SYNTHESIS OF JUVENILE LAMPREY MIGRATION AND PASSAGE RESEARCH AND MONITORING AT COLUMBIA AND SNAKE RIVER DAMS

Study Codes: LMP-P-12-2, LMP-W-13-2

Matthew G. Mesa, Lisa K. Weiland, and Helena E. Christiansen
U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501 Cook-Underwood Road
Cook, Washington 98605
(509) 538-2299, mmesa@usgs.gov

and

Christopher A. Peery
U.S. Fish & Wildlife Service
Idaho Fisheries Resources Office
Orofino, ID 83544
(208) 476-2257, chris_peery@fws.gov

Prepared for:
US Army Corps of Engineers
Portland and Walla Walla Districts

Submitted: December 2015
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ABSTRACT

We compiled and summarized previous sources of data and research results related to the presence, numbers, and migration timing characteristics of juvenile (eyed macrophthalmia) and larval (ammocoetes) Pacific lamprey *Entosphenus tridentatus*, in the Columbia River basin (CRB). Included were data from various screw trap collections, data from historic fyke net studies, catch records of lampreys at JBS facilities, turbine cooling water strainer collections, and information on the occurrence of lampreys in the diets of avian and piscine predators. We identified key data gaps and uncertainties that should be addressed in a juvenile lamprey passage research program. The goal of this work was to summarize information from disparate sources so that managers can use it to prioritize and guide future research and monitoring efforts related to the downstream migration of juvenile Pacific lamprey within the CRB.

A common finding in all datasets was the high level of variation observed for CRB lamprey in numbers present, timing and spatial distribution. This will make developing monitoring programs to accurately characterize lamprey migrations and passage more challenging. Primary data gaps centered around our uncertainty on the numbers of juvenile and larval present in the system which affects the ability to assign risk to passage conditions and prioritize management actions. Recommendations include developing standardized monitoring methods, such as at juvenile bypass systems (JBS’s), to better document numbers and timing of lamprey migrations at dams, and use biotelemetry tracking techniques to estimate survival potentials for different migration histories.
INTRODUCTION

Numbers of adult and juvenile Pacific lamprey *Entosphenus tridentatus* in the Columbia River basin (CRB) of the interior Pacific Northwest have declined precipitously from historical levels (Close et al. 2002). Pacific lampreys possess a complex anadromous life cycle and so are likely influenced by multiple factors during both their marine and freshwater stages. In freshwater, adults, must pass up to eight dams to return to spawning areas in the Columbia and Snake rivers. As juveniles, these fish must pass the same eight dams and their associated reservoirs to reach the ocean to begin their adult life stage. Factors affecting the adult and juvenile migrations are likely limiting population viability, particularly for fish in upstream interior areas. Efforts are ongoing in the CRB to improve upstream passage success for adult migrants. To date, however, little research has been directed towards understanding juvenile migrations and what factors affect survival during their passage to the ocean. We know little about the numbers and timing of out-migrating juvenile fish, the passage routes they take at dams, and their survival through reservoirs and at dams. Early netting studies indicated juvenile lampreys migrate deeper in the water column than salmonid migrants and so may predominantly pass into turbine draft tubes (Monk et al. 2004). However, many fish are also captured in juvenile bypass systems (JBS) at dams. How to best use that information and what additional information is needed is still being debated. A detailed understanding of the passage characteristics of juvenile lampreys through reservoirs and at dams is needed to guide mainstem management efforts. This summary is part of the first steps to understand and manage juvenile lamprey in the mainstem Columbia River migration corridor.

For this work, we compiled and summarized previous sources of data and research results related to the presence, numbers, and migration timing characteristics of juvenile Pacific lamprey, with a focus on CRB projects. Included were catch records of lampreys at JBS facilities, data from historic fyke net studies, turbine cooling water strainer collections, data from various screw trap collections, and information on the occurrence of lampreys in the diets of avian and piscine predators. We identified key data gaps and uncertainties that should be addressed in a juvenile lamprey passage research program. The goal of this work was to summarize information from disparate sources so that managers can use it to prioritize and guide future research and monitoring efforts related to the downstream migration of juvenile Pacific lamprey within the CRB.
METHODS

We obtained data on juvenile lamprey passage characteristics via email correspondence and telephone calls with relevant individuals from various agencies and by standard literature surveys. We collated and summarized data from the following categories: (1) screw trap information from CRB tributaries; (2) fyke net studies; (3) JBS passage at Columbia and Snake River dams; (4) incidental catches in turbine cooling water strainers and; (5) data from piscine and avian predation studies at Columbia River dams. For each of these categories, we focused on numbers of fish captured and the time (i.e., day, month, and season) of capture. Although data formats were inconsistent and much of the information was fragmented, we inputted data into spreadsheets, plotted it, and used it to describe trends and tendencies. Simple correlation coefficients and linear regression were used to look for relationships between river conditions and lamprey numbers counted at JBS’s. River variables included were flow, spill, proportion of flow that was spill, temperature and turbidity, when available.

RESULTS AND DISCUSSION

There is relatively little known about the outmigration of juvenile lamprey in the Columbia and Snake rivers. As with salmonids, it is known that lamprey ammocoetes undergo physical and physiological changes during their transition from freshwater to marine life stages, akin to smoltification. For lamprey, this includes development of eyes, sucking mouth parts and silvery coloration. Behavioral changes are little understood but a combination of a shift away from benthic sedentary habits combined with passive drifting likely occurs to facilitate the downstream migration of macrophthalmia. The most obvious signs of this downstream migration were the occurrences, sometimes in very large numbers, of juvenile lamprey in screw traps, juvenile bypass systems (JBS’s) and fish found impinged on turbine intake screens at Snake and Columbia River dams. More recently (2009), juvenile lamprey were also found in the turbine cooling water strainers and there has been some effort to document these occurrences in recent years, as will be described below.

Mechanisms that trigger transformations are unknown but lamprey metamorphosis appears to be more correlated with fish length than with age (Beamish and Levings 1991; van de Wetering 1998). Transformations have been reported to occur from July to November (Hammond 1979, Close et al.)
2002). In the Columbia River, it appears that lamprey predominantly metamorphose during the fall and winter in preparation for spring/summer outmigration.

When juvenile lamprey migrate may also be dependent on locality. In an Oregon coastal stream, screw trap records indicated that greater than 90% of the total outmigration occurred during November over two years (1994, 1995). Movements out of the stream were correlated with flow events in November (but not October) and mostly within 3 hrs after dusk (van de Wetering 1998). Dauble et al. (2005) reported that more than 90% of juvenile lamprey activity occurred at night during their laboratory study. In the Columbia River, juvenile migrations can occur from later fall and through the spring. For example, in the Mid-Columbia River, juvenile lamprey are encountered during juvenile salmon sampling from March through August, with peak numbers observed during May and June (BioAnalysts 2000). At Wells Dam, peak numbers were observed April to July in fyke net sampling (BioAnalysts 2000). At Rocky Reach Dam, most juvenile lamprey were observed during May and June (CPUD 1991).

**Inputs to the Hydrosystem; Tributary/Screw Trap Records**

The best information available on when juvenile lamprey enter the mainstem Columbia River hydrosystem may be from tributary screw trap records. Screw traps have been deployed at sites across the CRB to track movements of outmigrating juvenile salmonids but juvenile and ammocoete lamprey are often collected incidentally in these traps.

We collected and summarized the data from several screw trap operations that had sufficient information to demonstrate trends in fish abundance and movement timing from CRB tributaries. These included the Okanogan, Methow, Entiat and lower Wenatchee rivers on the upper Columbia (Figure 1), Asotin Creek in the Snake River and the John Day River and Fifteenmile and Mill creeks near The Dalles, Oregon on the lower Columbia River (Figure 2). We also include some published information on the Umatilla River in the mid-Columbia reach.
While there was much inter-annual variation in the numbers collected and intra-annual patterns tended to be dominated by a few large daily events, some generalization can be made. For example, few lampreys were captured from the Okanogon River during the four years 2006 to 2009 and all were eyed juveniles (Figure 3). Most lamprey were seen during late April, prior to peak spring runoff (Figure 4). On the Methow River, both ammocoetes and juvenile lamprey were collected during 2004 to 2012, but the majority were ammocoetes (Figure 5). Peak catches for both life stages occurred during the second half of April during the rising portion of the hydrograph for the spring runoff (Figure 6).
Figure 2. Screw trap locations in Oregon, including John Day River (North Fork, Middle Fork, Mainstem, and South Fork), Mill Creek, and Fifteenmile Creek traps.

When ammocoetes were seen in the traps on the Entiat River was more variable than on the Methow River (Figure 7) with significant numbers being collected from about early March to late July with another peak in October even though the flow patterns were similar to those for the Methow River (Figure 8). Very few juvenile lamprey were captured in traps on the Entiat River (Figure 9). In the Wenatchee River, ammocoetes were captured in the trap from early February to early August (Figure 10). Daily catches were usually fewer than 50 fish and were more frequent during the spring. Like other locations, very few eyed juvenile lampreys were captured in the Wenatchee River trap (Figure 11) and most lamprey were observed prior to peak spring flows (Figure 12).
Figure 3. Number of juvenile lampreys captured in the screw trap on the Okanogan River, 2006 – 2009.

Figure 4. River flows in the Okanogan River, 2006 to 2009.
Figure 5. Number of ammocoete and eyed juvenile lampreys captured in a screw trap on the Methow River, 2004 – 2012.
Figure 6. River flows in the Methow River, 2004 to 2012.

Figure 7. Number of ammocoete lampreys captured in two screw traps on the Entiat River, 2007, 2008 and 2009.
Figure 8. Number of juvenile lampreys captured in two screw traps on the Entiat River, 2007, 2008 and 2009.

Figure 9. River flows in the Entiat River, 2004 to 2012.
Figure 10. Number of ammocoete lampreys captured in a screw trap on the Wenatchee River, 2007 to 2013.

Figure 11. Number of juvenile lampreys captured in a screw trap on the Wenatchee River, 2007 to 2013.
Few lamprey have been collected in the two large screw traps operated in the Snake (Lewiston, ID) and Salmon (White Bird, ID) rivers (Table 1). The most lamprey collected was 58 in the Salmon River Trap in 2005, 48 of which were collected on a single day (1 May). In Asotin Creek, a tributary of the Snake River near Hells Canyon, larval lampreys were seen November through June (Figure 13). Peak numbers were generally seen in the spring coinciding with period of peak spring runoff (Figure 14). No lampreys were collected in the summer when flows were minimal.

![Figure 12. Flow in the Wenatchee River, 2007 to 2013.](image)

**Table 1. Numbers of juvenile lampreys collected in the Snake River screw trap, Lewiston, ID, and Salmon River screw trap, White Bird, ID, 1999 to 2011. (Source; C. Stiefel, IDFG)**

<table>
<thead>
<tr>
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<td>1</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmon R</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>58</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The numbers of lamprey collected in screw traps in the John Day River were higher than observed for the mid-Columbia River tributaries but these collections were dominated by a few large (hundreds per day) events. Most fish were caught in the John Day River during March and April (Figure 15) Flows in the John Day River generally increase through this time period, peaking in May and June (Figure 16).
Figure 13. Number of lampreys, ammocoetes captured in a screw trap on Asotin Creek, 2010 to 2014.

Figure 14. Discharge in Asotin Creek, 2010 to 2014 and plot of larvae collected vs. flow.
Figure 15. Number of ammocoete and juvenile lampreys captured in a screw trap on the John Day River, 2008 to 2012.
Early information (1998 to 2001) from the Umatilla River showed peak numbers of larval and juvenile lamprey were collected during February and March with a smaller group collected during November and December (Figure 17) (Kostow 2002). As was seen in other drainages, the bulk of the spring juvenile lamprey passage occurred during a period of increasing spring flows but prior to peak flow conditions while the fall collections appear to be more correlated with individual flow events (Figure 18).

The largest numbers of lamprey in this dataset were collected from Fifteenmile Creek, a small tributary stream just downstream from The Dalles Dam. When these fish were collected spanned a longer interval than in other streams, from February into June. The numbers of eyed juvenile lampreys captured in Fifteenmile Creek was particularly impressive with many events of between 500 to 1,000 collected per day (Figure 19). In contrast, in Mill Creek, another small lower river tributary, daily catches of ammocoetes and juvenile lamprey were significantly lower, 10 or fewer per day typically (Figure 20).

There is no information available on movements of juvenile lamprey from the Deschutes River, but in Shitike Creek and Warm Springs River, tributaries to the Deschutes River, peak screw trap collections had a bimodal distribution, peaking in the spring (April-May) and early winter (November-December) (i.e. Graham and Brun 2004).
Figure 17. Percent of ammocoet and eyed juvenile lamprey collected in a screw trap in the Umatilla River 1998 to 2001. From Kostow (2002).

Figure 18. Flows in the Umatilla River during 1998 to 2001.
Figure 19. Number of ammocoete and juvenile lampreys captured in a screw trap on Fifteenmile Creek, 2010, 2012, and 2013.
Figure 20. Number of ammocoete and juvenile lampreys captured in a screw trap on Mill Creek, 2012 and 2013.
Summary
Several patterns emerged from this dataset. First, if absolute numbers of larval and juvenile lamprey are an index of their abundance than it appears lamprey production is relatively higher in downstream tributaries than for mid- and upper Columbia River sites. This pattern would match with the numbers of adult lamprey counted at dams as runs progress upstream. That is, areas with higher juvenile production correlates with higher adult escapement. Second, the general pattern observed was that most lamprey were collected in the early spring coinciding with the rising hydrograph. This pattern was somewhat unexpected in that larval and juvenile lamprey movements are thought to be largely passive in nature and coincide with high flow events. If so, we would expect numbers collected to be more directly correlated with flow (i.e. highest numbers of lamprey would be observed at times of highest flow). Instead a more prevailing pattern appears to be that early tributary flow events correlated with, or trigger, the initiation of migration (Close et al. 1995; McGee et al. 1983). By the time peak flows are occurring the bulk of juvenile and larval lamprey have left the tributary streams and moved into the mainstem river. And third, in most cases the numbers of larval (ammocoete) lamprey far outnumbered the juvenile lamprey in screw trap collections. This may be because juvenile lamprey are better at avoiding or escaping traps than larval lamprey. Regardless, it appears that a potentially significant portion of the lamprey production enters the Columbia River mainstem and reservoirs. Fates of these lampreys after reaching the mainstem Columbia River is unknown, although lamprey ammocoetes have been found in Columbia River reservoir habitats (J. Jolley et al. 2015 Annual Report to COE; In review) suggesting some of these larvae are rearing in the mainstem Columbia River.

Data gaps
Screw trap records for lamprey are only of marginal utility primarily because of the lack of metadata that would allow better interpretation of the data. Most notably, trapping effectiveness and trapping efficiencies for juvenile lamprey are mostly unknown so it is not yet possible to relate numbers caught to numbers present. Not all existing data was made available for this synthesis and some tributaries are not currently being monitored for lamprey. Notable gaps in this synthesis were the middle and lower Columbia and Snake rivers. Where lamprey are being noted, there are no standardized protocols for recording and reporting lamprey collections making it challenging to compare production levels and timing among locations.


**Passage at Dams**

**Depth distribution and potential turbine passage at dams**
Within the hydrosystem, migrating juvenile lamprey likely occupy positions in the water column deeper than those observed for salmonid smolts. Because lamprey lack a swim bladder, they tend to sink unless actively swimming. For example, at Rocky Reach Dam, “…most macropthalmia juvenile lamprey that pass through the turbine intake are within 21 feet of the bottom (based on fyke net studies), and below the screens on generation units one and two, the only two screened units at the Project” (Chelan PUD 2005)

Multiple studies have used fyke nets deployed at turbine entrances to gain a better understanding of juvenile fish passage routes, specifically through turbines. Fyke nets are a series of nets deployed vertically that collect fish moving at different depths in the water column. For juvenile lampreys, they have been used to detect untagged and PIT-tagged fish to determine the percentage of fish committed to turbine passage (those migrating low in the water column) versus fish that are moving high enough in the water column to be routed into juvenile bypass facilities. These studies have also been used to determine the efficacy of turbine intake screens designed to protect fish from turbine passage and route them into the JBS.

During fyke net evaluations of run-of-the-river fish at John Day, McNary, Bonneville, and other dams, the majority (> 70%) juvenile lamprey appeared to move downstream low in the water column under the turbine intake screens of bypass systems installed for salmonids at USACE dams (BioAnalysts Inc. 2000; Moursund et al., 2003; Monk et al., 2004; Moursund et al. 2006). The remaining 30% could be near the top of the turbine intakes where they can encounter screens, such as observed at John Day Dam, although many may be passing through gaps at the top of the screens, committing them to turbine passage as well (Moursund et al. 2003). Fyke net studies at Priest Rapids Dam indicated that lamprey were more evenly distributed by depth within the turbine intake (Carlson 1995, unpublished data as cited in Nez Perce, Umatilla, Yakima and Warm Springs Tribes 2008). The general conclusion from this depth distribution information is that the majority of juvenile lamprey (as high as 99%) that approach a powerhouse would tend to pass the dams through the turbines. Because of this, the USACE funded laboratory studies with Pacific Northwest National Laboratory that demonstrated (as noted above) that juvenile lamprey are much less likely than salmon to be harmed by high pressure, sudden changes in

**Risk from impingement**

For lampreys that enter turbine intakes high enough to reach the intake screens but not guided to JBS’s, impingement on turbine intake screens can be a source of loss at dams. Juvenile lampreys are relatively weak swimmers, with an average burst speed of 2.3 feet per second (ft/s) (70 cm/s). Sustained juvenile lamprey swim speeds averaged 0.75 ft/s (23 cm/s) over a five-minute interval and 0.5 ft/s (15 cm/s) over a 15-minute interval (Moursund et al. 2000). Actual velocities at screens averaged 2.4 ft/s (73 cm/s). During swim trials, most juvenile lamprey exposed to water velocities greater than 1.5 ft/s (46 cm/s) became impinged on bar screens in a flume (Moursund et al. 2000).

In later studies, Moursund et al. (2001) reported that 10% to 70% of juvenile lamprey became impinged in 1/8th inch (0.32 cm) bar screens used with extended length submerged bar screens (ESBS), such as those at John Day and McNary dams, and impingement became more likely the longer lamprey were in contact to the screens and the higher the water velocity they were exposed to. Impingement by lamprey was not likely with 3/32nd inch (0.24 cm) and 2/29th inch (0.18 cm) bar screen materials and with 1/8th inch mesh such as used with submerged traveling screens (STS) (Moursund et al. 2001; 2003).

It is generally accepted that juvenile lamprey can, and likely do, become impinged and die on turbine intake screens at dams. However, the information available is primarily anecdotal in nature with sightings and occasional photos (see Figure 21 below) provided as evidence. To date, there has been little in the way of systematic monitoring to confirm the number of lamprey that may be stuck and lost on screens at dams. One example was the observations conducted at McNary Dam in 2001 using underwater video cameras (Moursund et al. 2002). During 42 hours of filming, covering approximately 20% of one screen at the dam, 12 lamprey were observed, seven of which were wholly or partially impinged (unable to lift themselves away from the screen face) on an intake screen.
Summary
Juvenile lampreys tend to move downstream lower in the water column than salmonids. As a result, 70 to 99% of those that approach powerhouses may pass through turbines. Evidence suggests lampreys are less susceptible to injuries from turbine passage than salmonids. Results from laboratory studies and limited field observation indicate that there is a good probability that juvenile lamprey that encounter turbine screens will become impinged with bar gaps of 1/8\textsuperscript{th} inch or larger and surface water velocities greater than 1.5 ft/s.

Data gaps
The primary gap is a solid estimate of the number of juvenile lamprey that enter turbine intakes and their fates. Although evidence suggests lampreys are less susceptible to injuries from turbine passage, there has been no direct studies to estimate short and long-term effects from turbine passage. Also unknown are the numbers of juvenile lamprey impinged on turbine intake screens and the number of those fish
that die at each dam each year. Without understanding the total number of juvenile lamprey that pass
dams, it is not possible to assess the population level impacts from lamprey being lost on intake screens.

**Juvenile Bypass Systems**

Most dams on the mainstem Columbia River have juvenile fish bypass systems (JBS), which are used to
collect outmigrating juvenile fish and route them past the dam. These systems are primarily managed to
improve downstream survival for endangered juvenile salmonids. However, juvenile lampreys (and
other fish) are collected incidentally and, since 1997, numbers of collected lamprey have been reported
by the Fish Passage Center (www.fpc.org). Beginning in 2011, additional information about sampling
rate was collected allowing extrapolation of a collection estimate. The collection estimate is the sample
count divided by the sample rate, not adjusted for flow. It estimates the total number of fish entering the
JBS.

When juvenile lampreys enter a JBS, they appear to pass through readily. For example, PIT-tagged
juvenile lampreys released directly into the John Day Dam JBS downstream of the powerhouse had a
detection rate of 99.6% (Moursund et al. 2003). Although detection of fish released in the gatewell was
initially poor (11.7%), it was later discovered that a vertical barrier screen in the gatewell was damaged,
which would have allowed an unmonitored exit for lampreys from the gatewell. Further, releases of
juvenile lampreys into the JBS at McNary Dam indicated that passage through that system was also
efficient, and few losses were occurring (Moursund and Bleich 2006). Fish were released in groups of
111 – 116 at six different locations in the JBS. Of the 679 fish released, 99.4% were detected in the JBS.
On average, 98.4% of fish from each of the releases were detected exiting to the river. No specific
locations of fish loss were identified, and juvenile lampreys passed quickly through the JBS (91% exited
within one hour of release). Similar rough calculations can be made using a group of 1,486 PIT-tagged
juvenile lamprey released at Lower Granite Dam in 2013. These fish were released directly into the
collection channel and 1,402 (>94%) of those were detected in the JBS facility. Thus, high detection
efficiencies in the JBS suggest that if juvenile lampreys can make it into these systems, passage is not
inhibited by bypass system structures (i.e., fish and debris separator, diversion fork, dewatering screens,
switch gate).

One consequence of juvenile lampreys passing through a JBS is that they are often inadvertently
collected in raceways for transport downstream by truck or barge. Because the effects of transport on
lampreys are unknown and they can become entangled, injured, or killed in raceway tailscreens (Moser and Vowles 2011), it is desirable to separate juvenile lampreys from juvenile salmonids within the JBS raceways. One method of separation is to increase the spacing on raceway tailscreens to allow juvenile lampreys (but not salmonids) to return to the river. Moser and Vowles (2011) used dewatering and crowding experiments in the laboratory to determine the mesh size needed to allow passage of juvenile lampreys and showed that juvenile lamprey of all sizes could pass through 11-mm (on the diagonal) mesh. In field studies at McNary Dam, they showed that 7-mm mesh caused more impingement and retained more juvenile lampreys than 9-mm mesh. Similarly, at Lower Monumental Dam, 9-mm mesh allowed passage of all but the largest juvenile lampreys (>155 mm). Thus, Moser and Vowles (2011) recommended the use of 11-mm woven mesh to allow passage of all juvenile lamprey size classes. In an earlier study, Moser and Russon (2009) found that screen orientation was also important for volitional lamprey passage. Both juvenile (macrophthalmia) and larval (ammocoetes) lampreys moved volitionally through a vertically-oriented screen. However, only ammocoetes moved readily downward through a horizontally-oriented screen. These studies indicated that a vertically-oriented screen with a mesh size of 11-mm would allow optimal passage of juvenile lampreys out of JBS raceways.

**Abundance and timing of juvenile lamprey at JBS’s**

We obtained passage data for juvenile (macrophthalmia or “eyed”) juvenile Pacific lampreys for seven dams from the Fish Passage Center; Lower Granite (LGR), Little Goose (LGO), and Lower Monumental (LMO) on the Snake River, Rock Island (RIS) on the mid-Columbia River, and McNary (MCN), John Day (JDA), and Bonneville (BON) on the lower Columbia River. Data included JBS sample counts for the years 2004–2013. These data reflect the actual number of fish counted in samples at the JBS’s. We also obtained data (for 2011–2013) on JBS collection estimates. Some information were available for lamprey ammocoetes, the larval stage of lamprey development. However, we did not include those data here because they were limited in scope. The JBS’s typically began operating in March or early April and stopped in September or October, occasionally extending into November or December at certain facilities, subsequently data were not available for the winter months.

Mean numbers of juvenile lamprey counted at JBS’s each year ranged from 385 at Rock Island Dam to 10,644 at John Day Dam during 2004–2013 (Table 2). The general trend was for higher counts at downstream locations with the exception of Bonneville Dam which had the third lowest mean lamprey sample count for this dataset. Mean collection estimates extrapolated from sample counts for the three
years 2011 to 2013 were 10 to 38 times the sample counts with the exception of Rock Island Dam. The higher number of fish observed at lower mainstem Columbia River dams compared to the upper Columbia and Snake River dams roughly resembles the pattern seen in screw trap records and so may result from the relative levels of lamprey production for upstream versus downstream tributaries in the basin. However, it is difficult to interpret these values or attribute any level of certainty as to their accuracy without additional information on the behavior and distribution of juvenile lamprey in the forebays of these projects. Information that is not currently available.

Table 2. Yearly Mean, standard deviations (sd) and range of number of juvenile lamprey counted in the JBS sampling during 2004 to 2013 and the yearly mean and sd of collection estimate for juvenile lamprey during 2011-2013 at seven Columbia River dams with JBS’s

<table>
<thead>
<tr>
<th>Dam</th>
<th>Mean count</th>
<th>sd</th>
<th>Range</th>
<th>Mean collection</th>
<th>sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIS</td>
<td>385</td>
<td>301</td>
<td>86 – 1,029</td>
<td>191</td>
<td>74.2</td>
</tr>
<tr>
<td>LoGr</td>
<td>461</td>
<td>627</td>
<td>43 – 1,959</td>
<td>4,952</td>
<td>572.1</td>
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<tr>
<td>LiGo</td>
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<td>1,926</td>
<td>158 – 8,295</td>
<td>23,645</td>
<td>27,406</td>
</tr>
<tr>
<td>LoMo</td>
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<td>2,671</td>
<td>6 – 10,392</td>
<td>22,206</td>
<td>35,966</td>
</tr>
<tr>
<td>McNary</td>
<td>3,265</td>
<td>2,173</td>
<td>844 - 8,817</td>
<td>124,094</td>
<td>38,720</td>
</tr>
<tr>
<td>John Day</td>
<td>10,644</td>
<td>7,614</td>
<td>312 - 26,998</td>
<td>377,632</td>
<td>17,132</td>
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<tr>
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<td>946</td>
<td>22 - 3,153</td>
<td>21,101</td>
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</tr>
</tbody>
</table>

When juvenile lampreys were collected was highly variable among years for each dam and between dams within years. At Rock Island Dam, the numbers were low (1 to 5 per day, 385 lampreys counted per year on average) but relatively continuous during the year. Because of the duration that juvenile lampreys were present, we found no correlations with juvenile lamprey counts and river conditions (flow, spill, percent spill, turbidity and temperature) at Rock Island Dam. For example, lamprey were seen at times with water temperatures that ranged from 3.5 to 20.6 °C. Although peak numbers tended to occur in the range of 9 to 12 °C (Figure 22). Likewise, no variable was significantly correlated with the three years (2001-2013) of collection estimates.
Figure 22. Counts of juvenile Pacific lamprey at Rock Island Dam JBS 2004 to 2013 versus daily average water temperature.

On the Snake River, counts were lowest at Lower Granite Dam, averaging 461 per year (range = 43 to 1,959) and with a three-year collection estimate averaging a little less than 5,000 per year (Table 2 and Figure 23). Counts of juvenile lamprey were higher at Little Goose and Lower Monumental dams, averaging 1,09 and 1,897 per year and three-year average collection estimate around 22,000 to 23,000 juvenile lampreys per year (Figures 24 and 25). At Little Goose Dam, juvenile lamprey were observed in the sample counts over most of the year but total counts and collection estimates were dominated by a few large events that occurred in April and May. No environmental variable had a strong correlation with sample counts or collection estimates (highest $r^2 = 0.19$ for spill).
In the lower Columbia River, counts were highest at John Day Dam, averaging 10,644 per year (range = 312 to 26,998) (Figures 26, 27 and 28). The three-year average collection estimate at John Day was 377,632 juvenile lamprey per year. Counts and collection estimates at McNary Dam were intermediate of those seen at John Day Dam and the Snake River projects while numbers of juvenile lampreys at Bonneville Dam were more similar to those for the Snake River dams. The pattern of lamprey in the lower Columbia River was characterized by multiple peak abundance periods, starting in March when sampling began and trailing off in June at McNary Dam and in July at John Day and Bonneville dams. While correlations between lamprey numbers and environmental variables were still low, they were relatively higher at John Day Dam than in the Snake River and upper Columbia River. The best correlation occurred between counts of juvenile lamprey and flow ($r^2 = 0.464$) and spill ($r^2 = 0.456$).
Figure 24. Mean count (1997-2013) and collection estimates (2011-2013) by date for juvenile Pacific lamprey at Little Goose Dam (top), cumulative collection estimates (middle) and plot of counts of juvenile Pacific lamprey (all years) versus daily average spill (bottom).
Figure 25. Mean count (1997-2013) and collection estimates (2011-2013) by date for juvenile Pacific lamprey at Lower Monumental Dam

Figure 26. Mean count (1997-2013) and collection estimates (2011-2013) by date for juvenile Pacific lamprey at McNary Dam
Figure 27. Mean count (1997-2013) and collection estimates (2011-2013) by date for juvenile Pacific lamprey at John Day Dam (top), cumulative collection estimates (middle) and plot of counts of juvenile Pacific lamprey (all years) versus daily average flow (bottom).
Summary

Currently, counts of juvenile lampreys at JBS facilities are the best indicator of outmigration timing and other characteristics (such as size and health metrics), but they are far from complete. There are concerns related to the ability of JBS entrances to attract juvenile lampreys and to other effects caused by passage through the JBS. Preliminary PIT tag studies suggest juvenile lamprey are readily routed through the JBS passages but they can collect in significant numbers in the holding raceways and tanks. Modifying JBS tanks with appropriate sized screening (i.e. 11 mm vertically oriented mesh) may reduce numbers that accumulate at facilities.

Many fish are often counted at JBS facilities and collection estimates can seem high, but the JBS is likely not a common route of passage for lampreys at dams compared to turbines. Moursund et al. (2003) suggested that less than 1% of PIT-tagged juvenile Pacific lampreys released directly into turbine intakes at John Day Dam passed through the JBS. Fyke net studies at other dams also suggested that most juvenile lampreys are approaching the dams low in the water column and, therefore, not accessing JBS entrances (Long 1968; BioAnalysts Inc. 2000; Moursund et al. 2003; Monk et al. 2004; Moursund and Bleich 2006).
We found little in the way of correlations between river environment and lamprey counts because of the patchiness of lamprey abundances. Consequently, the best correlations (with flow and spill) occurred at John Day Dam, the location with the highest sample count dataset.

**Data gaps**

It is not possible to verify how accurate or consistent the 1% guidance estimate is at John Day Dam nor what similar estimates may be at other projects. Given the highly variable nature of lamprey data, a significant amount of monitoring will be needed to be able to characterize when and how many juvenile lamprey are present and what are their relative routes of passage at dams. JBS’s are not operated during winter and so a potentially significant portion (see below) of lamprey passage is not currently being documented.

**Incidental Catches in Turbine Cooling Water Strainers**

Hydroelectric turbines are cooled using forebay water piped in from the turbine’s scroll case¹. It was only recently (2009) that regional biologists became aware that dead juvenile lamprey were regularly being seen in the material that collected on the debris screens for the turbine cooling water. We obtained data from the U. S. Army Corps of Engineers (USACOE) on the number of lampreys found in turbine cooling water strainers for LGR, LGO, LMO, Ice Harbor Dam (IHR), and MCN. Data were for the years 2010 – 2013 and spanned the entire year. Turbine cooling water strainers were usually inspected once or twice per month at dams except LGO, where they are inspected weekly. The number of juvenile lampreys found in turbine cooling water strainers during a single inspection ranged from 0 to over 1,600 (at LMO during February 2011), depending on year and site. The percentage of inspections when lampreys were found in the strainers ranged from 44 to 62% (2010: 36 of 81 inspections; 2011: 61 of 103; 2012: 65 of 109; 2013: 63 of 102). Most of the incidental catch corresponded with the typical spring outmigration period (i.e., April through June; e.g. Figures 29 and 30), but many fish were also captured during the winter months, January to March. In total over the four years, about 16,242 juvenile lampreys were caught incidentally in the turbine cooling water strainers of LGR, LGO, LMO, IHR, and MCN, ranging from a low of 1,633 in 2013 to a high of 6,342 in 2011 (Table 3). The highest number of lampreys observed was at LMO (4,741) and the lowest number was found at MCN (1,754; Table 3).

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¹ Intakes for cooling water are generally 15 to 20 ft (4.6 to 6.1 m) off the scroll case floor and about 19 in. (28 cm) diameter covered with 1 inch (2.5 cm) bars with 1.5 inch (3.8 cm) gap space.
Figure 29. Numbers of juvenile Pacific lamprey counted during inspections of turbine cooling water strainers at McNary and the four lower Snake River Dams during 2011, a high count year. Data were standardized by month and for the number of turbines in operation.
Figure 30. Numbers of juvenile Pacific lamprey counted during inspections of turbine cooling water strainers at McNary and the four lower Snake River Dams during 2013, a low count year. Data were standardized by month and for the number of turbines in operation.
Table 3. The total number of juvenile lampreys found in turbine cooling water strainers at McNary (MCN), Ice Harbor (IHR), Lower Monumental (LMO), Little Goose (LGO), and Lower Granite (LGR) dams, 2010–2013.

<table>
<thead>
<tr>
<th>Year</th>
<th>MCN</th>
<th>IHR</th>
<th>LMO</th>
<th>LGO</th>
<th>LGR</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>427</td>
<td>856</td>
<td>908</td>
<td>233</td>
<td>727</td>
<td>3,151</td>
</tr>
<tr>
<td>2011</td>
<td>530</td>
<td>1,595</td>
<td>2,333</td>
<td>906</td>
<td>978</td>
<td>6,342</td>
</tr>
<tr>
<td>2012</td>
<td>565</td>
<td>622</td>
<td>1,305</td>
<td>872</td>
<td>1,658</td>
<td>5,022</td>
</tr>
<tr>
<td>2013</td>
<td>232</td>
<td>296</td>
<td>195</td>
<td>557</td>
<td>353</td>
<td>1,633</td>
</tr>
<tr>
<td>Total</td>
<td>1,754</td>
<td>3,369</td>
<td>4,741</td>
<td>2,568</td>
<td>3,716</td>
<td></td>
</tr>
</tbody>
</table>

The annual number of lampreys found by turbine unit varied widely with no clear pattern (Figures 31 to 35). At IHR, the majority of lampreys were found in turbine units 3–5, and at MCN, the highest number of lampreys was usually found in turbine unit 1. Total annual catches were heavily influenced by only one or two collection dates. There was no correlation between the number of lampreys found in turbine cooling water strainers and turbine unit run time (i.e., the number of hours a turbine unit was on between collections) at any dam (Figures 36 to 43).

Consistent observations and counting of biota captured and killed within turbine cooling water strainers is a relatively recent activity conducted by the USACOE. Although the most consistent efforts are from the Walla Walla District, there are anecdotal accounts of lampreys being found in strainers at JDA, The Dalles (TDA), and BON². The numbers of juvenile lampreys found in the turbine strainers are important for at least two reasons: (1) thousands of lampreys are seen annually during inspections, although it is difficult to put these numbers into context; and (2) the data indicate, like other information, that juvenile lampreys are present at times other than the normal spring outmigration period. The numbers of lampreys found in turbine strainers are difficult to interpret because we lack knowledge of the total number of fish approaching each dam. Thus, we do not know whether the numbers of fish found in turbine strainers represent a large or small percentage of the fish passing any given dam.

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² Regular inspections are not conducted at these three projects because the self-cleaning mechanisms on strainers make it impractical.
Figure 31. Number of juvenile lampreys collected per turbine unit cooling water strainer at Lower Granite Dam, 2010 – 2013.
Figure 32. Number of juvenile lampreys collected per turbine unit cooling water strainer at Little Goose Dam, 2010 – 2013.
Figure 33. Number of juvenile lampreys collected per turbine unit cooling water strainer at Lower Monumental Dam, 2010 – 2013.
Figure 34. Number of juvenile lampreys collected per turbine unit cooling water strainer at Ice Harbor Dam, 2010 – 2013.
Figure 35. Number of juvenile lampreys collected per turbine unit cooling water strainer at McNary Dam, 2010 – 2013.
Figure 36. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at Lower Granite Dam, 2010 and 2011.
Figure 37. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at Lower Granite Dam, 2012 and 2013.
Figure 38. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at Little Goose Dam, 2010 and 2011.
Figure 39. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at Little Goose Dam, 2012 and 2013.
Figure 40. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at Ice Harbor Dam, 2010 and 2011.
Figure 41. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at Ice Harbor Dam, 2012 and 2013.
Figure 42. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at McNary Dam, 2010 and 2011.
Figure 43. Number of juvenile lampreys collected in turbine cooling water strainers relative to month and turbine run time at McNary Dam, 2012 and 2013.
Summary
As with other sampling methods reviewed here, inspection of turbine cooling water debris screens demonstrated the variable nature in lamprey movement patterns. Observing four years of data from five dams showed a significant variation in the number of lamprey counted by years although the annual variation was more evident at the four Snake River dams than at McNary Dam. At any one dam, the variation within years was strongly temporal in nature with annual totals dominated by a few large sample counts, similar to that observed with JBS sampling. Unlike the JBS data however, sampling through the winter showed that lamprey can be abundant at times when the JBS’s are not operating, particularly January to March. Numbers of lamprey observed in the debris screens did not appear to be correlated to amount of time an individual turbine had been in operation, again likely because of the patchiness of lamprey abundance.

Data gaps
The year-around sampling of the turbine cooling water debris screens provides more insight on when lamprey are present at dams than previously available from the JBS sampling. Sampling intervals were inconsistent among dams and years, ranging from monthly to weekly at times, and this makes comparisons among dams difficult and potentially biased. We have observed that juvenile lamprey carcasses decompose relatively quickly and, without the benefit of bones or other hard structures as indicators, it is possible that some lamprey collected on screens are lost before they can be counted. As with other sampling methods, the lack of understanding of the abundances of lamprey passing dams makes it impossible to estimate the proportional loss of fish from being caught on the debris screens. Lastly, data summarized here were only available from five dams. Comparable information is not available from the lower Columbia River projects.

Predation on Juvenile Lampreys by Fish and Birds
Recently, juvenile lampreys have been identified in the stomach contents of fish (mainly Northern pikeminnow Ptychocheilus oregonesis) and birds (mainly California gulls Larus californicus). These studies provide some insight into where predation is occurring and its relative magnitude, but they do not provide any new insight into juvenile lamprey migration timing because the work was done to coincide with juvenile salmon migrations.
Fish predation
The Northern Pikeminnow Management Program (NPMP) was implemented to reduce the numbers of large, predatory northern pikeminnow in Columbia River reservoirs and thereby decrease predation on endangered outmigrating juvenile salmonids. As part of this effort, diet samples were analyzed from northern pikeminnow captured by angling at John Day and The Dalles dams. Recent reports by the NPMP (Porter 2010, 2011, and 2012) indicated that juvenile lampreys were a common prey item for northern pikeminnow. In diet samples from pikeminnow collected in 2006 – 2011, lamprey were the most common prey item though diet composition varied by month (Porter 2010 and 2011). Typically, lampreys were the primary prey fish in May and primary or secondary prey fish in June (Porter 2010 and 2011). In 2012, juvenile lampreys, along with juvenile salmon, were the most common fish prey items. Finally, Porter (2010, 2011, and 2012) also reported that angling crews observed large numbers of juvenile lampreys regurgitated from pikeminnow collected at The Dalles Dam during May and June. These data suggest that northern pikeminnow could be a significant source of predation on juvenile Pacific lampreys as they attempt to navigate Columbia River dams. Interestingly, previous predation studies rarely mentioned juvenile lampreys as prey for several Columbia River piscivores, including northern pikeminnow (e.g. Poe et al. 1991; Zimmerman 1999).

Avian predation
Recent studies of avian predation at Columbia River dams have focused on the California gull, the primary avian piscivore at The Dalles and John Day dams. In studies from 2009 – 2011, Zorich et al. (2010, 2011, and 2012) showed that numbers of California gulls feeding at The Dalles and John Day dams peaked concomitant with seasonal peaks in juvenile lamprey passage rather than juvenile salmonid passage. However, diet samples from 127 California gulls collected at John Day Dam in 2009 contained only four juvenile Pacific lampreys in spite of frequent observations of gulls feeding on juvenile lampreys during the peak in juvenile lamprey passage (Zorich et al. 2010). In 2010, diet analysis included 349 gull stomach samples. Twelve juvenile lampreys were found in stomach samples from John Day Dam and 113 juvenile lampreys in samples from The Dalles Dam (Zorich et al. 2011). The authors explained that they were unable to collect diet samples at John Day Dam during the peak in juvenile lamprey passage due to weather conditions, which may explain the low number of juvenile lampreys detected. No diet samples were collected in 2011 (Zorich et al. 2012). At John Day Dam, gulls primarily foraged
immediately downstream of the avian line array a deterrent consisting of 125 synthetic lines that spanned the tailrace of the dam (Zorich et al. 2010, 2011). At The Dalles Dam, gulls were concentrated below the spillway, but Zorich et al. (2011) suggested that some redistribution of gull foraging to below the power houses occurred during the juvenile lamprey migration. Zorich et al. (2010, 2011, and 2012) concluded that California gulls were indeed feeding on outmigrating juvenile lampreys and that further work is needed to determine the full impact of avian predation on juvenile lampreys and methods for reducing this impact. Caspian terns and double-crested cormorants are also feeding on larval and juvenile lamprey in the Columbia River (Roby et al. 2003).

Summary
There is good evidence that predators in the Columbia River will take advantage of juvenile lamprey as a food source when present. Sampling of Northern pikeminnow guts indicate they are the dominant food source in May and June and researchers have observed what appears to be high consumption by California gulls (although stomach contents analyses have not supported this observation). Given the various estimates for predator numbers and predation rates, total consumption of Pacific lamprey by piscine and avian predators could range by orders of magnitude, from tens of thousands to millions per year.

Data gaps
Information on lamprey predation is biased for time intervals when salmonids are migrating. Hence, information of the potential predation earlier and later in the year is lacking. More complete sampling, especially in winter and early spring, will be needed to more accurately characterize predation for juvenile lamprey. Reliable estimates of the numbers of predators in the system are needed to quantify the number of juvenile lamprey consumed annually. As with all other lamprey monitoring, an estimate of juvenile lamprey abundances in the system is needed to adequately quantify the population loss from predation.

Other Factors
Other factors can potentially affect larval and juvenile Pacific lamprey within the Columbia River mainstem but have not been addressed here because of the lack of information to discuss. The most obvious is the potential relationship between travel times and migration success to the
ocean. Impoundment of the Columbia and Snake rivers have decreased flow velocities and likely have increased the time it takes for juvenile lamprey to reach the estuary and transition to ocean feeding stage. Current lamprey travel times and how these are affected by flow volume and water velocities are unknown. Do juvenile lamprey currently have sufficient energy reserves to allow them reach the estuary, and if not, will they begin feeding during the downstream migration? What species would most likely be their prey? Do longer travel times increase juvenile lamprey’s risk from predation? Temperatures, disease exposure and other stressors present in the system will all likely interact with those we have mentioned here to modify survival potentials. As with other topics discussed, a significant tagging and tracking effort would be required to directly measure system-wide survival for lamprey populations. Limited tagging studies combined with probabilistic modelling may be a better strategy to develop rough estimates of survival potentials for different migration histories.

**SUMMARY AND RECOMMENDATIONS**

Information on migration, passage, and other characteristics of juvenile lampreys in the CRB described here has been generally available and considered under various forums. The goal of this work was to provide managers a resource to help prioritize and guide future research and monitoring efforts related to the downstream migration of juvenile Pacific lamprey within the CRB. Collectively, this information suggests several areas where information is limited and monitoring effort should be targeted. A prevailing theme for most datasets investigated here has been the high level of variation observed for CRB lamprey; interannually, intrannually and spatially. Some of the observed variation may be related to the limited data available but it also indicates the level of patchiness for lamprey larval and juveniles in their distribution and movement patterns. Some of this patchiness could be traced back to one fundamental aspect of Pacific lamprey life history. Since these fish do not home to natal spawning areas they must rely on other cues to guide their migration behavior. A major migration cue may be pheromones (or other chemical cues) from conspecifics, such as adult lamprey being attracted to pheromones of larval to guide them to spawning areas. This characteristic would help explain the spatial patchiness for lamprey rearing areas. But if juvenile lamprey are also attracted to other migrating juvenile lamprey, this could create a cascading effect that would result in pulses of juvenile
lamprey moving downstream through the system. Evolutionarily this could be an adaptive strategy to synchronize movements to match optimal migration conditions (flow, temperature, etc.) and reduce risk from predation from the swarming effect.

A second recurring theme presented here is the need to determine the abundances of juvenile and larval lamprey present in the system. Understanding the numbers and proportions of lamprey involved with the different aspects of their downstream migration is needed to quantify risks and prioritize management actions. Accurately estimating abundances will most likely require some form of active (such as a miniaturized acoustic tag) or passive (e.g. PIT tags) telemetry tagging and tracking program which will in turn rely on research to develop reliable tagging and tracking methods. Managers and others involved with lamprey research must understand, however, that these two types of tracking techniques provide different types of information and can, in many ways, be mutually exclusive. It is highly likely that both types of studies will need to be used to gain sufficient and relevant information needed to address the data gaps described here.

The following list summarizes our major findings, information gaps, and recommendations for future work or research.

1. *Screw Trap Summary.*—Screw trap data indicates tributaries that serve as production inputs to the CRB and, importantly, can provide information on when and how many downstream migrating juvenile lamprey will be present at dams. This information would aid managers decide when operations to facilitate lamprey passage would be most effective. Lamprey collected at screw traps could be a source of study animals for monitoring (e.g. tagging) efforts for CRB managers.

*Data Gaps.*— Recording and archival of lamprey information is not standardized among locations and agencies operating screw traps. Access to data is haphazard at present, mainly depending on personal contacts on what data may be available to managers. To our knowledge, there has not been no significant attempt to develop trap efficiencies or use screw trap records to quantify tributary lamprey populations. Protocols on this should be developed. More research is needed to identify other screw trapping efforts that could potentially contribute information on lamprey, such as in the Snake and lower Columbia (i.e. Bonneville pool) rivers.
Recommendations.—To be most useful, screw trap data collection and archival/storage should be standardized so as to be comparable among locations. Protocols should include methods to measure trapping efficiencies and to estimate numbers of fish moving downstream past trap locations and entering the CRB. A network of screw trap operations should be identified to provide coverage of the extent of CRB tributaries.

2. Passage at Dams Summary.—Information indicates that the majority of juvenile lamprey that approach dams in the vicinity of the powerhouse will pass through turbines. Risk of injuries from turbine passage is likely less than that for salmonids. Some lampreys are at risk of being impinged on turbine intake screens.

Data Gaps.—There is no information on the horizontal distribution of lampreys in the forebays at dams that would indicate the proportion if fish that pass at spillways. Although existing laboratory studies indicated conditions associated with turbine passage should pose minimal risk of injury to juvenile lamprey, actual short and long term effects of dam passage and of multiple dam passages (injuries, risk from predation, etc.) are not known. Actual numbers and proportions of lampreys impinged on intake screens has not been adequately quantified.

Recommendations.—Tracking studies using appropriate sample sizes and tagging methods will be needed to quantify passage behavior and survival potentials for juvenile lamprey at CRB dams. Studies should develop the horizontal and vertical distributions at dams so as to be able to effectively infer effects of river conditions and dam operations on passage routes and resulting fates. More systematic monitoring is needed to accurately quantify the numbers and proportions of lampreys impinged and lost at turbine intake screens. Screens should be used so as to reduce overlap with juvenile lamprey peak movement when possible and should be modified to use bar spacing ≤ 1/8\textsuperscript{th} inch.

3. JBS Summary.—Counts of juvenile lampreys at JBS facilities provide useful information on the presence and condition of juvenile and larval lamprey in the Columbia River system. Using proper procedures, JBS sampling could be used to track abundances and survival and gauge passage conditions for lamprey at dams and through the system.
Data Gaps.—JBS’s do not operate during winter when significant numbers of lamprey can be moving. Information on lamprey size and condition are not collected or are not collected consistently at all projects. The relationship between numbers of lamprey counted and their abundance at dams is not known.

Recommendations.—Sampling and reporting for lamprey at all JBS’s should be standardized so that information collected among projects and across years is comparable. Information on fish condition should be expanded to included indices of injuries, disease and size. Sampling should be conducted in combination with a tagging effort to provide estimates of lamprey numbers being diverted and how this varies with dam operations. If these procedures can be implemented, future sampling could be used to estimate abundances independent of a tagging program. Consideration should be given to keeping JBS facilities open as long as possible during the year. Evidence presented here indicates that juvenile lampreys may move year-round, and monitoring lampreys at JBS facilities for as much of a year as possible would provide more complete information of lamprey passage performance. Use of JBS’s will need to be weighed against risk of impingement at diversion screens and other potential sources of loss. JBS facilities should incorporate appropriate screening to reduce accumulations and delays of lamprey in salmon holding facilities.

4. Turbine Cooling Water Sampling Summary.—Data from incidental catches of lampreys in turbine cooling water strainers provides some insight into the magnitude and timing of seasonal movements. Such data can also be alarming because some of the catches seem relatively high. However, like the JBS counts, these data are hard to put into perspective because we do not know the proportion of the downstream migrating population that fish captured in the strainers represent.

Data Gaps.—Sampling methods are inconsistent among dams and not currently being conducted at the lower Columbia River dams. In some cases, the number of lamprey collecting on strainers may be biased because lamprey carcasses may decompose between sample events. The population effect of fish lost on turbine cooling water strainers is unknown.
**Recommendations.**—Sampling methods, intervals and reporting should be standardized at all projects, including the three lower Columbia River dams. A study should be conducted to determine the rate of decomposition of juvenile lamprey at different temperatures to establish the appropriate sampling interval. Similar to our recommendation for JBS counts, sampling should be conducted in combination with mark-recapture-release studies of juvenile lampreys upstream of several dams to estimate the proportion of fish collecting on strainers. Such work will provide an understanding of the relative seriousness of incidental catches in turbine cooling water strainers, help identify which dams may be more “problematic” for lamprey passage, and would provide data for comparison with counts of fish at JBS facilities. Data should be recorded in a consistent format, and an outlet for its rapid dissemination should be established. We note, that the utility of sampling strainers as a source of information on timing and abundance for lamprey migrants at dams overlaps with sampling outlined for JBS’s. If all recommendations for JBS sampling described above are implemented the utility for intensive sampling of strainers will diminish except as a means to document loss of lampreys on strainers.

5. **Predation Summary.**—Juvenile lampreys can be a significant component of the diet of some piscivores. Avian predation on lampreys has not been well documented but may also be significant.

**Data Gaps.**—The total and proportional loss of lampreys from predation in the CRB is unknown. Current predation studies are designed to track salmonid runs and do not span the entire time periods when juvenile lamprey are migrating.

**Recommendations.**—Current predation monitoring efforts should be modified to better document the numbers of lamprey being consumed by both avian and piscivorous predators. We recognize that the current predator abatement programs intended to address losses to salmonids have likely benefited lamprey populations. Without additional information on the effects of predation on lamprey in the CRB, it is difficult to make recommendations on additional actions to reduce losses from predation.
REFERENCES


Porter, R. 2010. Report on the predation index, predator control fisheries, and program evaluation for the Columbia River Basin Experimental Northern Pikeminnow


