Note: Response to Request for Lamprey Culvert Passage Criteria (February 18, 2004)

Passage Considerations for Pacific Lamprey

Endorsed by the
Columbia Basin Fish and Wildlife Authority
www.cbfwa.org
October 5, 2004

Prepared by the
Columbia River Basin Lamprey Technical Workgroup
September 3, 2004

Workgroup Coordinator:
Jen Stone, U. S. Fish and Wildlife Service
http://columbiariver.fws.gov/lamprey.htm

Workgroup Members:
Abel Brumo, Oregon State University
Christopher Claire, Idaho Fish and Game
David Clugston, U. S. Army Corps of Engineers
Debbie Docherty, Bonneville Power Administration
Dan Domina, Portland General Electric
Mark Fritsch, Northwest Power and Conservation Council
Jen Graham, confederated Tribe of the Warm Springs of Oregon
Mike Gray, Coast Lamprey Interest Group Liaison
Molly Hallock, Washington Department of Fish and Wildlife
Doug Hatch, Columbia River Inter-tribal Fish Commission
Tom Iverson, Columbia Basin Fish and Wildlife Authority
Gary James, Confederated Tribe of the Umatilla Indian Reservation
Bao Lê, U. S. Fish and Wildlife Service
Matt Mesa, U. S. Geological Survey*
Mary Moser, National Oceanographic Atmospheric Administration—Fisheries*
Russell Moursund, Pacific Northwest National Laboratory
Dave Ward, Oregon Department of Fish and Wildlife
*indicates primary authors

Note: Response to Request for Lamprey Culvert Passage Criteria (February 18, 2004)

Passage Considerations for Pacific Lamprey

Purpose

The following summary of passage considerations for Pacific lamprey was developed in response to concerns raised regarding the passage of both adult and juvenile lamprey through culverts. Due to the lack of information available, specific passage criteria are not defined in this document. However, we identified data gaps and research needed to address these concerns.

Introduction

Pacific lamprey (*Lampetra tridentata*) are anadromous throughout their range in the Columbia River basin. The adults spawn in tributary streams and the larval lamprey (ammocoetes) bury into the stream sediments soon after hatching and exhibit a largely sedentary lifestyle for the next 4-6 years (Beamish and Levings 1991). While it is known that Pacific lamprey ammocoetes make downstream movements during freshwater residence, the extent of upstream movements by juveniles is not known. After this period of freshwater residence, the juvenile lamprey metamorphose (becoming macrophthalmia) and migrate to the sea. The parasitic adults remain in the marine environment for 2-3 years and then embark on a free-swimming migration to freshwater spawning habitats (Beamish 1980). In the Columbia River drainage, the adult lamprey can migrate hundreds of kilometers to reach headwater streams in tributaries of both the upper Columbia and Snake rivers.

During both juvenile and adult migrations lamprey may encounter a variety of obstacles to passage. Large hydropower dams can delay or obstruct adult passage and are known to result in some juvenile mortalities as a result of turbine entrainment or screen impingement. However, other less dramatic obstacles to lamprey passage may occur along their migration routes. These include but are not limited to: culverts, irrigation diversion dams, weirs, and other low-head structures (Kostow 2002). The extent to which these structures affect both juvenile and adult movements is not known. However, recent research on lamprey swimming performance and migration behavior at large hydropower dams has provided insights into physical factors that can limit lamprey movements. In this document, we drew from recent field and laboratory studies to compile a list of physical factors that should be considered when designing structures that are most likely to afford passage to Pacific lamprey. Here we caution that these considerations should not be viewed as design criteria until adequate testing has been conducted to insure that behavior of lamprey documented at large hydropower dams is applicable to culverts and low-head structures.

Swimming Performance

Information on the swimming performance of juvenile and adult lampreys would be useful for evaluating the efficacy of structures for allowing lamprey passage. Some analyses of the swimming performance of the sea lamprey (Beamish 1974; Bergstedt et al. 1981; Hanson 1980; Mcauley 1996) and the Pacific lamprey (Moursund et al. 2003; Mesa et al. 2003; Close et al. 2003) have been done. In general, all of this research has confirmed that the anguilliform mode of swimming is inefficient and that lampreys are poor swimmers when compared to teleosts.

Beamish (1974) showed that the distance (m) sea lampreys could swim declined with an increase in swimming speed between 20-60 cm/s. Swimming speed was positively related to temperature (range 5-15°C). For example, the maximum sustained swimming speed of adult sea lampreys at 15°C was about 35 cm/s, but was only 23 cm/s at 2°C. The total distances traveled were 21.3 and 13.8 m. Bergstedt et al. (1981) swam adult sea lampreys in a tunnel respirometer at 6 and 10°C and reported that fish could not swim for more than 1 min at about 1.4 m/s. Hanson (1980) swam large numbers of adult sea lamprey in a flume at different temperatures and a velocity range of 1.5 to 4 m/s. At temperatures below 15°C, few fish attempted to swim upstream in the 3-m-long flume, regardless of velocity. At 16-24°C, however, 17% (98 of 590) of the lampreys tested attempted to ascend the flume. He noted that lampreys were able to endure velocities of about 4 m/s for an average of 1.3 s. Mcauley (1996) allowed adult sea lampreys to volitionally swim up a 30-m-long flume at a variety of water velocities and temperatures. At velocities of about 1.5 m/s fish were able to swim for up to 50 s, but at 3 m/s fish could swim for only 2-3 s.

Mesa et al. (2003) reported that the mean ($\pm$ SD) critical swimming speed of adult Pacific lampreys was 86.2 $\pm$ 7.5 cm/s at 15°C. They swam their fish to exhaustion and noted significant physiological changes (e.g., increased blood lactate levels, decreases in blood pH) in fatigued fish that lasted for 1-4 h. Close et al. (2003) swam radio-tagged and untagged adult Pacific lampreys in a 4-m-long flume for up to 1 h at 40 cm/s. The times that both groups of fish were able to swim at this speed ranged from about 100 to 3,600 s. Finally, Moursund et al. (2003) studied the burst and sustained swim performance of juvenile Pacific lamprey. Maximum burst speed of lampreys from 125-170 mm long ranged from 0.27 to 1.0 m/s. Sustained swim speeds for similar sized fish ranged from 0.15 to 0.60 m/s.

Role of attachment.

When confronted with rapid current velocities, adult Pacific lamprey use their suctorial disc to hold fast and rest between intervals of burst swimming. This saltatory mode of movement is most pronounced in current velocities of greater than 60 cm/s (W. Daigle, University of Idaho, unpublished data). Consequently, it is critical that adult lamprey are provided with adequate attachment surfaces in fishways or culverts where lamprey might encounter high current velocity.

Both laboratory experiments (W. Daigle, University of Idaho, unpublished data) and radiotelemetry data (Ocker et al. 2001, Moser et al. 2002a, Moser et al. 2003) have indicated that metal grating in the floor of fishways can result in poor lamprey passage efficiency. In this case, diffuser grating (2.5 cm × 10.0 cm grating of 0.5 cm thick aluminum) prevented lamprey from achieving suction and was observed in the laboratory to obstruct upstream movement through areas of rapid current velocity. These same laboratory experiments indicated that attaching a 30.5 cm wide metal plate over the grating allowed lamprey to attach near and pass through an orifice opening with > 2.4 m/s velocity (W. Daigle, University of Idaho, unpublished data).

At this time the most optimal surface for lamprey attachment has not been identified. Smooth surfaces, such as polished metal and glass, apparently provide a good surface for holding and lamprey are even able to achieve suction on roughened, wetted concrete. However, it is likely that tightly corrugated metal pipe could preclude lamprey attachment on culvert walls and floors. Consequently, allowing for natural substrate in culverts is needed to insure that adult lamprey have adequate attachment areas during periods of high flows.

Both laboratory and field experiments at Bonneville Dam (Rkm 235 on the Columbia River) have indicated that lamprey have difficulty negotiating 90° corners in high velocity situations. Sharp angles prevent the lamprey from being able to stay attached as they move around a corner in high velocities, such as at bulkheads adjacent to fishway entrances. When bulkheads were rounded, lamprey achieved better entrance success (Moser et al. 2002b). Moreover, laboratory testing indicated that rounded corners (on 20.3 cm diameter) at entrances had significantly higher passage success than squared of corners (W. Daigle, University of Idaho, unpublished data).

Sea lamprey managers have recently worked to develop barriers to pre-spawning adult lamprey in streams. Effective structures feature an overhang that precludes lamprey passage over the barrier (K. Mullett, U.S. Fish and Wildlife Service, personal communication). Consequently, it is likely that perched culverts would also be an impediment to migrating adult Pacific lamprey.

Behavior

Light effects

Both juvenile and adult lamprey are nocturnal, exhibiting higher levels of activity during the night than during the day (Moser et al. 2002b). Other lamprey species also exhibit negative phototaxis (Tunnainen et al. 1980, Ullen et al. 1997). Therefore, it is likely that both high light intensity and abrupt changes in lighting could affect lamprey movements. Experiments both in the field and in the laboratory at Bonneville Dam found no evidence that lighting at night (1-3 lux) was avoided by adult Pacific lamprey (Moser et al. 2002c). While this provides some indication that adult lamprey will move through a shallow, brightly lighted area, it is not clear how adult lamprey would respond to complete darkness (for example inside culverts) or to abrupt changes in lighting as they enter and exit a culvert. Laboratory observations have indicated a very strong negative phototaxis by ammocoetes exposed to white light and to abrupt changes in lighting (R. Moursund, Batelle/Pacific National Laboratory, personal communication). Consequently, ammocoete movements during the day might be affected by changes in lighting that are produced by culverts.

Temperature effects

Changes in temperature clearly dictate both juvenile lamprey outmigration and the timing of spawning migrations by adults. Adult lamprey exhibited reduced delay while moving through the tailrace and fishways at Bonneville and The Dalles (Rkm 308) dams during radiotelemetry investigations. That is, as temperature increased, lamprey moved more rapidly upstream. However, exceedingly high temperature could be a barrier to lamprey movement. Ocker et al. (2001) reported that significantly fewer lamprey successfully migrated upstream at Bonneville Dam when temperatures at tagging exceeded 19.5°C. While the effects of high temperature in small streams have not been evaluated, it is possible that lamprey behavior could be altered by thermal barriers.

Research Needs

Relatively little is known about the migration behavior of Pacific lamprey and the cues that they use to orient and navigate. The following basic information is needed to better assess lamprey use of culverts:

1) information on the mechanisms of migration initiation
2) the extent to which ammocoetes move upstream
3) behavior of ammocoetes and macropthalmia in strong currents
4) the effects of lighting on lamprey behavior, and
5) the cues adult lamprey use to find spawning areas.

The highest priority should be assigned to determining whether the worst-case culvert scenario even represents an obstacle to either adult or juvenile lamprey, which are very different from salmonids in both their swimming abilities and behaviors. Based on this work, more specific studies may be needed to develop specific passage criteria:

1) availability and quality of attachment surfaces in culverts
2) the ability of lamprey to enter perched culverts (or any structure that featured an overhanging lip or vertical barrier), and
3) the effects of lighting at culverts on both adults and juveniles.

Literature Cited

Beamish, F. W. H. 1974. Swimming performance of adult sea lamprey, *Petromyzon marinus*, in relation to weight and temperature. Transactions of the American Fisheries Society 103:355-358.

Beamish, R. J. 1980. Adult biology of the river lamprey (*Lampetra ayresi*) and the Pacific lamprey (*Lampetra tridentata*) from the Pacific Coast of Canada. Canadian Journal of Fisheries and Aquatic Sciences 37:1906-1923.

Beamish, R. J., and C. C. Levings. 1991. Abundance and freshwater migrations of the anadromous parasitic lamprey, *Lampetra tridentata*, in a tributary of the Fraser River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 48: 1250-1263.

Bergstedt, R. A., D. V. Rottiers, and N. R. Foster. 1981. Laboratory determination of maximum swimming speed of migrating sea lampreys: a feasibility study. U. S. Fish and Wildlife Service Administration Report No. 81-3.

Close, D. A., M. S. Fitzpatrick, C. M. Lorion, H. W. Li, and C. B. Schreck. 2003. Effects of intraperitoneally implanted radio transmitters on the swimming performance and physiology of Pacific lamprey. North American Journal of Fisheries Management 23:1184-1192.

Hanson, L. H. 1980. Study to determine the burst swimming speed of spawning-run sea lampreys (*Petromyzon marinus*). U. S. Fish and Wildlife Service, Research Completion Report, Millersburg, Michigan.

Kostow, K. 2002. Oregon lampreys: Natural history, status, and analysis of management issues. Oregon Department of Fish and Wildlife, Portland, Oregon.

Mcauley, T. C. 1996. Development of an instream velocity barrier to stop sea lamprey migrations in the Great Lakes. Master’s thesis, University of Manitoba, Winnipeg.

Mesa, M. G., J. M. Bayer, and J. G. Seelye. 2003. Swimming performance and physiological responses to exhaustive exercise in radio-tagged and untagged Pacific lampreys. Transactions of the American Fisheries Society 132:483-492.

Ocker, P. A., L. C. Stuehrenberg, M. L. Moser, A. L. Matter, J. J. Vella, B. P. Sandford, T. C. Bjornn, and K. R. Tolotti. 2001. Monitoring adult Pacific lamprey (*Lampetra tridentata*) migration behavior in the lower Columbia River using radiotelemetry, 1998-99. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moursund, R. A, M. D. Bleich, K. D. Ham, and R. P. Mueller. 2003. Evaluation of the effects of extended length submerged bar screens on migrating juvenile Pacific lamprey at John Day Dam in 2002. Final Report of Research, U. S. Army Corps of Engineers, Portland, Oregon.

Moser, M. L., P. A. Ocker, L. C. Stuehrenberg, and T. C. Bjornn. 2002a. Passage efficiency of adult Pacific lampreys at hydropower dams on the lower Columbia River, U.S.A. Transactions of the American Fisheries Society 131:956_965.

Moser, M. L., A. L. Matter, L. C. Stuehrenberg, and T. C. Bjornn. 2002b. Use of an extensive radio receiver network to document Pacific lamprey (*Lampetra tridentata*) entrance efficiency at fishways in the lower Columbia River. Hydrobiologia 483: 45-53.

Moser, M. L., L. C. Stuehrenberg, W. Cavender, S. G. McCarthy, and T. C. Bjornn. 2002c. Radiotelemetry investigations of adult Pacific lamprey migration behavior: evaluation of modifications to improve passage at Bonneville Dam, 2000. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moser, M. L., D. A. Ogden, S. G. McCarthy, and T. C. Bjornn. 2003. Migration behavior of adult Pacific lamprey in the lower Columbia River and evaluation of Bonneville Dam modifications to improve passage, 2001. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon

Tuunainen, P., E. Ikonen, and H. Auvinen. 1980. Lamprey and lamprey fisheries in Finland. Canadian Journal of Fisheries and Aquatic Sciences 37:1953-1959.

Ullen, F., T. G. Deliagina, G. N. Orlovsky, and S. Grillner. 1997. Visual pathways for postural control and negative phototaxis in lamprey. Journal of Neurophysiology 78:960-976.