Zachary A. Sutphin, Fisheries and Wildlife Resources Group, United States Bureau of Reclamation, Denver, Colorado 80225

and

Charles D. Hueth[1], Fisheries and Wildlife Resources Group, Science Application International Corporation, Denver, Colorado 80225

Swimming Performance of Larval Pacific Lamprey (*Lampetra tridentata*)

Abstract

Laboratory experiments were conducted to measure the prolonged-sustained and burst swimming speeds of wild larval (ammocoete) Pacific lamprey (*Lampetra tridentate*). Prolonged-sustained speeds were measured using an annular variable speed swimming chamber and burst speeds were determined using a swimming raceway and digital video analysis. During prolonged-sustained swimming experiments, the mean length of time lamprey (72 – 143 mm TL) were able to swim in the chamber ranged from 43.0 min when exposed to a velocity of 10 cm/s, to 0.4 min when exposed to 50 cm/s. The burst swimming speeds of lamprey tended to increase as length increased from 107 to 150 mm TL, and ranged from 33.3 to 75.0 cm/s. Our estimates of the overall swimming performance of this life-stage are the first reported for this species, and can provide important information when developing approach velocities and infrastructure to improve lamprey passage while minimizing entrainment loss.

Introduction

Pacific lamprey (*Lampretra tridentata*) have declined in abundance throughout much of their native range, including the Columbia River Basin, over the last half century (Close et al. 1995, 2002; Close 2001). A multitude of anthropogenic factors (see Close et al. 1995) have contributed to the decline and subsequent protected status by the state of Oregon (Kostow 2002) and recent petitioning for protected status under the ESA (Dauble et al. 2006). Of particular concern to larval (ammocoetes) and juvenile (macropthalmia) life-stages of the lamprey are the direct and indirect effects of water diversions, barrier screens, and fish pathways that are abundant throughout much of their native habitat and are typically not designed considering the species physical (i.e. swimming ability) requirements (Dauble et al. 2006).

Pacific lamprey are of significant ecological importance in the Columbia River Basin. They play a key role in benthos nutrient cycling (Kan 1975), are an important food source for native piscivores (Close et al. 2002), and are of significant cultural importance for native peoples of the Pacific Northwest (Close et al. 2002). Though generally spending much of their larval life (4 – 6 years) burrowed in the soft sediments (Kan 1975, Richards 1980), scouring events (Close et al. 2002) and significant water discharges (Pirtle et al. 2003) may cause ammocoetes to be dislodged from the sediments and enter the water column. Without suitable refuge ammocoetes risk exposure to water velocities they are physically unable to traverse, increasing the likelihood of damage and mortality as a result of exposure to hydropower turbines, water diversions, and barrier screens (Moursund et al. 2003, Dauble et al. 2006).

Based on a thorough literature review, data on the swimming performance of ammocoete Pacific lamprey has yet to be published. Therefore, there is a lack of basic knowledge pertaining to the sustained, prolonged and burst swimming capabilities of the species which can provide important information for their management. For example, the entire range of swimming speeds that can be achieved by a species, the sustained and prolonged speeds in particular, provide important information that can be used in the development of improved physical and non-physical barrier designs, diversion structures, and the establishment of suitable water velocities at such structures (Conrad et al. 1999, Wolter and Arlinghaus 2003, Tudorache et al. 2008). Also, burst speeds attained by fish are ecologically significant because these speeds are most commonly employed as a means to evade predation (Beamish 1978). Therefore, the objec-

[1] Author to whom correspondence should be addressed
Email: chueth@usbr.gov

[2] Present address: P.O. Box 25007, Mail Code 86-68290, Denver, Colorado, 80225.

tive of this study was to measure the swimming performance of larval Pacific lamprey over the entire range of swimming speeds (sustained, prolonged and burst speeds) they may be forced to utilize in their natural environment.

Methods

Ammocoete Pacific lamprey were collected by electrofishing on July 24, 2009 from the Umatilla River (rivermile 67.5) by Umatilla Tribe employees, were transferred via aerated coolers to holding tanks and slowly (over one day) tempered from 23 to 20 °C. A subset of these fish (~ 300 individuals), identified by tribal biologists as 1-4 year olds (A. Jackson 2009, personal communication), were transported to the Bureau of Reclamation's (BOR) Mobile Fisheries Research Laboratory (MFRL) for holding and testing on July 28, 2009. The MFRL, a transportable and self-contained fish testing laboratory, was positioned adjacent to McKay Creek, a tributary of the Umatilla River, just upstream of the McKay Creek adult fish barrier in Pendleton, Oregon. During swim performance testing ammocoetes were maintained in 87-L circular polyethylene holding tanks and provided continuous flows, at approximately 0.5 L/min of treated (ultraviolet sterilization and particle filtered), temperature controlled (in-line chiller; Aqualogic, Inc., San Diego, CA) water maintained at 20.8 ± 1.3°C (mean ± SD). Fish were held and tested at a water temperature near the temperature recorded during capture to minimize the time required for thermal acclimation. Water quality was checked at least twice daily using a YSI85 multifunction meter (YSI, Inc., Yellow Springs, OH.) and an ammonia test kit (LaMotte Company, Chestertown, MD.). Mean (± SD) dissolved oxygen and total ammonia nitrogen levels were 8.8 ± 0.6 mg/L and 0.2 ± 0.1 mg/L, respectively. Ammocoetes were provided a narrow range (1- 4 cm/s) of velocities during holding, but were not provided substrate or cover. Pacific lamprey were not fed during testing.

Burst Swimming Tests

A burst swimming raceway (220-cm length and 30-cm wide), filled to 25 cm depth and provided with a black 1 x 1-cm grid on the bottom to provide scale, was used to measure the burst swimming speed of ammocoete Pacific lamprey. Water in the raceway was quiescent during testing and there was no water exchange. However, due to the short duration of each replicate (< 5 min) there was no measurable change in water temperature during testing and dissolved oxygen levels remained > 8 mg/L. For each replicate, a single ammocoete was netted from its holding tank, transferred to a 19-L bucket containing ~ 8 L of water, placed in the raceway, and allowed to adjust to the new environment for one minute. The ammocoete was then induced to swim by touching their caudal region with a plastic rod. Induction of swimming via plastic rod was conducted by the same individual to minimize differences in force applied to the test specimen. Repeated touching of the caudal region continued for an approximate one minute period or until researchers observed the ammocoete making a significant effort to avoid contact from the plastic rod (e.g., burst swimming). Burst swimming of lamprey was recorded at 60 frames per second using an overhead video camera (Hitachi, Ltd.; Chiyoda-ku, Tokyo). The maximum burst speed for an individual lamprey was considered the fastest speed achieved over a 10-cm distance during the one minute test period.

Prolonged-Sustained Swimming Tests

Two circular swimming flumes were used to measure the prolonged-sustained swimming abilities of ammocoete Pacific lamprey. Both flumes were equipped with a fish swimming chamber, interchangeable honeycomb filters, adjustable vanes and cross-wings for producing laminar flow through the swimming chamber, and were precalibrated using a Marsh McBirney flow meter (Hach Company, Loveland, Colorado). Water was circulated through each chamber using a variable speed 120V/60Hz motor (SEW-Eurodrive, Hayward, CA.) controlled by a digital motor control center. Prolonged swimming of fish was generally defined as the water velocity a fish can maintain for periods between 20 seconds 200 min, whereas sustained swimming can be maintained for periods > 200 min (Beamish 1978). However, even at our lowest test velocities (10 cm/s) lamprey either (1) chose not to swim for periods > 60 minutes or (2) were able to anchor themselves on the bottom of the flume. Thus, for this research we combined prolonged and sustained fish swimming categories. Preliminary observations suggested larval lamprey were occasionally unwilling to swim in a flume and against current, and early life-stages of Pacific lamprey tend to be most active at night (Dauble et al. 2006). All tests were completed

with the laboratory lights off, the upstream end of the swimming flume covered with black sheets of plastic, and the downstream end exposed to a high intensity light to deter ammocoetes from entering this region. This configuration generally resulted in lamprey being more willing to swim against the current to stay away from the light. Due to the short duration of each replicate the water temperature was minimally affected by the use of lights during testing, and the range of increasing temperatures during testing was between 0.0 and 0.3°C. For each replicate, a single ammocoete was netted from its holding tank, transferred to a 19-L bucket containing ~ 8 L of water, placed in the raceway, provided 15 minutes of exposure to 0 cm/s velocity, then 5 minutes with a velocity of 5 cm/s to allow ammocoetes the opportunity to sense and orient into the current. The water velocity was then increased to a randomly selected velocity, between 10 and 50 cm/s in 5 cm/s intervals, at which point the ammocoetes swam until fatigued or until 60 min was reached. Fatigue was defined as complete impingement of the fish on the downstream end of the test chamber. Once fatigue (or 60 min) was reached, water velocity in the flume was returned to 0 cm/s, time (min and sec) the individual was able to swim at the given velocity was recorded. After each replicate, for both burst and sustained-prolonged swimming tests, lamprey were removed from the test flume, measured for wet weight (WW) to the nearest 0.1 g and for length (standard, fork, and total length) to the nearest 1 mm.

Statistical Analysis

One-way analyses of variance (ANOVA) was used to compare fish morphometrics among treatments. Exponential models were fitted to data from prolonged-sustained swimming data. All statistical analyses were conducted using SAS 9.1 (SAS 2005), and the alpha level for all analyses was set at 0.05. During both burst swimming and prolonged-sustained swimming trials fish that did not choose to swim at full capacity, based on our judgment, were considered to have not participated in the experiments and were therefore not included in the data analysis.

Results

During holding and prior to testing lamprey were generally quiescent, remaining still on the tank bottom, but occasionally swimming for short durations before returning to the tank bottom. Burst swimming speeds of ammocoete Pacific lamprey ranged from 31.6 to 75.0 cm/s (2.55 – 5.56 body lengths per second [BL/s]), with a mean (± SD) of 51.6 ± 13.0 cm/s (3.74 BL/s, n = 19). In general, ammocoetes displayed burst swimming (i.e., avoidance behavior) after initial contact from the plastic rod, but would only burst swim for short (< 40 cm) distances. Also, the burst swimming speed of lamprey tended to increase with increasing size (Figure 1). Of the 25 fish tested, a total of six lamprey did not perform in the burst swimming experiments. Mean total length and weight of lamprey used during burst swimming tests were 112.1 ± 28.3 mm and 3.4 ± 1.7 g, respectively. Mean (± SD) water temperature during burst swimming experiments was 21.1 ± 0.3°C.

During prolonged-sustained swimming replicates the length of time sustained in the swimming chamber tended to decrease from a mean (± SD) of 43.04 ± 19.65 min when exposed to a velocity of 10 cm/s (n = 4) to 0.55 ± 0.07 min and 0.35 min when exposed to velocities of 45 (n = 4) and 50 cm/s (n = 1), respectively (Figure 2). One fish each at velocities of 25, 30, 35, and 40 cm/s, and two fish each at velocities of 15 and 45 cm/s did not participate in the prolonged-sustained swimming experiments. Lamprey used in sustained-prolonged

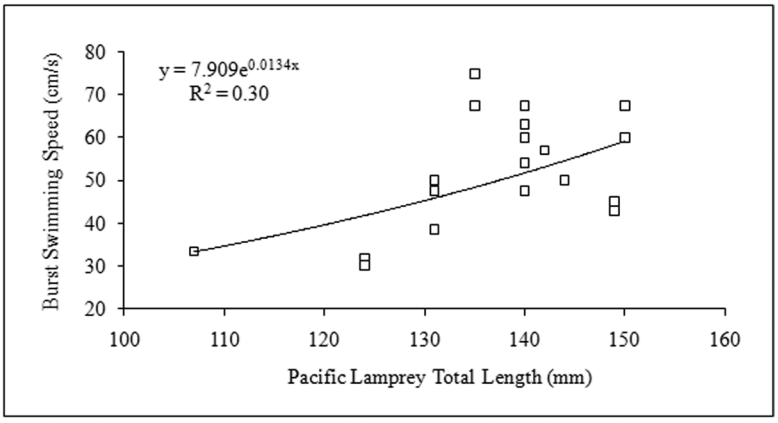

Figure 1. Burst swimming speeds (cm/s) of Pacific lamprey.

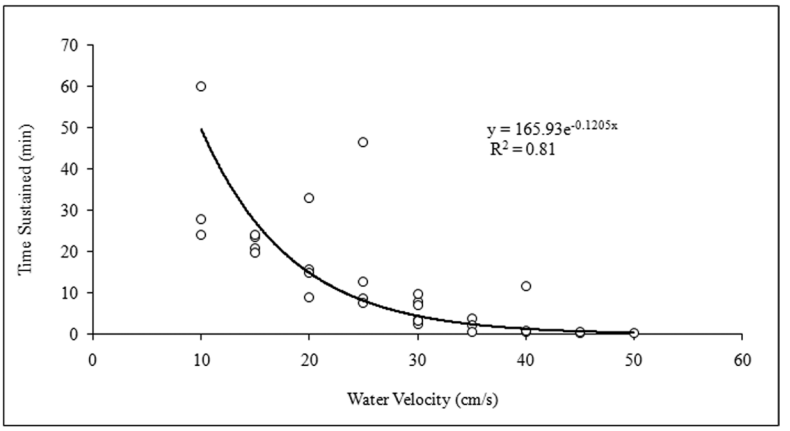

Figure 2. Minutes that individual ammocoete lamprey were able to sustain position in the swimming chamber at water velocities (cm/s) between 10 and 50 cm/s before becoming impinged. Trials lasted for a maximum of 60 minutes.

swimming trials were of similar total length (120.2 ± 25 mm; ANOVA: $P > 0.05$) and wet weight (3.27 ± 0.97 g; ANOVA: $P > 0.05$). Mean (± SD) water temperature during prolonged-sustained swimming experiments was 20.9 ± 1.0°C.

Discussion

Based on our literature review this is the first available data on the swimming performance of larval Pacific lamprey. Interestingly, sustained swimming speed, and to a lesser extent the burst swimming speed, of juvenile Pacific lamprey as reported by Dauble et al. (2006) are similar to our measured values. Dauble et al. (2006) reported slightly higher mean (± SD) burst speed of juvenile lamprey (71 ± 5 cm/s) and indicated swimming endurance decreased as velocities increased from 15 to 30 cm/s, but decreased rapidly with increases in velocity > 46 cm/s. These similarities in swimming performance are likely because the size of our test fish, for both burst and prolonged-sustained swimming experiments, were similar to the length of juvenile lamprey (136 ± 5 mm) used by Dauble et al. (2006). It would therefore be beneficial to include smaller size classes of ammocoetes in any future research aimed at measuring swimming performance of Pacific lamprey. This is particularly relevant because events that cause larval lamprey to be dislodged from their burrows typically results in dislodging of multiple age-classes.

In comparison to other resident fish of similar size in the Columbia River basin, larval Pacific lamprey are poor swimmers. For example, Bainbridge (1958) reported juvenile (40 -130 mm TL) rainbow trout (*Oncorhynchus mykiss*) can achieve burst speeds up to 18 BL/s and 220 cm/s, and in a later document Bainbridge (1960) reported 103 – 150 mm TL trout can achieve burst speeds between 105 and 175 cm/s. Also, Hale (1996) reported late-larval stage (30 – 35 mm TL) Chinook salmon (*O. tshawytscha*) achieve burst speeds > 80 cm/s. Brett et al. (1958) reported 6.9 cm sockeye salmon (*O. nerka*) can sustain swimming speeds of 35 cm/s for one hour. This likely poses a problem for poor swimming larval and juvenile Pacific lamprey in the Columbia River Basin because much of the water velocity criteria used to develop water diversion and intake velocities consider the swimming ability of native salmonids. For example, water velocity at screening structures near water withdrawal pumps exclude juvenile salmon by requiring maximum approach velocities of 15.3 cm/s, whereas fishways adjacent to dams promote salmon passage by maintaining entrance velocities near 305 cm/s (Ostrand 2004; Johnson et al. 2008). It is therefore no surprise that lamprey often incur elevated impingement rates at man-made structures and are often unsuccessful at bypassing dams in the Columbia River Basin (Moursund et al. 2003).

In conclusion, our results provide basic data on the swimming abilities of larval Pacific lamprey that could potentially be used by water diversion designers concerned with lamprey passage or entrainment. Our results also suggest larval Pacific lamprey are generally poor swimmers and if dislodged from the sediments they may have difficulty negotiating and avoiding water diversions and barriers. However, it would be appropriate to conduct similar research on a wider size range of ammocoetes over the broader range of temperatures they encounter in the Columbia River

Basin. Also, future research requiring holding of lamprey should aim to minimize possible stress and energetic output of lamprey by providing an environment (i.e., soft substrate for burrowing) more representative of natural conditions.

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