First International Forum on the Recovery and Propagation of Lamprey

April 19-21, 2011

Portland, Oregon

Workshop Report

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Prepared for

Columbia River Inter-Tribal Fish Commission
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Attendees listed in ***bold*** *were presenters.*

***** Forum Coordinator

Introduction

Workshop Introduction from Bob Rose, Confederated Tribes and Bands of the Yakama Nation:

The context and goals for this workshop are all carefully embedded in its title, which simultaneously expresses the reasons for assembling this particular meeting and the longer-term goals of this type of collaboration moving forward.

First – This is the "First International Forum" on this issue and we sincerely hope the friendships and experiences we establish here will provoke a second and a third gathering. We hope this will not be the only or the last, but the beginning of an ongoing conversation.

International – It is apparent that the decline in lamprey populations is an international issue. Over the next few years we hope to encourage greater international involvement and gather lots of success stories from which an international community can not only learn, but learn at a greatly accelerated rate.

Forum – A forum is a discussion; it is an opportunity. This forum is intended to be informal. We have a room, we will have food, and most importantly we have the right people here. The objective is 3 days of discussion and sharing of ideas.

Recovery – Our ultimate goal is the recovery of lamprey populations, and not just in one place but in all places.

Propagation – We know that the factors that have brought lamprey populations to perilous decline will take a long time to fix. Artificial propagation may be the lifeline for some species. Propagation certainly opens up many doors for research, which is also very important to us.

Lamprey – In time, we hope to include all lamprey in this discussion, not just Pacific lamprey or Arctic lamprey or European River lamprey.

These are the reasons for the title of this workshop, which are lofty ideas. But here we are today – we are starting.

Key Questions

Is the artificial propagation of Pacific lamprey possible?

Are there existing facilities and resources in the Columbia Basin that would be appropriate for the artificial propagation of lamprey?

Where are the most appropriate or most beneficial locations for outplanting?

Invocation

An invocation was given by Mitch Pond (CTUIR).

Day 1

State of the Lamprey

The presentations of the opening session clearly illustrated that despite differences in geography, history and lamprey species, the state of the lamprey is remarkably similar among the Columbia Basin, Japan and Finland. In all three regions, lamprey populations are dramatically below their historic levels, having suffered from the exposure to a suite of fairly common threats that continue to exert pressure on lamprey habitat and survival. Lamprey are important both as a traditional food source and integral part of the local ecology in these regions. In each of these regions, there exists a small but dedicated group of people working on conservation initiatives with effectively the same goals and encountering similar obstacles to successful restoration of lamprey.

Lamprey species

Within the Columbia Basin, the focal species of lamprey for this forum is the Pacific lamprey (*Entosphenus tridentatus*), although Western Brook lamprey is also present in some of the watersheds. In Japan, there are several species of lamprey, but Arctic lamprey (*Lethenteron camtschaticum*), has the widest distribution and the highest commercial value. Arctic lamprey has an anadromous parasitic form and a fluvial nonparasitic form. Siberian lamprey (*Lethenteron reissneri*), also a fluvial nonparsitic species, has a wider geographic range in Asia, but a much smaller distribution in Japan relative to the Arctic lamprey. Pacific lamprey (*Entosphenus tridentatus*) occurs in only a few particular river systems in Japan. In Finland, the species of concern is River lamprey (*Lampetra fluviatilis*), which has both anadromous and fluvial forms.

Importance of Lamprey

In all three regions, lamprey represents a traditional food source for local peoples. Lamprey is used in traditional medicines in Japan and by the tribes in the Columbia Basin, for whom lamprey is also important for religious reasons. Lamprey also play an essential ecological role, especially in their freshwater habitats.

Decline

Lamprey abundance has declined substantially from historic levels in all three regions (**Figures 1-3**). However, in many cases estimates of abundance are quite poor due to methodological concerns, the reliance on catch data as a proxy for abundance, or large gaps with no data.

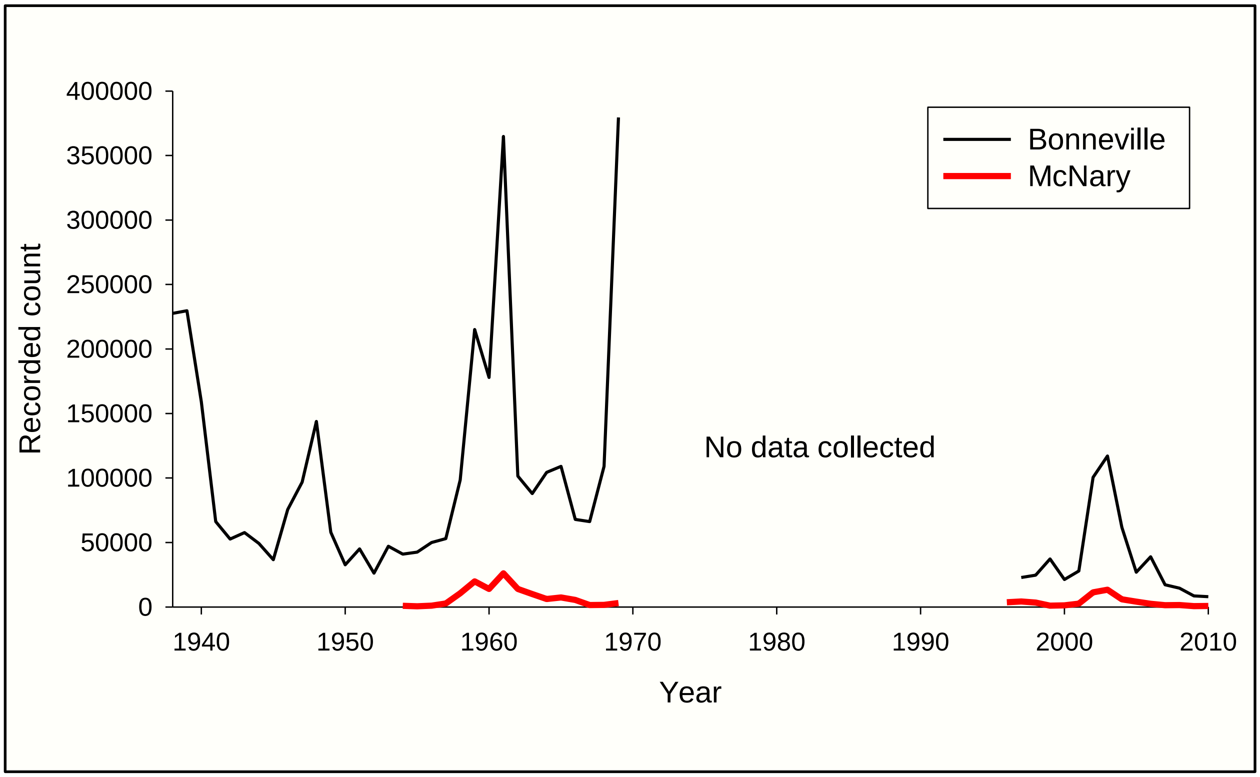

Figure 1. The decline of lamprey in the Columbia River. Reported counts of Pacific lamprey at Bonneville and McNary dams are shown.

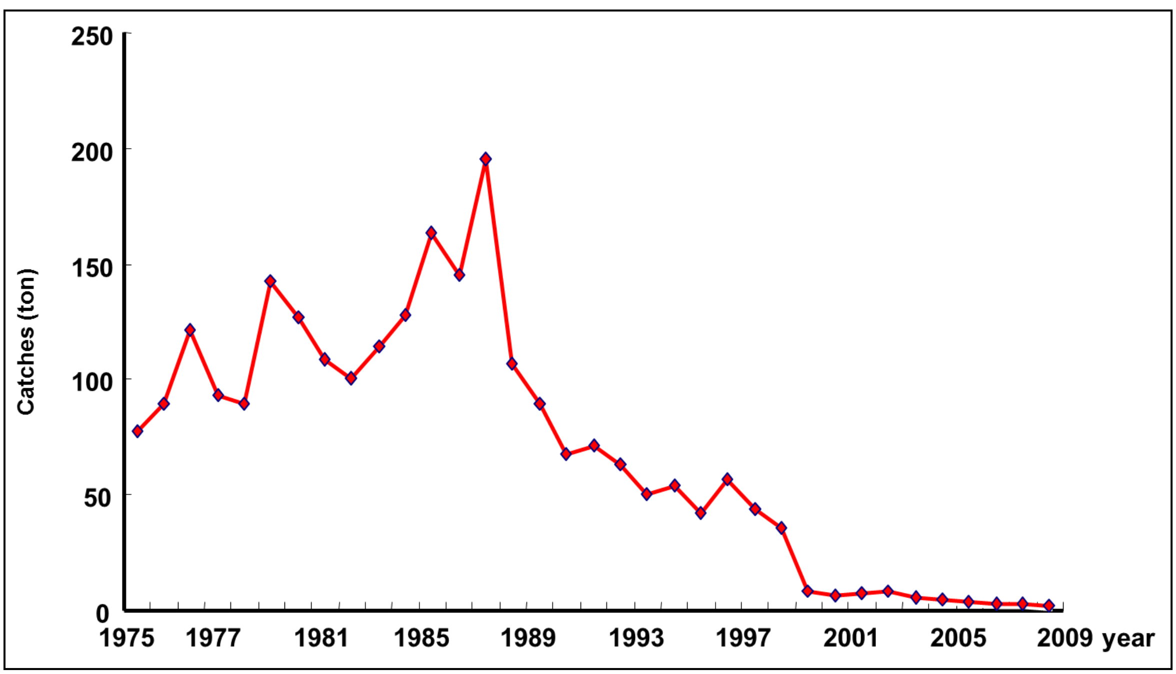

Figure 2. The decline of lamprey in Japan. Arctic lamprey fisheries catch in northern Japan.

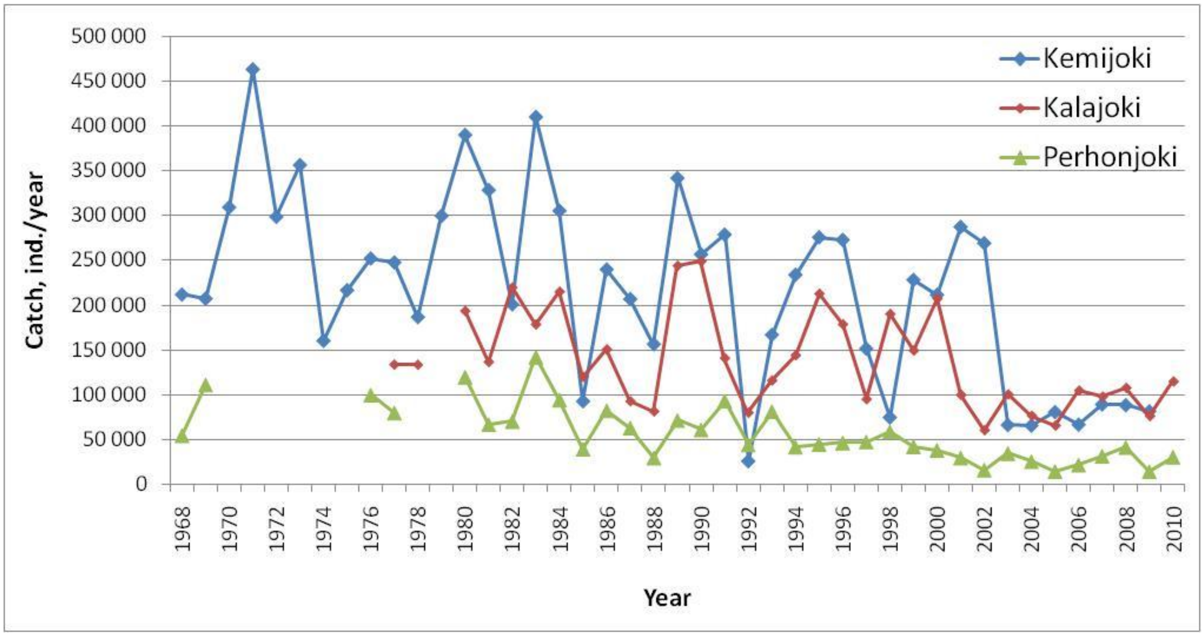

Figure 3. The decline of lamprey in Finland. River lamprey catch in three Finnish rivers.

Threats

Lamprey face a suite of threats, many of which are similar across all three regions. These threats can be classified into: changes in hydraulic properties of fluvial habitat; man-made barriers to habitat; loss of physical habitat; water quality issues; and overfishing.

Most of the rivers considered are highly regulated. Dams withhold and release water according to the needs of power generation, which can produce both unnaturally high and low flows. In some systems the flow will change many times per day, forcing lamprey to move and stop many times, which may have high energetic costs and increase the duration of upstream migration. Weirs, modify the flow characteristic of rivers, are widespread throughout each of these regions. Additionally, large amounts of water are diverted for irrigation in all three regions, which can result in low water levels. In the Columbia Basin, the hydrograph has been changed / reduced by approximately 40% relative to its historic level.

Dams, weirs and agricultural diversions also present barriers to lamprey passage. Some of these obstacles are an absolute barrier to passage, isolating lamprey from viable habitat. For example, Arctic lamprey are not good at climbing and therefore cannot overcome any obstacle taller than 1 meter. Other barriers are passable but only with a low success rate. For example, it is estimated that only half of migrating adult lamprey pass each of the mainstem dams on the lower Columbia River. These barriers are numerous throughout mainstem and tributary rivers.

Physical habitat has been lost as a result of extensive river modification and channelization in many of the river systems examined. Degradation of the physical river habitat can be from direct human action, or as an indirect consequence of the manipulation of the natural hydrograph, which can increase erosion of critical sediment and features of river morphology. In Finland, many rivers were historically dredged in order to facilitate log floating or rafting.

Water quality is a concern because lamprey spend a large portion of their lives in freshwater and depend heavily on olfactory signals. Pesticides and fertilizers from agriculture are a major pollution source. Another emerging threat, with very sparse information, is endocrine disruptors. In Finland, sulfate acid soils are a major concern and can produce river reaches that are effectively dead.

Overfishing was noted as an important threat to lamprey in Japan. In the Columbia Basin and Finland, traditional fisheries have been greatly affected by the decline of lamprey but have not been identified as significant underlying causes.

Conservation Efforts

In the Columbia Basin, the four Tribes have been a major driver behind conservation and restoration efforts. The Vision Statement of the tribal restoration plan reads, "Pacific lamprey are widely distributed within the Columbia River Basin in numbers that fully provide for ecological, tribal cultural and harvest utilization values". At a broader scale, the USFWS is working on a range-wide conservation initiative with the ultimate goal to coordinate, integrate and implement the regional recovery plans and partnerships needed to prevent lamprey from needing to be listed. In Japan, conservation initiatives can be classified into five themes: monitoring, genetic research, aquaculture, restoration, and education. In Finland, there have been some grass-roots recovery efforts carried out by fishermen, but most of the research and supplementation initiatives have been dictated by orders of the Environmental Court. The Finnish government's Fisheries Research Institute has generally not been interested in lamprey, mostly because of its relatively low value.

Obstacles

Throughout the presentations, several factors appear to be somewhat common obstacles to restoration and recovery efforts across all regions. The public appears to be poorly informed, often misinformed, and generally not interested in lamprey ecology and conservation. In the U.S., failure to have lamprey listed under the Endangered Species Act has been another obstacle – a successful listing would offer greater opportunities for funding and provide a mandate for conservation and recovery planning. The lack of knowledge on lamprey was a major factor in the decision not to list lamprey and is a common issue across regions. But improvements to the knowledge base are heavily constrained by the general lack of funding available for lamprey research at the institutional level. In the Columbia Basin, the difficulties in coordinating resources and efforts among the multiple actors involved have also been a potential obstacle.

Critical Uncertainties

Three critical uncertainties were frequently identified. First, the population structure of Pacific lamprey (and others) is not well understood. It is clearly very different than for salmon and there is little evidence to support any fine scale structure. Second, the marine phase of lamprey is poorly understood. Even the number of years spent in the ocean appears to be variable within populations. Third, relatively little is known on the homing ability of migrating and spawning adult lamprey. Research has shown that adult lamprey returning from the ocean respond to a pheromone or pheromones released by juvenile lamprey upstream. The current understanding is that this may be a critical mechanism that causes adult lamprey to return to streams inhabited by juvenile lamprey, which in turn suggests that the presence of juvenile lamprey in upstream reaches is a vital component of the natural life history of lamprey. However, the degree to which lamprey return to their natal streams it is much less clear. The limited evidence available suggests that lamprey may potentially be a panmictic species or possess only a weak homing behaviour. Other factors that may influence the return migration and stream selection of adult lamprey are also poorly understood.

Current Research, Monitoring and Propagation Efforts

Finland – Kimmo Aronsuu, ELY

Overview of Research, Monitoring and Supplementation Efforts in Finland

In Finland, the majority of research has been driven by to fulfill orders of the Environmental Court. Research began in the late 1970s and 80s, primarily focusing on how river regulation affects lamprey (including abundance of upmigrating adults and larval density). During the 1990s, research focused primarily on establishing the foundation for rehabilitation efforts. The information required included: studying the habitat requirements for spawning and larvae; investigating effect of poor water quality on eggs, larvae of different sizes, and wintering adults; and conducting surveys to determine the quality and quantity of existing habitat that was available to lamprey. Research in the 2000s was predominantly aimed at improving rehabilitation, by advancing propagation methods and monitoring the effectiveness of rehabilitation measures. Rehabilitation requires a sequence of three important stages: 1) decreasing the levels of harmful human impacts; 2) restoring the ability of rivers to support natural production and migration; and 3) helping lamprey over any limiting life stages. Many other smaller, river specific research projects have been conducted over time. The future of lamprey research in Finland is uncertain, as there has been an increasing trend towards outsourcing the work and research traditionally done by government agencies.

Japan – Yuji Yamazaki, University of Toyama

Current Research, Monitoring, and Supplementation Efforts in Japan

In Japan, research to advance for conservation and propagation of lamprey is focused in three areas: artificial propagation methods, natural ecology, and genetics. Techniques of artificial breeding and cryopreservation have improved (discussed on Day 2). Field surveys have been successful in improving the knowledge about the ecology of larval and adult lamprey (discussed on Day 2).

Genetic research has provided valuable information (e.g. taxonomy, population structure, gene flow, and genetic diversity) for conservation and propagation efforts in Japan. Genetic research can help answer many important questions such as determination of conservation and propagation units, understanding of indigenous species and forms, and estimation of population persistence. Research has shown that gene flow among anadromous-parasitic populations was historically abundant but that contemporary gene flow has been directional. The directional gene flow is consistent with host migration (i.e. chum salmon) and demonstrates importance of northern populations as the supply source to maintain southern populations. Dams have resulted in genetic isolation and therefore reduced genetic diversity within fluvial lamprey populations. The influence of river barriers on gene flow has even been observed over the scale of a couple generations within a small agricultural channel with sluice gates.

Question: Does genetic research address whether the Lamprey home to natal streams?

Answer: Lamprey generally have lower ability to home. There's often not a lot of difference between close rivers.

Question: What makes lamprey go to a particular river?

Answer: It's based on the nearest rivers and pheremones from juveniles, but they will still migrate up streams without juveniles too.

Columbia Basin

Note: No formal presentation. Brief summaries were given by a selection of individuals representing different organizations in the Columbia Basin.

Bob Rose, Yakama Nation Fisheries

The state of lamprey in the Columbia is such that we know we're going to need to consider artificial propagation as a component of recovery efforts. A manual for propagation is being assembled, consisting of three documents compiled into one report:

Question/document 1 – Can we propagate Pacific Lamprey?

Question/document 2 – What facilities do we have that could be used?

Question/document 3 – Where would you release propagated lamprey and why?

The table of contents is now available. The plan is to finish the document this spring before having it reviewed by lamprey biologists. The "finished" document will still be considered to be a draft in that it is expected that it will be a living, working document that will evolve over time as the knowledge base is advanced.

The Yakama Nation Fisheries are developing a conceptual foundation to describe and "unify" important components our knowledge base, critical uncertainties and path(s) for moving forward. The conceptual foundation, as described by Jim Lichatowich (1998) lays out the uncertainties, assumptions, and boundaries, providing the scientific framework within which questions can be asked and goals and objectives can be integrated. It is critical to describe a conceptual foundation to provide a clear and defensible rationale for this framework.

Mary Moser, NOAA Fisheries

Mary's research has focused on fish passage, especially with regards to large structures on the Columbia. However, she is also interested in small structures because they are so abundant throughout the entire basin. Since small structures are so numerous, the critical research will be on how to design solutions that are inexpensive. At the moment, there is no funding for research on even smaller barriers such as culverts, but some of the results from the research on small structures may still be useful because it identifies common structural problems and important hydraulic conditions. For large dams, the focus is still on how to design effective means for attraction and collection to lamprey-specific structures, because the lamprey tend to do well once they successfully make it to the ladder/ramp.

Matt Mesa, USGS

The USGS Columbia River Research Laboratory has been working on developing the ability to PIT-tag juvenile lamprey. PIT-tags have been a foundational aspect of salmon management in the Columbia Basin because they produce such valuable information. This type of information is going to be necessary to improve our understanding of lamprey, and therefore it is critical to learn how to successfully PIT-tag juveniles with a high survival rate. The most critical issue to resolve is that handling the lamprey results in a high rate of fungal infection.

The USGS has also been studying the impact of different common designs for irrigation diversions screens. Approximately 80% of diversions are unscreened. For the 20% of diversions with screens, a variety of designs are used but all are based on criteria for juvenile salmon and their impact on lamprey is variable.

Carl Schreck, OSU

Multiple research projects relating to lamprey were briefly discussed:

What is the migratory behavior of adults above Willamette Falls? This project aims to explore the timing of migration behavior, where adults go, where they hold and in what types of habitat, and what different life histories exist. This information might help decide what places would be best for conservation easements, if they were able to be purchased.

What is the lag between infection occurring and the onset of the disease? A primary interest is furunculosis.

What effects do forest herbicides have on lamprey? Olfactory recognition is important for lamprey.

How do lamprey do in different sediments, including toxic sediments from the EPA superfund site in the Port of Portland?

Ralph Lampman's Masters in Science work has used radio-tagging of lamprey in the Umpqua river to assess dam passage. Interestingly, lamprey might actually be using some of the gaps in older wooden dams as habitat.

David Close, UBC / CTUIR

A lot of work has gone into developing an Aboriginal Fisheries Centre at UBC. Research is being done on the endocrinology and physiology of both outmigrants and reproductive adults. Recent research has identified putative migratory pheromones, which would have major implications for restoration. Sex pheromones are also being studied. The research on outplanting in the Columbia has been finished, concluding that successful outplanting is definitely possible. The habitats studied appear good for seeding and much was learned about important ecological processes. But in order to be successful, lower reaches would need to be seeded too.

Day 2

Spawning, Fertilization and Incubation

Finland – Jukka Tuohino, ELY

Research in spawning, fertilization and incubation

Some experimental propagation began in the 1980s in a couple regions. In 1997 artificial propagation became a mandatory measure for supplementing lamprey stocks. The "cookbook" manual for artificial propagation of lamprey was released in 2002, having been developed over several years. There are three lamprey production facilities in Finland. The Kannus facility (focus of presentations) occupied the basement of an old hydropower plant, was operated by the West Finland Environmental Center from 1997-2009, and produced 17 million larvae/year that were outplanted in the Perhonjoki River.

The major steps covered in this presentation include: 1) acquiring, keeping and sorting adult lamprey, 2) hand spawning, and 3) egg handling. Adult lamprey are acquired in August/September, bought from local fisherman. Careless handling during this stage can cause mortality during the winter. Lamprey are kept in storage tanks over winter, where it is important to have a large surface area for the lamprey to attach to. Checkups for water conditions, removing dead lamprey and disease control are only performed every few weeks, so having a reliable water source, circulation system, air pumps, lighting timers, and escape-proof tanks are critical. Males and females are sorted once sexual characteristics become visible in the spring. Females exhibit larger abdomen and males display a sexual protrusion. Sorting makes hand spawning and determining the timing of spawning easier.

Hand spawning needs to be done once most lamprey are ready, otherwise they will die. It is critical to minimize overall handling. Spawned eggs are mixed together, diluted with water, given time to fertilize, rinsed, and poured into incubation funnels. The effects of fertilization time, amount of water used, length of rinsing time have been studied to determine the most effective way of handling the process. However, data is only available for this one facility. The first 24-48 hours of incubation are the most hectic because the eggs are sticky and need constant maintenance. Experience (earned through lots of trial and error learning) is critical. Daily maintenance is required for the next several weeks to adjust water, ensure movement and remove particles. Water filtration may be important depending on the water source. Hatching larvae can be moved to rearing plates immediately or after a couple extra days in the funnels.

Japan – Satoshi Kusuda, Salmon and Freshwater Fisheries Research Institute

Artificial propagation of Arctic Lamprey in Japan

Three areas of research were presented. First, there have been studies evaluating the conditions that induce spawning and behavior of lamprey during spawning. Gravel is vital for spawning and spawning behavior was stimulated by coelomic fluid.

Second, artificial insemination and egg incubation have been studied to assess optimum conditions. The major conclusions of these studies are summarized here. Mature female ovulated at 13°C for 3 days. Higher hatching success was observed for egg batches with small volume of coelomic fluid and higher egg adhesion rates. Milt obtained from 2-3 males is necessary and sufficient to fertilize eggs obtained from 2 females (goal was to find minimum necessary). Mixing ASP with milt did not improve hatching success. Optimum incubation temperature of fertilized eggs may be 10-18°C. Eggs preserved for 24 hrs at 10°C and milt preserved for 120 hrs at 4°C maintained their fertility. Adequate egg density is about 2 g / 100 cm^2 container base area. The major overall conclusion of these research projects is that mass production of larvae is possible using these recommended criteria and conditions.

Third, the behavior and habitat conditions of larva were examined after their release at several study sites. Predation appeared to be very high and very few larva were able to hide under the algae and sediments. Larvae need to be protected from predation immediately after release. The recapture rate was 0.01 % and the growth rate was 60 mm/day for 27 days after releasing; however, it was unclear whether the larvae were from the release group (DNA testing is in progress). In order to improve artificial propagation, we need to better understand the structure and the function of ammocoete habitats in order to conserve such habitat.

Question: Why aren't lamprey reared beyond hatching? Has this been tried?

Answer: Rearing larvae past hatching has been tried but with very poor survival rates; it is better to release the larvae to nature.

Answer (Finland): There has been experimental feeding of the larvae, with promising results but there is no space when you have 10-30 million. The Environmental Court orders are to produce larvae. The facility keeps them slightly longer, but not much.

Question: How do you determine where to release? Or where to reseed?

Answer: The priority is to release at sites within the river basin with the least predators. Because of dams, there are hardly any lamprey in the upper reaches, making them a priority for reseeding and making it easier to find the released lamprey.

Question: What about the strategy of releasing at night, or in lower density, or in quicker water?

Answer: We don't know.

<u>Columbia Basin – Matt Mesa, USGS</u>

Spawning, fertilization, incubation, and rearing of lamprey at the Columbia River Research Laboratory

The USGS Columbia River Research Laboratory has worked on propagation of lamprey since the early 2000s. However, the primary focus has been to be able to propagate lamprey for research purposes; the processes and techniques applied are not scaled for aquaculture. Adults are collected from the wild in late spring/summer and held at the facility for approximately a year. Spawning and fertilizing are not complicated steps and should be pretty easy for those with experience in salmon/trout hatcheries. The incubation process is designed such that a steady flow is maintained and it cannot overflow. Hatch time is dependent on temperature. Survival to hatching stage and survival to larval stage are also both dependent on temperature. At high temperatures (i.e. 22°C), significantly more larval abnormalities occur.

There are significant obstacles to overcome in order to achieve a scale necessary for hatchery production. Critical knowledge gaps (i.e. future research directions) include: the influence of rearing density on growth; food quality, quantity, and feeding methods; health and physiology; and “up-scaling” techniques for intensive culture. Growing lamprey to larger sizes will be difficult. Salmon and trout hatcheries have learned from 100+ years of experience.

Question: What is the advantage of growing larger instead of just releasing larvae?

Answer: We’re not sure yet. There may be size benefits in terms of lower predation and higher overall survival (due to reduced predation and other factors). Salmon and trout hatcheries have size thresholds that are better understood, but we don't yet know enough about lamprey.

Comment: For salmon, the decision to raise smolts instead of just fry is an issue of cost effectiveness.

Question: What are the initial limiting factors to hatchery-scale production? Are there opportunities to use existing facilities in the Columbia Basin? Is it practical to build independent facilities?

Answer: Raising lots of larvae does not seem to be an issue; there are not many limitations at that stage. In the mid-Columbia, there are facilities with the ability and desire. Space is not an issue but one of the limitations is likely to be the ability to heat water. The water temperature in the spring is important to sexual maturation, but we don't know how important. There is no need to build new facilities.

Question: How do you measure the success of any program? It will be very difficult without homing behavior.

Answer: Could not agree more. That is a critical and very difficult question, but you cannot start anything without knowing how you will monitor its success.

Columbia Basin – Chris Peery, USFWS

Translocation of Pacific Lamprey

The USFW has been doing research in collaboration with the Nez Perce Tribe to evaluate the utility of translocating adult lamprey. Adults are collected, held in a hatchery over winter and released in the spring. The principal question is, “how would we know if translocation has been effective?” Only a small number of adults were collected, but that was driven by limited availability of lamprey – the goal of the Nez Perce Tribe is to translocate 500, if available. A subset of the collected lamprey was radio-tagged. In most cases, the lamprey appeared to have stayed in the stream where they were released, which was one of the key questions. Lamprey redds were observed, but only incidentally while looking for lamprey, so it was uncertain whether they represented the best spawning habitat or simply the locations where redds happened to be actually seen. Adults were released in May and sampling for juveniles was performed at the end of the summer. Some juveniles were found upstream of the release sites, but many more were found downstream. Wherever juveniles were found, they were found in high numbers. The size of juveniles increased downstream, implying an older age but it was not possible to determine whether they had been flushed passively or actively moved to seek better habitat. The overall conclusion is that translocation is possible.

Juvenile Rearing Research

Japan – Hokotu Shirikawa, Hokkaido University

Juvenile rearing research: Lamprey larva and the potential alarming disappearance of their important ecosystem functions.

This presentation covers three topics relating to lamprey larva in Japan: 1) the basic ecology of lamprey larvae; 2) the ecological function of lamprey larvae; and 3) potential future changes in distribution.

Lamprey larvae typically inhabit mud and sand substrates within the slower portions of rivers and streams. Larvae are often found along river banks, the inside and outside of meanders, side channels, or back water pools. Side channel alcoves are suitable locations for research on the ecology of lamprey larva because they are seasonally isolated from the main channel and provide habitat to a diversity of other organisms. The distribution of lamprey larvae was patchier than the dominant fish species but total biomass was the highest. Larvae were most abundant in the soft riverbed and displayed the highest density of any species in this side channel alcove habitat. The position of lamprey larvae in the food web is that of a 1st consumer, but it is currently unclear whether the larvae are feeding directly on the cellulose or on bacteria.

Lab experiments examining the patterns, frequency and impact of larval movements in the sediment found that lamprey larvae act as “ecosystem engineers” because their behavior actually modifies the physical conditions of the riverbed habitat. Other lab experiments were conducted to investigate how larval density affects other biotic and environmental factors (i.e. tubificids, algae, fallen leaves, nutrients, oxygen conditions, and soil hardness).The results show that lamprey larvae may play a significant role in affecting the biological and physical characteristics of stream ecosystems.

Simulation of the current and future distribution of lamprey larvae generated three important results. First, the southern limit for the distribution of lamprey larvae will move toward the north. Second, at a regional scale, there may be a drastic shift in the location of the most suitable habitat, with the current habitat no longer being suitable. Third, the most important driver of these changes in distribution is changing temperature.

Finland – Jukka Tuohino, ELY

Research on Juvenile Rearing and Health and Outplanting

After all or most of the larvae have hatched, they are moved from the funnels to the rearing plates. The specific design of the rearing plates is based on experience. Rearing plates and the pools below them can be stacked. Proper water flow is important. Plates should not be used longer than is necessary - tens of thousands of larvae left in the plates may need to be sacrificed because there are millions of larvae under the plates that cannot be looked after until the plates are removed. Larvae begin to swim after approximately 200 dd (7mm) and burrow after approximately 250 dd (7.5-8mm). Larvae are packed into "oxygen bags" to transport to outplanting sites. Maintaining oxygen and temperature conditions is important because outplanting locations can be 2-3 hours away; sudden changes in temperature or lack of oxygen will easily kill the larvae. Outplanting sites are determined by the size of the larva (e.g. smaller larvae are outplanted in faster stream sections) and carefully selected in advance. It is important to release the larva as close as possible to the bottom.

Getting enough females is often a problem. Water quality and temperature are always a concern through all stages. The whole process should take place in a proper fish hatchery facility with overall control of water quality and plenty of working space. The biggest costs are for purchasing lamprey and for labor, although it takes the same amount of labor to produce 10 million and are confident to produce 30 million. Overall survival from hand spawning until release is about 70-80% at its best. With the man power and hatchery experience in the Columbia Basin, it would be definitely possible to produce millions of larva within a few years.

The key outstanding questions are: What are the survival rates after outplanting? What is the optimal larvae size for outplanting? Is bigger better? What is the optimal outplanting habitat for different size larvae? Is it feasible to feed larvae on a production scale?

Columbia Basin – Rob Chitwood and Carl Schreck, OSU

Knowns & Unknowns: Propagation of Juvenile Pacific Lamprey

The Fish Performance and Genetics Lab has been working on developing the aquaculture and technological methods needed to rear juvenile lamprey. However, the objective has been to figure out the methods needed to study the effects of toxic sediment on larvae rather than to develop commercial production processes. Pacific lamprey larvae were collected from Siletz River then transported to the lab. Larvae were fed yeast and larval supplement. Lamprey were held in large tanks with masonry sand, alder chips and an even flow of water. In order to determine appropriate methods, experiments done with depuration, individual vs. free range holding conditions, different sizes of mesh bag for individual holding, and comparisons of yeast/supplement versus biologically conditioned water for optimal feeding.

Studies of ammocoete behavior showed that ammocoetes were active predominantly between 9pm and 4am. In the sediment preference trials, the ammocoetes appeared to be selecting for the Siletz sediment. Initial findings suggest that injecting feed under the surface is the best delivery approach.

Future research will look at fertilization methods, incubation systems and methods of maintaining large numbers of juveniles. Most of the issues for lamprey aquaculture are similar to the main issues for salmon aquaculture, but lamprey have important differences in life history and habitat needs.

Lamprey have a range of life histories and age types, so one of the most important questions is what the source for adults should be (e.g. location, timing, stage of maturity). Some of the key question for future work on juvenile rearing include: what are the optimal characteristics of a natural/artificial sediment; what is the optimum flow delivery; what are the best methods for assessing growth; should juveniles be released fed or unfed; what is the best diet and method of delivery; how to obtain juveniles from substrate; and how to transport and liberate juveniles.

Whatever we do, we need to be very, very careful to, at the very least, do no further harm.

Columbia Basin – Matt Mesa, USGS

The USGS Columbia River Research Laboratory needed to learn how to keep and rear juvenile lamprey in order to use them in experiments. Density is the most limiting factor and (in the literature) has been a major stumbling block for rearing lamprey. Pacific lamprey of different sizes (25-100 mm) were collected from the wild. In the lab, lamprey were reared in tanks with clean, filtered sand and a low flow of water. Feeding was done twice per week using a suspension of bakers' yeast and Gemma Wean (marine fin fish culture supplement). The water was turned off during feeding. Tanks were cleaned twice per month. The major conclusions were that the size of lamprey and the density in their rearing tanks are both important factors. Future work will focus on isolating the impacts of density independent of other factors, which had not been part of the research design of this work.

Questions raised in discussion that currently remain unknown:

Do the lamprey occupy specific places in the tank (i.e. does the density measure for the tank reflect the density of the areas the lamprey are actually using)? Would it be an advantage to have an ammocoete-seeded environment instead of a clean environment? Does the time of year matter? What effect would different rates of feeding have?

Day 3

Natural Environment – Research and Monitoring

Japan – Seiji Yanai, Ishikawa University

Research and study on Arctic Lamprey in the natural river environment in Japan

Rivers in Japan are relatively short but with high gradients due to the young geology and high uplift. Many of the river modifications are for the prevention/mitigation of natural disasters.

Channelization in the downstream reaches started 100 years ago and accelerated after World War II, driving extinction of many native species.

Interviews of farmers were conducted to reconstruct presence/absence data for spawning lamprey because there are no historical data. The results reveal that something drastic has occurred between historic and current estimates of lamprey presence. The major factor appears to have been dams and weirs, which interrupt the sediment supply and act as barriers to movement. Lamprey cannot pass any structure >1m unless it is sloped. In addition to sediment and passage issues, water quality and quantity are also problems in the middle reaches. Channel simplification has greatly reduced the habitats available for larvae and juveniles, which require soft sediment with coarse organic matter that would be deposited in places with low flow.

Government agencies have engaged in habitat restoration projects, including dam modification in upstream areas to increase sediment supply, and habitat creation or larva in downstream areas. But such projects only restore a section of a stream – to restore an entire stream takes time and resources for many projects.

In their fluvial environment, lamprey require very different types of habitat conditions (e.g. flow, substrate, organic inputs, etc.) for their different life stages. Lamprey may be unique in the level of diversity they require, and thus the presence of a healthy lamprey population may be an ideal indicator of healthy river systems.

Finland – Kimmo Aronsuu and Jukka Tuohino, ELY

Monitoring and Research in the Natural Environment in Finland

Fishing mortality and the abundance of upmigrants have been studied since the late 1970s by using mark-recapture methods. Fishing mortality is high, but no studies have examined what effect that has. The number of upmigrants has decreased but the reasons are also not known. There has been no detectable increase in response to the rehabilitation measures, but this may possibly be due to the lack of homing behavior – adult lamprey may be returning to other rivers or even other countries (e.g. Sweden).

Since early 1980s the effects of different measures on larval densities have been studied with the 'shovel-sieving' method, using different sampling protocols depending on the purpose of the study. Larval density has been strongly affected by river regulation measures. Different methods for measuring young of year (YOY) larvae have been tried. The first larval habitat surveys were carried out to show the effects of river regulation measures and short term regulation; but more recently they have been used for restoration purposes and for selecting the best outplanting sites.

Outmigrants have been monitored by using the drift nets and mark-recapture methods. However, monitoring outmigration is difficult because it occurs over a very short period that corresponds with when the river has high discharge, debris and ice floats. Studies using telemetry and PIT-tags have also been performed to investigate other issues such as the behavior of transplanted lamprey, the passage efficiency of fishways, and the behavior of upmigrating lamprey.

Columbia Basin – Bruce Jim, Columbia River Inter-Tribal Fish Commission

The current situation with lamprey has existed for a long time. Lamprey have always been an important resource traded among tribes, but progress and development deteriorated these connections. When the lamprey began to jam irrigation pipes, they were intentionally poisoned, along with whitefish and other important fish. There has been a lot of frustration for a long time because nothing is being done fast enough to save the lamprey – we need something today. This meeting and the sharing of knowledge is encouraging. There is common knowledge and use of a particular resource which is important to different cultures. Out of nowhere, people have appeared from other parts of the world with similar concerns and irreplaceable knowledge about similar eels. This is a very good step.

Columbia Basin – Nez Perce – Dave Statler & Elmer Crow

Adult Pacific Lamprey Translocation Initiative

Pacific lamprey are an ancient species. Each of the different life history stages of Pacific lamprey are ecologically important for different reasons. Lamprey also have substantial cultural value. Poor adult passage at mainstem dams has been one of the important factors contributing to the decline of lamprey. The translocation initiative was started in order to overcome this barrier by moving adults past the mainstem dams into spawning habitat in tributaries of the Snake River. This is a stop-gap measure to prevent local extirpation of lamprey in the Snake River Basin, avoid the total loss of pheromone attractants from larval lamprey, and preserve the cultural connection with the lamprey. Adults were collected/salvaged at John Day and The Dalles dams and transported to the Nez Perce Tribal Hatchery in Idaho, where they were inoculated for furunculosis and held over winter. Prior to release, a subset was radio-tagged. Lamprey were released into target streams in the Clearwater and Asotin subbasins. Radio-tracking allowed documentation of movements, behavior, redds, and post-spawning fate. Follow-up larval sampling documented larval production in Lolo and Newsome Creeks, which had previously been reported as devoid of lamprey. A total 423 adult lamprey were translocated from 2006 through 2009.The 86 radio-tagged fish generally showed high affinity to the target release streams. Lamprey redds were observed in all release streams where surveys were conducted except for Asotin Creek in 2009.

The “next steps” include: continued adult translocations; follow-up ammocoete surveys; monitoring adult returns to target translocation tributaries (in 9-10 years). Radio-tagging will probably not be continued because the question of whether the transplanted adults stay in the stream system has been answered. However, the most important step is to assure substantial improvement in adult and juvenile mainstem passage because otherwise restoration cannot be achieved. This is critical and cannot be emphasized enough. But until substantive mainstem passage improvements are made, we must continue to do whatever we can to help the Pacific lamprey.

Columbia Basin – Umatilla Tribe – Gary James

Pacific lamprey Research and Restoration Project

The Umatilla River makes an excellent case-study because lamprey were historically abundant but virtually extirpated. The overarching research question is, “can translocated adult lamprey increase natural production and restore self-sustaining and harvestable levels of lamprey?” Larval populations, outmigrating juveniles, and upmigrating adults were all monitored to evaluate the impact of the translocation program. Adult passage success over low elevation diversions was monitored and new structures were developed to improve passage. Juvenile lamprey screening criteria are being investigated in collaboration with the USGS.

The project’s initial findings were positive. Adult lamprey can be held until sexually mature with low mortality. Outplanted lamprey successfully built redds and egg viability was relatively high. Larvae increased in headwaters and moved downstream. Larvae grew fast and their density increased. Outmigration of metamorphosed lamprey increased. The number of adult lamprey increased slightly (still very early). Adults began using new lamprey passage structures.

Telemetry studies were done to assess passage success of adults. Passage success was low at most diversions and directly related to flow and temperature. Additional lamprey structures and flow modifications are needed to increase passage success of adult lamprey. Improved screens will be implemented and evaluated in the Umatilla River once results are available from the USGS research.

Columbia Basin – Yakama – Patrick Luke

Yakama Nation Pacific Lamprey Program

The Yakama Nation has been the last of tribes to develop a lamprey program, building it from the ground up over the last few years. The program goals are to restore natural production of Pacific lamprey to a level that will provide robust species abundance, significant ecologic contributions and a meaningful harvest. The Yakama Nation intends to achieve this goal by supporting regional efforts and by developing and implementing subbasin-specific Restoration Action Plans. The program objectives include: documenting historic distribution; standardizing regional data collection, analysis and reporting;

assessing the distribution and relative abundance of larval lamprey; documenting the biologic condition and migration behaviors of adults and juveniles; identifying preferred habitat characteristics; identifying potential and known limiting factors (then developing and implementing Action Plans); implementing a translocation program; conducting research towards supplementation with translocation and artificial propagation.

Yakama Nation staff biologists have felt that it is important to lay out their conceptual foundation for others to see. The conceptual foundation will provide answers to the fundamental questions of, “where are we going to go” and, “why are we going to go there”. Yakama Nation staff biologists also believe strongly that without a Conceptual Foundation there will not be a coherent strategy and there will be a greater risk of doing harm. The theories, principles and assumptions within the conceptual foundation cannot be stated in a linear manner - relationships are dynamic in time and space and have many connections (environmental, ecological, physiological, etc). The conceptual foundation must address a variety of spatial and temporal scales.

The most critical obstacle to restoration is passage. Without passage, other restoration activities are of limited use, but fixing passage will take a long time.

Habitat sampling has been done in several subbasins. Action plans will be developed for each subbasin; the Yakima subbasin action plan is already complete. The future steps for the program include: continuing the presence/absence surveys in the subbasins; documenting habitat capacity; establishing index sites; conducting focused studies within the Yakima subbasin; initiating a translocation program, and moving strongly toward artificial propagation.

Columbia Basin – Warm Springs – Cyndi Baker

Pacific Lamprey Studies

The Warm Springs lamprey program has been doing research projects since 2002, though it was already a member of the lamprey working group in 1997. Research on ammocoete habitat associations showed that ammocoetes appear to prefer depositional areas with fine substrate, shallow water with low flow, canopy coverage, and the presence of woody debris. Studies on adult lamprey in the lower Deschutes River were conducted to determine adult over-wintering locations, spawning areas, and the timing and patterns of migration. Temperature appears to be an important environmental influence of movement patterns.

A capture efficiency model was developed for the larval electrofishing method so that ammocoete catches could be converted to estimates of abundance. These estimates of abundance were then used to develop an ammocoete abundance model to relate abundance to environmental variables. This model has been used to determine whether reintroduction of lamprey above the Pelton Round Butte Complex would be feasible. Important components of the potential viability include appropriate physical habitat (i.e. substrate composition) and thermal constraints. The project demonstrated that there is habitat upstream of Lake Billy Chinook that could support lamprey if passage were possible.

Ongoing research under the auspices of the Columbia Basin Fish Accords includes: escapement estimates at Sherars Falls; habitat use and the limiting factors in the Deschutes River and tributaries; monitoring recolonization of the Hood River after the removal of Powerdale Dam; and escapement estimates over Willamette Falls.

Conclusions

The primary goal of this workshop was to bring together people who have been working on various lamprey issues with many years of experience, for a discussion about the recovery and artificial propagation of lamprey. Furthermore, for the first time, this conversation was expanded beyond the experts in Columbia Basin to include international colleagues from Finland and Japan. Inarguably, this goal has been achieved. All three regions face similar challenges in the recovery of their respective lamprey populations. The knowledge shared among these groups about lamprey behavior, genetics, habitat preferences, habitat restoration, threats, monitoring, translocation, propagation, and how these issues differ by lamprey life stage will certainly be beneficial for efforts toward recovery.

The second goal of this workshop was to address three central questions about the artificial propagation of Pacific lamprey.

Is the artificial propagation of Pacific lamprey possible?

Based on the experience in Japan, Finland and initial work in the Columbia Basin, the answer to this question is definitively yes. Over many years of experimentation and “learning by doing”, Finland has developed the knowledge base and expertise to be able to rear tens of millions of lamprey larvae per year. The Finnish experts have a wealth of knowledge on how to successfully propagate lamprey at a production scale and have learned many valuable lessons along the way. Research in Japan has also concluded that it is possible to produce large numbers of lamprey larvae if certain guidelines are followed. In the Columbia Basin, research by the USGS and OSU, has improved the understanding of some of the key factors and steps in the artificial propagation process. These two organizations have also conducted research on rearing juveniles, but the focus has been on rearing individuals for research projects rather than for aquaculture-scale production. In Finland, there have been some attempts to grow lamprey beyond larvae, but there has been relatively little focus on this since their court-ordered mandate is simply to grow and release larvae.

However, many important questions still remain: What is the optimal size to grow lamprey? It is possible to artificially grow lamprey beyond the larval stage? How would you achieve this? Why would you choose to grow beyond the larval stage? What are the trade-offs?

Are there existing facilities and resources in the Columbia Basin that would be appropriate for the artificial propagation of lamprey?

The answer to this question is yes. The experience in Finland has demonstrated that it is possible to produce 10-30 million lamprey larvae per year in facilities that are certainly less than ideal. Their largest lamprey production facility was built in the basement of a hydropower plant building. Space is such a limiting factor that a temporary structure must be constructed outside every year to accommodate the hand spawning process. But even with inadequate infrastructure and a small annual budget, the Finnish facility has been very successful at producing lamprey larvae. Within the Columbia Basin, there are numerous facilities which are much better equipped for lamprey propagation. Preliminary reconnaissance of facilities in the mid-Columbia by the USGS revealed that there are existing facilities with both space and interest.

Where are the most appropriate or most beneficial locations to for outplanting?

This question was not clearly answered. However, results from Finland and Japan with outplanting larvae into different types of habitat conditions do offer some insight. Laboratory experiments in Japan and the Columbia (i.e. USGS, OSU) on habitat preferences of larval and juvenile lamprey offer further guidance, as do the results of the Nez Perce and Umatilla translocation studies and the Warm Springs ammocoete habitat association models. Although there is a lot of information available that is helpful in evaluating this question, there are no clear answers yet and many key uncertainties and knowledge gaps remain.

The Columbia Basin is a much larger river system than those studied in Finland or Japan and it contains a wide diversity of habitats. The question of where to outplant has multiple scales, all of which are important. Within the whole basin, one must identify the most beneficial subbasins for outplanting. There are important upstream/downstream issues to consider. Upstream locations may have appropriate habitat but many more dams to pass; but restoration of upstream areas may directly benefit the restoration of downstream areas. Another important consideration is that the concerns and interests of each of the tribes may differ based on their own upstream/downstream geography. Within a subbasin, one must then address the tradeoffs of outplanting in different tributaries, and then further assess the fine scale questions of which specific reaches are most appropriate within that stream.

However, given the scale of the Columbia basin and the diversity of potential habitats available for outplanting, there is an opportunity to design a strategy that would help answer this question. A carefully constructed program that included outplanting sites representing a strategic range of environmental and geographic conditions (e.g. upstream/downstream sites, substrate composition, hydraulic conditions, temperature characteristics, different subbasins, etc.) could provide a lot of useful information necessary to develop an effective long-term outplanting strategy.

Next Steps and Future Work

1. One of the first "next steps" is to determine how to continue this conversation, among tribes, agencies, and international colleagues. There may be opportunities through foundations supporting Japanese-American collaboration to continue this conversation in Japan. There are also other more immediate methods to maintain interaction and engagement via various internet-based technologies.

2. The structured, annotated bibliography on the artificial propagation of lamprey will be available soon. In the short term, this document will be reviewed by experts and added to as necessary. In the long term, this will be a living document to be expanded upon as the knowledge advances and new literature becomes available.

3. Development of the knowledge base for an artificial propagation and translocation plan in the Columbia Basin needs to continue. This will require collaboration among the tribes, all of which have been engaged in many of their own lamprey research and monitoring projects. There appears to be interest in developing a comprehensive strategy for lamprey in the Columbia Basin, which would outline goals, objectives, targets, strategies, and actions. To proceed efficiently and effectively will require a high degree of coordination and collaboration among all parties. Within the Columbia Basin there is a great diversity of habitats and geography (e.g. upstream, downstream, substrate composition, water temperature, level of flow, flow variability, number of dams, number of diversions, lower reaches, far upstream reaches, elevation, biotic communities, organic inputs, etc.). With this array of habitats, there is a potential to develop a program that would answer many questions, especially if strategically designed to maximize the amount of useful information generated from its activities. Developing and designing this comprehensive strategy through collaboration among the tribes and agencies would be a huge challenge – this cannot be overstated. However, with coordinated research, management and monitoring activities in the Columbia Basin, the opportunities for learning would be enormous with much better chances of progress towards the ultimate goals.

4. What does it mean to move forward but "do no harm"? This is a critical question that needs to be discussed within the community of tribes and agencies working on lamprey. There is a strong sense of urgency to take action immediately and a high degree of frustration with the perceived lack of action thus far, but it is crucial to ensure that well-intended initiatives do not cause more damage than good. How can we ensure genetic diversity is maintained? How can we avoid the "mining" of fish and natural production? These questions should not be taken lightly and can be used to help guide the development of the comprehensive strategy identified above.

Appendix 1: Agenda & Schedule of Presentations

Lamprey Workshop (April 19 - 21, 2011)

Tuesday, April 19 **State of the Lamprey**

8:00	Welcome, Invocation, Introduction	Lorne Greig (ESSA)
8:45	State of the Lamprey - Columbia River	Howard Schaller & Christina Luzier (USFWS)
9:00	State of the Lamprey - Columbia River	Bob Heinith (CRITFC)
9:15	State of the Lamprey - Japan	Yuji Yamazaki
10:15	Break	
10:30	State of the Lamprey - Finland	Kimmo Aronsuu
11:30	State of the Lamprey - Tribal perspective	David Close (UBC)
12:30	Lunch	
1:30	Current Research, Monitoring and Propagation Efforts - Finland	Kimmo Aronsuu
2:30	Current Research, Monitoring and Propagation Efforts - Japan	Yuji Yamazaki
3:30	Break	
3:45	Current Research, Monitoring and Propagation Efforts - United States	
4:15	Questions - Round Table Discussion	Facilitator

Wednesday, April 20 **Propagation and Research**

8:00	Welcome - Introductions	Lorne Greig (ESSA)
8:15	Spawning, Fertilization and Incubation - Japan	Seiji Yanai
9:15	Spawning, Fertilization and Incubation - Finland	Jukka Tuohino
10:15	Break	
10:45	Spawning, Fertilization and Incubation - Columbia River	Chris Peery (USFWS)
11:45	Spawning, Fertilization and Incubation - Columbia River	Matt Mesa (USGS)
12:15	Lunch	
1:00	Juvenile Rearing: Research - Finland	Jukka Tuohino
1:45	Juvenile Rearing: Research - Japan	Hokuto Shirakawa
2:30	Open Discussion	
3:15	Break	
3:30	Juvenile Rearing: Research - Columbia River	Rob Chitwood & Carl Schreck (OSU)
4:00	Juvenile Rearing: Research - Columbia River	Matt Mesa (USGS)
4:15	Open Ended Discussion	Facilitator

Thursday, April 21 **Restoration, Monitoring, and Natural Environment**

8:00	Welcome - Introductions	Lorne Greig (ESSA)
8:30	Natural Environment - Research and Monitoring - Japan	Satoshi Kusuda
9:30	Natural Environment - Research and Monitoring - Finland	Kimmo Aronsuu
10:30	Break	
10:45	Natural Environment - Research and Monitoring - Warm Springs	Cindy Baker (CTWSO)
11:15	Natural Environment - Research and Monitoring - Nez Perce	Dave Statler & Elmer Crow (NPT)
11:45	Natural Environment - Research and Monitoring - Umatilla	Gary James (CTUIR)
12:15	Natural Environment - Research and Monitoring - Yakama	Patrick Luke & Bob Rose (CTBYN)
12:45	Discussion and next steps	Facilitator
1:00	Lunch	
	Travel to Bonneville Dam	