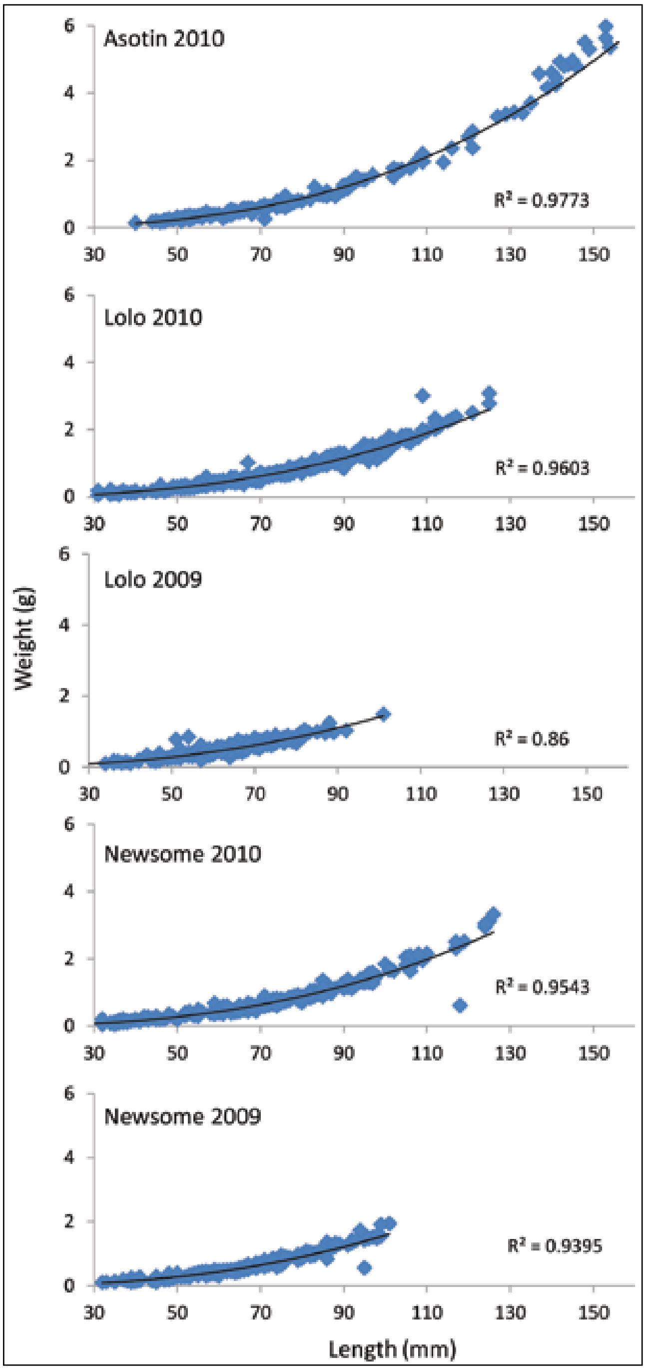

Figure 10. Length–weight relationship for juvenile Pacific lamprey ammocoetes collected from study streams during 2009 and 2010.

fish ladder, continuing the trend of increased adult abundance following translocations.

The delay in observing appreciable increases in the number of naturally spawning adults is due at least in part to ammocoetes spending at least 3–6 years in freshwater (Richards 1980). In addition, the concept of "returning adults" as used for Pacific salmonids is likely inappropriate for use with Pacific lamprey. Pacific lamprey likely do not return to natal streams (Hatch and Whiteaker 2009) but are guided to spawning locations by other factors. Yun et al. (2011) demonstrated that adult Pacific lamprey are attracted to odors emanating from ammocoetes. Docker (2010) determined that levels of genetic differentiation among Pacific lamprey from different areas were low, providing support for a lack of population differentiation that would occur with natal homing.

A primary benefit of translocation efforts may therefore be increased production of juvenile lamprey in the augmented watershed, "seeding" underutilized rearing habitat, and increasing pheromone cues to attract adults. Translocation and other restoration programs could therefore have a synergistic effect in breaking the downward cycle of Pacific lamprey abundance and recruitment.

Another potential benefit of translocation is expanded distribution of Pacific lamprey, via occupation of subbasins where they have been severely depressed or extirpated. Until passage is better understood and improved at mainstem dams, translocation from lower dams may also produce an escapement benefit for lamprey. These benefits 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 approximately 600%–800% based on 2009 and 2010 counts.

Lamprey translocation may also produce ecosystem benefits. Because ammocoetes are filter feeders and detritivores, increased production may facilitate nutrient cycling in 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

TABLE 3. Movement by radio-tagged adult Pacific lamprey following release into four study streams as part of a translocation program, the proportion that were known to have left the study streams after release, and number of suspected lamprey spawning redds observed in study streams per year. NA signifies that no fish were released. Data from Peery (2010).

	Pacific Lamprey with Radio Transmitters											
	Mean Distance Moved (km)				Proportion That Left Stream				Redds Observed			
Stream	2007	2008	2009	2010	2007	2008	2009	2010	2007	2008	2009	2012
Lolo	3.2	1.6	3.6	7.6	0	0	0	0.1	8	3	6	3
Newsome	5.1	2.1	4.3	5.0	0.3	0.2	0.2	0.22	6	8	4	3
Asotin	NA	4.2	3.9	1.4	NA	0.22	0.1	0	NA	5	0	0
Orifino	3.2	NA	NA	NA	NA	NA	NA	NA	2	NA	NA	NA

upper reaches of the Columbia River Basin. Lamprey restoration will also increase the prey base available to native fish and avian predators.

Although the best long-term sustainable option for increasing Pacific lamprey abundance and distribution may be completion of improvements to passage for adults and juveniles, translocation of adults may be the best immediate option to begin the process of rebuilding populations in depressed subbasins. An aggressive program by the U.S. Army Corps of Engineers to improve adult passage is currently underway (USACE 2009) but will take more than 10 years to implement and likely another 10 years to monitor and adjust. Juvenile passage improvements are more challenging and will likely require even longer. As passage problems are addressed and lamprey survival increases, translocation efforts could be downsized or phased out.

Potential risks from lamprey translocation include disruption of population structure and associated genetic adaptations, exposure to survival risks such as pathogens and disease, and decreased abundance in donor areas. These potential risks have been recognized, and steps have been taken to avoid or reduce them by adherence to lamprey translocation guidelines agreed to by the Columbia River Inter-Tribal Fish Commission (CRITFC 2011).

Little evidence exists of broad-scale genetic differentiation among Pacific lamprey sampled along the West Coast of North America (Docker 2010); however, Keefer et al. (2009) and Clemens et al. (2010) found that adult Pacific lamprey body size may be associated with the distance of upstream migration and swimming ability. Although relatively little is known about the heritability of body size in fishes or the relative importance of different factors causing intra- or inter-population variation, work by Thériault et al. (2007) on brook trout (*Salvelinus fontinalis*) suggests that life history tactics may evolve in response to selective pressures acting either directly on the tactic itself or indirectly on body size. Docker (2010) suggested that most Pacific lamprey could be managed as a single unit based on the low amount of genetic variation in nine microsatellite markers examined in samples from nine populations in British Columbia (Canada), Washington, California, and Oregon. However, she did find genetic variation among a few sampled sites that she attributed to small population sizes and sampling effects rather than reproductive isolation. Therefore, though consideration should be given to potential disruption of stock structure and associated genetic adaptations, we feel that the risk of adverse effects on population and genetic structure from translocations is much lower than the risk of losing some of the populations if they are not sustained, at least in the short-term, through translocations.

Although disease transmission is a potential risk with interbasin transfers of lamprey, it has been low. Oregon Department of Fish and Wildlife Fish Health Services used standard fish health diagnostic methods to test Pacific lamprey for pathogens (85 adults and 21 larvae). The primary pathogen of concern was a bacterium, *Aeromonas salmonicida*, the causative agent of furunculosis. Nine (8.5%) of the lamprey tested were found to have systemic *A. salmonicida* infections over the past decade. These fish represent a single sample that died following collection and transfer in June 2005. Since this event, routine oxytetracycline injections (10 mg/kg) have been implemented and appear to be successful. Because *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease, has been found in sea lamprey (*Petromyzon marinus*; 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 potential use of pheromones by adult Pacific lamprey for orientation and navigation (Yun et al. 2011) has important implications for lamprey management. Moving lamprey between drainages raises the potential to alter future adult escapement in both the donor and recipient populations. Though the latter may be a desired objective, there is a possibility of shifting spawners from high- to low-productivity watersheds, with a risk of diminished overall productivity for the system. In addition, lamprey translocation programs should not cause a substantial decrease in abundance in any currently occupied subbasin. To date, mainstem Columbia River lamprey collection for the Umatilla program has ranged from 0.1% to 2.0% of the total estimated returns to Bonneville Dam, averaging 0.43%. As the abundance of Pacific lamprey languishes, the urge to translocate an ever-increasing number may compete with other interests in maintaining or increasing numbers in different parts of the Columbia River Basin.

In summary, translocation programs have resulted in some obvious successes (natural spawning of translocated adults, increased production of ammocoetes, etc.); however, important lessons have been learned. As summarized by Close et al. (2009), Pacific lamprey require post-reintroduction management and a well-designed monitoring program. This is in part due to the long life cycle of Pacific lamprey and the likelihood that they do not home to natal streams. Also pertinent is the effect of the suite of potential limiting factors both within and outside of recipient subbasins. Although these factors have not been fully addressed and ameliorated, translocation can serve to prevent further localized extirpations until long-term solutions are implemented.

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