Migration Behavior of Adult Pacific Lamprey in the Lower Columbia River and Evaluation of Bonneville Dam Modifications to Improve Passage, 2001

Mary L. Moser

Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East, Seattle, WA 98112

Darren A. Ogden and Sarah G. McCarthy

Pacific States Marine Fisheries Commission
45 S.E. 82nd Drive, Suite 100
Gladstone, OR 97027-2522

Theodore C. Bjornn

U.S. Geological Survey
Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho
Moscow, ID 83843

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EXECUTIVE SUMMARY

In previous years of study, we used radiotelemetry to identify obstacles to passage of adult Pacific lamprey (*Lampetra tridentata*) at lower Columbia River dams. Lamprey have the greatest difficulty gaining entrance to the fishways, negotiating collection channels and transition areas, and passing through count station areas at the top of the ladders. The objectives of our research in 2001 were to:

1) assess behavior, passage success, and migration rates of radio-tagged adult Pacific lamprey at lower Columbia River dams,

2) evaluate the effects of lower water velocity and structural modifications on passage of lamprey at the spillway entrances at Bonneville Dam,

3) evaluate effects of modifications to diffuser gratings (i.e., addition of plates to permit attachment of lamprey) on passage of adult lamprey at Bonneville Dam, and

4) more intensively monitor lamprey passage at the tops of Bonneville Dam ladders to identify obstacles to lamprey passage.

We captured 894 adult lamprey in traps at Bonneville Dam and surgically implanted 298 fish with radio transmitters: 150 with a 7.7-g transmitter and 148 with a 4.5-g transmitter. All of these fish were released approximately 3 km downstream from Bonneville Dam. The median travel time from release to first detection at Bonneville Dam was 4.3 d, and 93% of the tagged lamprey were detected at the base of Bonneville Dam.

The percentage of radio-tagged lamprey that initially approached Powerhouse 2 in 2001 was higher than in 2000, perhaps due to increased discharge from Powerhouse 2 in 2001. Overall passage efficiency (the percentage of lamprey that passed over the dam of those that approached the dam) at Bonneville Dam (46%) in 2001 was slightly lower than in 2000 (47%) and median passage time from the first detection outside a fishway entrance to the last detection at the ladder exit (11 d) was over twice as long as in previous years. The reduced passage performance we observed in 2001 at Bonneville Dam was likely related to greater use of Powerhouse 2 fishways, where lamprey passage is typically low relative to Powerhouse 1 fishways.

As in 2000, structural modifications to a fishway entrance (rounding the bulkhead at the spillway entrance on Cascades Island) appeared to improve lamprey entrance success more than efforts to reduce nighttime water velocity at the spillway entrances. The velocity manipulations were conducted without the aid of computer control and were not accurate. Nonetheless, these tests indicated no strong positive effect of lowering nighttime velocity at the spillway entrances.

We hypothesized that diffuser grating in the collection channels and transition areas reduces lamprey passage success by limiting areas for attachment. Consequently, a 41-cm wide metal plate was placed over the floor diffusers in the transition area at Bonneville Dam Powerhouse 2 to provide lamprey with more attachment sites. Passage efficiency through this area was higher in 2001 than in previous years, suggesting that laying a plate over the diffuser grating aided lamprey passage.

Intensive monitoring of lamprey movements at the tops of the fishways indicated that lamprey were primarily obstructed in the serpentine weir sections and not at the count windows. Lamprey that were delayed at the serpentine weirs either fell back downstream or were able to pass into the makeup water channel adjacent to this area. Some of the lamprey in the makeup water channel at Bradford Island were able to escape into the forebay via the Tainter gate at the upstream end of the channel.

Passage efficiency at The Dalles Dam was 73% (median passage time 2.1 d), and passage efficiency at John Day Dam was 53% (median passage time 1.3 d). Lamprey that passed over John Day Dam fell back downstream at a higher rate (36%) than lamprey that passed over either Bonneville or The Dalles Dams. We found that during the winter, lamprey made short local movements, including four fish that fell back over Bonneville Dam.

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INTRODUCTION

The Pacific lamprey (*Lampetra tridentata*) is an anadromous, parasitic fish that occurs along the west coast of North America from California to Alaska (Scott and Crossman 1973). Indigenous peoples from the Pacific coast to the interior Columbia River have harvested adult lamprey for subsistence, religious, and medicinal purposes for many generations (Close et al. 2002). In the Columbia River drainage, adult Pacific lamprey support fisheries that have recently experienced dramatic declines and unprecedented regulation (Kostow 2002).

In the Columbia River, adult lamprey undertake a free-swimming, spawning migration into fresh water during late spring and summer, and lamprey abundance has historically been monitored by counting adults as they pass viewing stations in fishways at hydropower dams. While these lamprey counts are not an accurate means of estimating absolute abundance, they provide a good measure of relative abundance patterns (Starke and Dalen 1995, Moser and Close 2003). Comparison of counts made at dams in the lower and middle Columbia River revealed a fourfold to tenfold decrease in yearly abundance during the past four decades (Close 2001). In addition, concerns that lamprey are declining have prompted recent commercial harvest restrictions in the Willamette River, a tributary of the Columbia River (Kostow 2002), and a recent petition to list this species under the Endangered Species Act.

Hydropower dams on the Columbia River may have contributed to declines in lamprey abundance by restricting access to historical spawning locations. While the distribution of lamprey spawning sites in upriver areas prior to dam construction is not well documented, there are historical accounts of lamprey in the headwaters of both the Columbia and Snake Rivers (Kan 1975, Hammond 1979, Simpson and Wallace 1982). Lamprey must pass four hydropower dams to reach the confluence of the Columbia and Snake Rivers, and up to five additional dams to attain spawning areas in the upper reaches of these rivers. We have used radiotelemetry to establish that lamprey passage at the lower Columbia River dams is significantly lower than that of salmonids. For example, less than half of the radio-tagged lamprey that approached Bonneville Dam in 1997-2000 were able to successfully pass upstream (Moser et al. 2000b), whereas passage efficiency for salmonids is typically greater than 90% (Bjornn et al. 2000a,b).

In 1997-2000, we used radiotelemetry to examine passage of adult Pacific lamprey through specific areas within the fishways at Bonneville, The Dalles, and John Day Dams. Over the past decade an extensive array of fixed-site radio receivers and antennas has been established on and around these dams to assess adult salmonid passage at discrete areas in each fishway (Moser et al. 2002a). We used this receiver array to document passage success of radio-tagged lamprey at each area and to identify obstacles to lamprey passage. Specific areas where lamprey are obstructed or delayed were identified: fishway entrances, collection/transition areas at the bottom of the fishways, and count station areas at the top of the fishways (Moser et al. 2002b). In contrast, lamprey exhibited relatively rapid and successful passage through the pool and weir sections of the fishways where they were exposed to rapid currents.

The goal of our research in 2001 was to assess lamprey passage and to evaluate measures taken to improve lamprey passage at Bonneville Dam, the first mainstem dam that adult lamprey encounter on their spawning migration. Specific objectives were to:

1) assess behavior, passage success, and migration rates of radio-tagged adult Pacific lamprey at lower Columbia River dams,

2) evaluate the effects of water velocity and structural modifications on passage of lamprey at the spillway entrances at Bonneville Dam,

3) evaluate effects of modifications to diffuser gratings (i.e., addition of plates to permit attachment of lamprey) on passage of adult lamprey at Bonneville Dam, and

4) more intensively monitor lamprey passage at the tops of Bonneville Dam ladders to identify obstacles to lamprey passage.

METHODS

Study Area

We collected and radio tagged adult lamprey at the Adult Collection and Monitoring Facility on the Washington shore of Bonneville Dam, River Kilometer (RKm) 235. We released radio-tagged fish downstream from the dam at the Hamilton Island boat ramp on the Washington shore (RKm 231) and at the mouth of Tanner Creek (RKm 232) on the Oregon shore (Fig. 1).

At Bonneville Dam, there are two powerhouses oriented perpendicular to river flow, with a spillway between them (Fig. 1). A complex system of fishways allows fish to pass at the southern powerhouse (PH1), at the spillway, and at the northern powerhouse (PH2). At The Dalles Dam (RKm 308), fish may pass upstream via a fishway adjacent to the spillway on the north shore (North Fishway), or via a more complex system of entrances and collection channels that lead to a fishway at the powerhouse (East Fishway, Fig. 2). John Day (RKm 347) and McNary (RKm 467) Dams have similar fishway configurations: one fishway is adjacent to the spillway on the north shore (North) and one is at the powerhouse on the south shore (South, Figs. 3-4). At all dams, fish can also pass upstream during operation of navigation locks; however, we only monitored lamprey passage via this route at Bonneville Dam (Fig. 1).

Lamprey passage was monitored by fixed-site receivers located on each dam (Figs. 1-4), at the dam tailraces, and at the mouths of major tributaries. Receiving stations in the tailraces and in tributaries had a scanning receiver with a Yagi aerial antenna. At the dams, receiving stations had digital spectrum processors coupled with a scanning receiver and one or more underwater coaxial cable antennas (range 9 m) to receive transmissions on a number of frequencies simultaneously. These receivers were strategically positioned to allow assessment of passage through discrete areas of the fishways: entrances, collection channels, transition areas, ladders, and counting stations. Both the outside and inside of each main fishway entrance were monitored by at least one antenna.

Collection channels were defined as the areas between a fishway entrance and the pool and weir sections of the fishway. Transition areas were defined as the pool and weir sections of the fishway that were inundated by tailwater, while ladders were pool and weir areas not inundated by tailwater. Counting stations, usually near the top of the ladders, allow enumeration of all fish passing through the ladder. Counting stations included a picketed lead that crowds fish into a narrow, brightly-lit channel which is viewed from the side through a window. Slot or overflow weirs upstream from the window that lead to the fishway exit were also included in the counting station area.

In 2001, as in 2000, we intensified monitoring at the count station areas to allow identification of specific regions that impeded lamprey progress. At the top of the Bradford Island fishway at Bonneville Dam, one antenna was positioned immediately

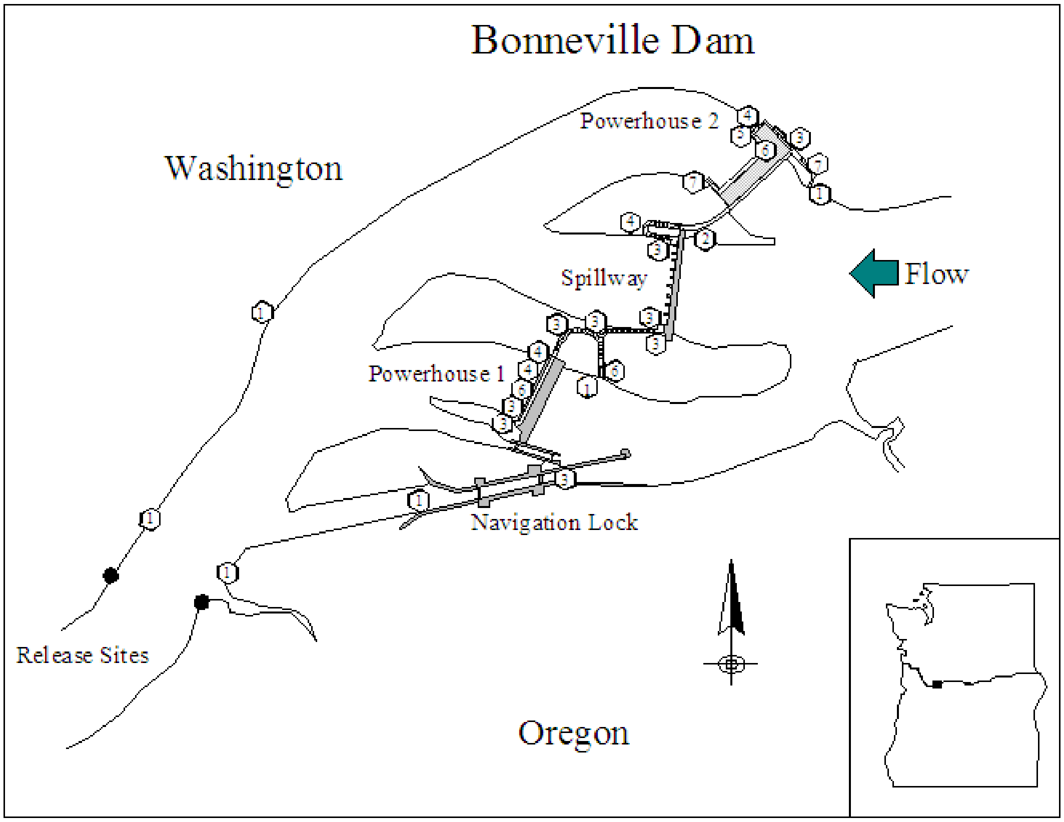

Figure 1. Study area at Bonneville Dam on the lower Columbia River (solid square in insert). Release sites used in 2001 are indicated by solid dots. Radio receiver sites (with the number of antennas used at each site) are indicated by hexagons.

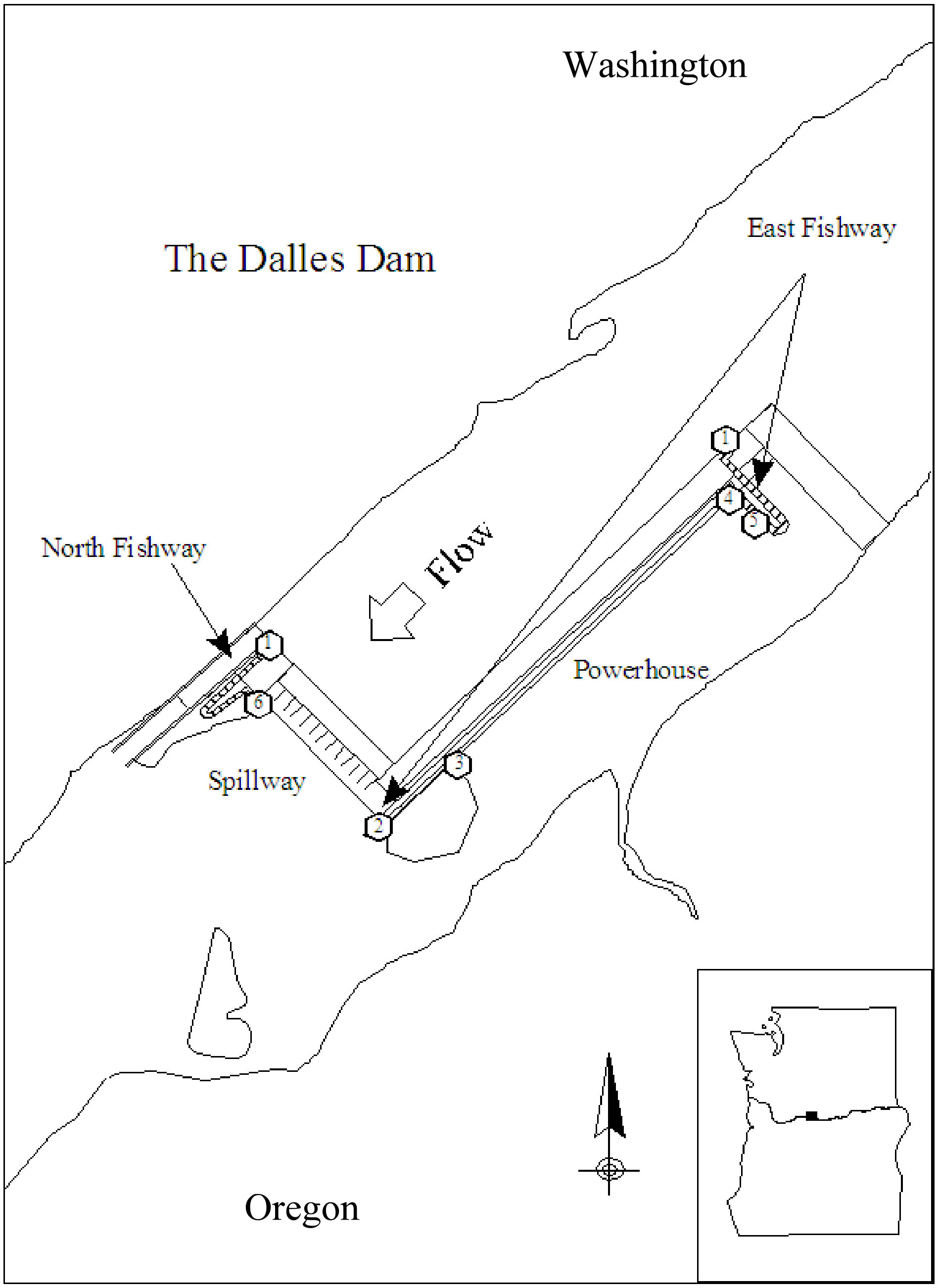

Figure 2. Study area at The Dalles Dam on the lower Columbia River (solid square in insert). Radio receiver sites (with the number of antennas at each site) are indicated by hexagons.

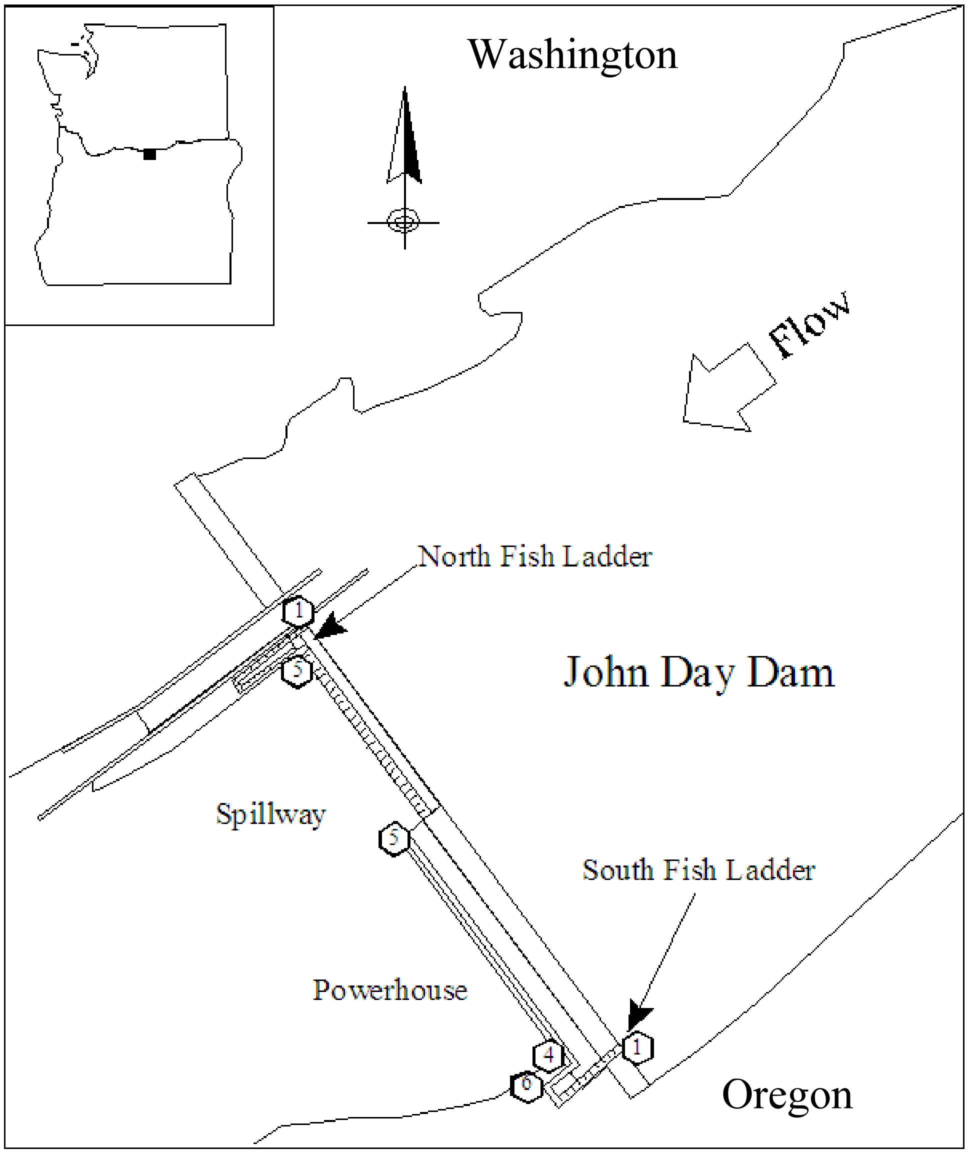

Figure 3. Study area at John Day Dam on the lower Columbia River (solid square in insert). Radio receiver sites (with the number of antennas at each site) are indicated by hexagons.

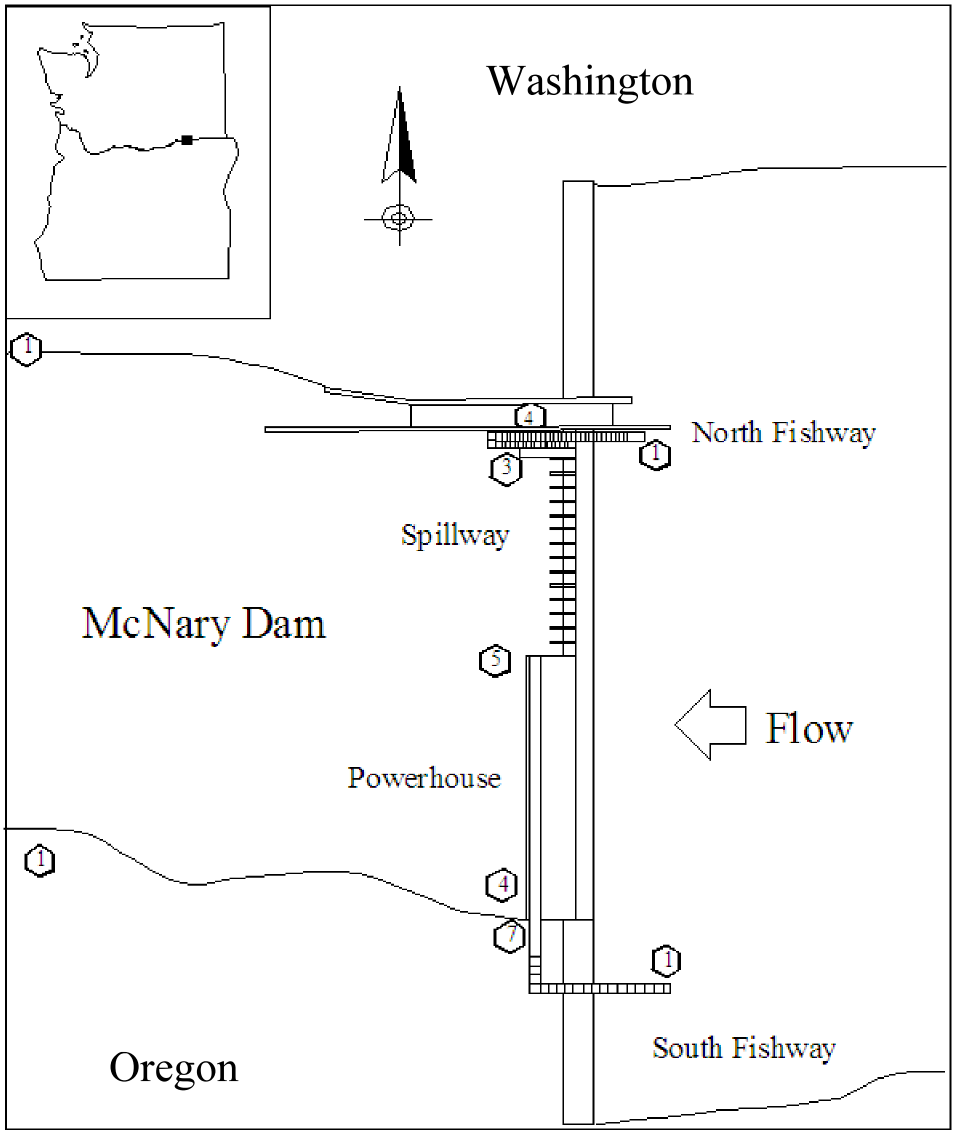

Figure 4. Study area at McNary Dam on the lower Columbia River (solid square in insert). Radio receiver sites (with the number of antennas at each receiver) are indicated by hexagons.

downstream from the counting window (at the upstream end of the picketed lead, Fig. 5). There were three antennas located in the serpentine slot weirs above the counting window, and an antenna at the top of the serpentine weir area. Two additional antennas were positioned in the make-up water channel that runs parallel to the serpentine weir area (Fig. 5). At the top of the Washington-shore fishway, an antenna was placed immediately downstream from the counting window (upstream end of picketed lead), four antennas were positioned through the serpentine weir area, and one antenna monitored passage at the fishway exit (Fig. 6). Two additional antennas were placed in the make-up water channel.

In 2001, we tested the efficacy of structural and operational modifications at Bonneville Dam fishway entrances by comparing entrance efficiency in 2001 to that documented in previous years of lamprey radiotelemetry. The bulkhead edge at the Bonneville Dam northern spillway entrance (Cascades Island) was changed from a square to a rounded edge in 2001 so that lamprey could remain attached as they moved along the bulkhead and into the fishway. This same modification was made to the southern spillway entrance (Bradford B-Branch) in 2000.

Tests were also conducted to determine whether lowering water velocity at the Bonneville Dam spillway entrances would improve lamprey entrance success. Operators at the dam decreased velocity from approximately 2.4 m/s to 1.2 m/s at night (2100 to 0400 h) at alternating spillway entrances during the period from 1 June to 29 August 2001. We then compared entrance efficiency for the two conditions: low nighttime flow and normal nighttime flow.

In 2001, tests were continued to assess the effects of closing orifice entrances on lamprey entrance and passage success. Orifice entrances at Bonneville Dam Powerhouse 1 (Fig. 1) were alternately opened and closed from 1 April to 31 October 2001 and all orifice entrances at The Dalles Dam were closed in 2001. We compared overall entrance success for fishways with and without orifice closures to determine whether closing orifice entrances affected lamprey passage success.

Finally, in 2001 a metal plate was fixed over diffuser grating at the PH2 transition area to test whether increasing attachment sites for lamprey would aid passage through this troublesome area. A 41-cm wide metal plate was attached to the diffuser gratings in a strip running parallel to the walls of the fishway and in line with the orifice openings at the north end of the weirs. This treatment was applied from the first to the tenth weirs in the Washington-shore fishway. We then tested whether lamprey approaching the first weir were more likely to ascend to the tenth weir than in years prior to addition of these "attachment plates."

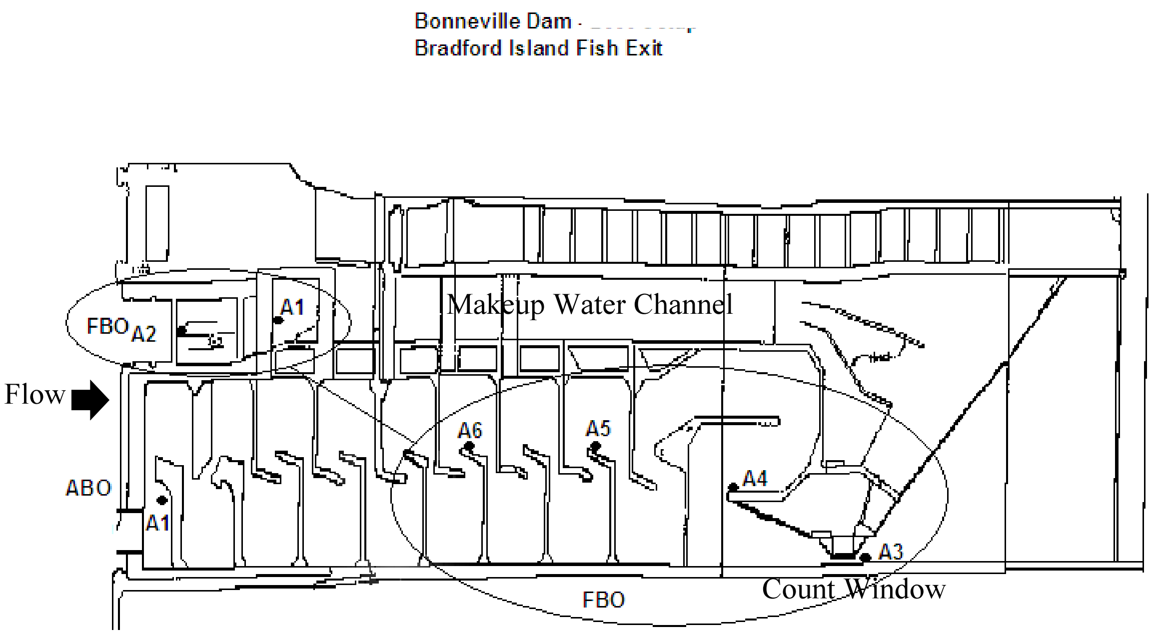

Figure 5. Location of the receivers (FBO and ABO) and individual antennas (FBO A3 at the counting window, A4, A5, and A6 in the serpentine weir section, A1 and A2 in the makeup water channel, and ABO A1 at the ladder exit) at the top of the Bradford Island fishway in 2001.

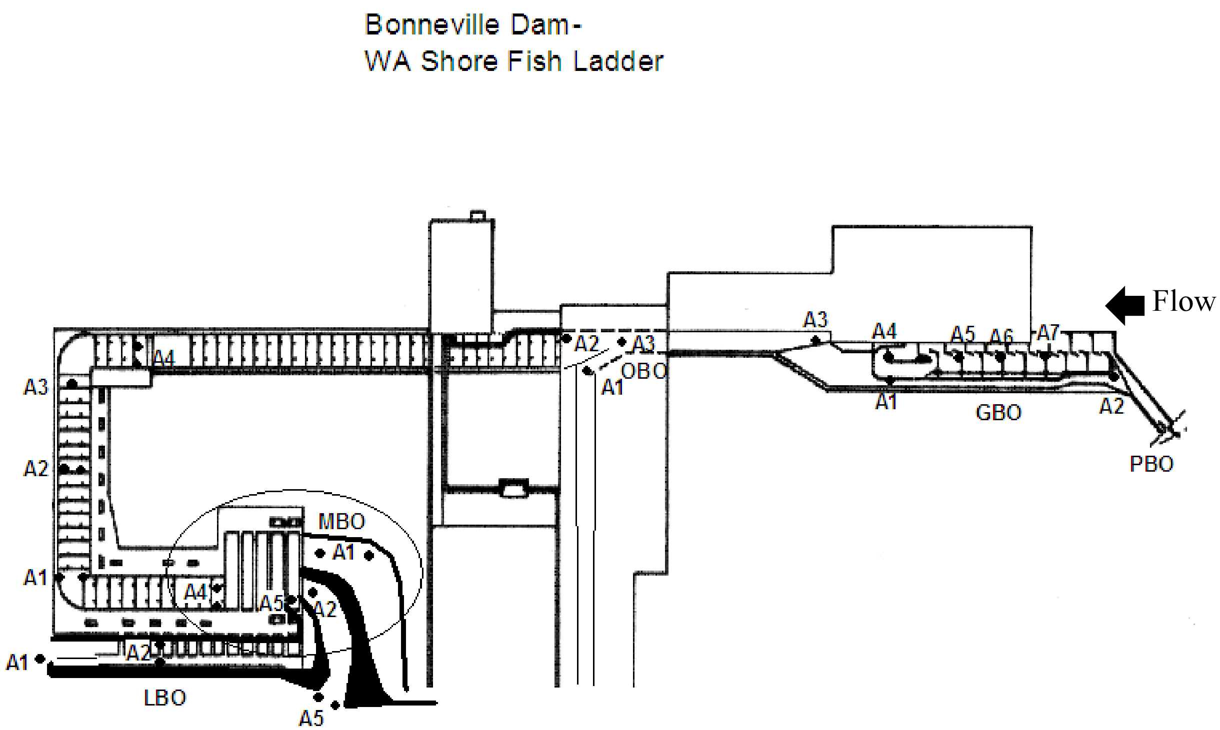

Figure 6. Location of the receivers (GBO and PBO) and individual antennas (GBO A3 at the counting window, A4, A5, A6, and A7 in the serpentine weir section, A1 and A2 in the makeup water channel, and PBO at the ladder exit) at the top of the Washington-shore fishway in 2001.

Tagging and Tracking

We captured lamprey during the night in a trap at the Adult Fish Collection and Monitoring Facility on the Washington shore at Bonneville Dam (described in Ocker et al. 2001). Lamprey were anesthetized using 60 ppm clove oil, measured (length and girth to the nearest mm), and weighed (nearest g). A radio transmitter representing less than 2% of the fish body weight was then surgically implanted into the body cavity of each fish. We used either 7.7-g (3.7 g in water), or 4.5-g (2.9 g in water) radio transmitters (hereafter referred to as large and small). All transmitters were uniquely coded to allow identification of individual fish and had a battery life of at least 7 months.

Fish to be tagged were transferred to a surgery cradle partly submerged in a 16-L bath of 60 ppm clove oil. Surgical tools and tags were sanitized in a solution of zephiran chloride and rinsed in a freshwater bath. A 3-cm incision was made approximately 1 cm off the ventral midline using a 3-mm fixed-depth disposable scalpel, with the posterior end of the incision ending in line with the anterior insertion of the first dorsal fin. The tag was inserted into the body cavity, and the antenna was threaded through the body wall approximately 3 cm posterior to the incision using a cannula. The incision was closed with a 19-mm needle and at least five simple, interrupted stitches of 3-0 absorbable surgical suture. After closing, a hypodermic needle was inserted into the incision, and the wound was irrigated with 0.75 cc of oxytetracycline and coated with an antibiotic ointment as a prophylactic measure.

In addition to the surgery to implant transmitters, we also collected a blood sample from some of the lamprey prior to tag insertion. A heparinized 1-mL disposable syringe with a 23-gauge needle was used to draw 1 mL from the caudal vasculature at a position approximately 2 cm posterior to the vent. The blood was slowly discharged into a 2-mL heparinized centrifuge tube and placed on ice. Within an hour of taking the blood, the samples were centrifuged at 3,000 rpm for 3-5 min, and the plasma was transferred to pre-labeled tubes and saved at -80°C. These samples were then transported to the U.S. Geological Survey, Columbia River Research Laboratory in Cook, Washington where they were stored for later sex steroid analysis (Mesa et al. 2003). After surgery, the lamprey were allowed to recover in an aerated tank for approximately 2 hours prior to release.

Radio-tagged lamprey were relocated via mobile tracking (using a portable receiver from a vehicle or vessel) and the fixed-site receiving stations (Figs. 1-4). Data from fixed-site receivers were downloaded every 1-2 weeks and processed following protocols detailed in Moser et al. (2002a). For each area of interest (entrances, collection channels, transition areas, ladders, and counting stations), we determined the number of lamprey that approached and the proportion that successfully passed (passage efficiency). Lamprey moved both upstream and downstream in the fishways (Matter et al. 2000). For analysis, we determined the furthest upstream position attained by each fish, even if it required several attempts to reach this position. At Bonneville Dam count station areas, we also computed the amount of time lamprey held position in specific areas by subtracting the first time of detection at a given antenna from the first time of detection at the next antenna upstream.

RESULTS

Trapping and Tagging

We set the lamprey trap nightly from May 23 to September 1. The trap was fished for a total of 1,046 hours and captured 894 lamprey (0.85 lamprey/h). This was higher than the catch per unit effort (CPUE) obtained using the same trap in the previous two years. CPUE was 0.7 lamprey/h in 1999 and 0.3 lamprey/h in 2000 (Moser and Close 2003). We compared the weekly mean (to account for travel time between trap and count window) number of lamprey counted per hour at the Washington-shore counting station and the trap CPUE during the same period using Spearman's rank correlation procedure (Zar 1994). As was the case in 2000 (Moser and Close 2003), we found no significant correlation in weekly means (Fig. 7) obtained using the two methods ($P > 0.05$).

We tagged 298 lamprey that were collected during the peak of their spawning migration at the Washington-shore fishway at Bonneville Dam (Fig. 8). We also took blood samples for USGS personnel from 173 of these individuals, 101 females and 72 males (Mesa et al. 2003). Due to the large number and size of lamprey collected in 2001, we were able to tag fish over most of the size distribution (Figs. 9-11). Tagged lamprey were of a similar size range as in previous years (both weight and length), but their average size was greater than in previous years (Table 1). The females used for tagging in 2001 (n = 181) were slightly larger (75 cm and 598 g) than the males (n = 117, 70.6 cm and 573 g).

We used the large transmitter on fish having a girth of at least 11.5 cm (n = 150) and the small tag on fish having a girth of at least 10.5 cm (n = 148)(Fig. 11). Consequently, the large tag was only used on the largest lamprey we collected (Figs. 9-10) and its wet weight represented 0.4-0.8% of lamprey body weights (Fig. 12). The small tags represented a similar percentage of the lamprey body weights (Fig. 12). However, the circumference of the small tag was a lower percentage of the lamprey girths (21-27%) than was the circumference of the large tags (24-29%)(Fig. 13).

We released all 298 radio-tagged lamprey below Bonneville Dam: 167 on the Washington shore and 131 on the Oregon shore.

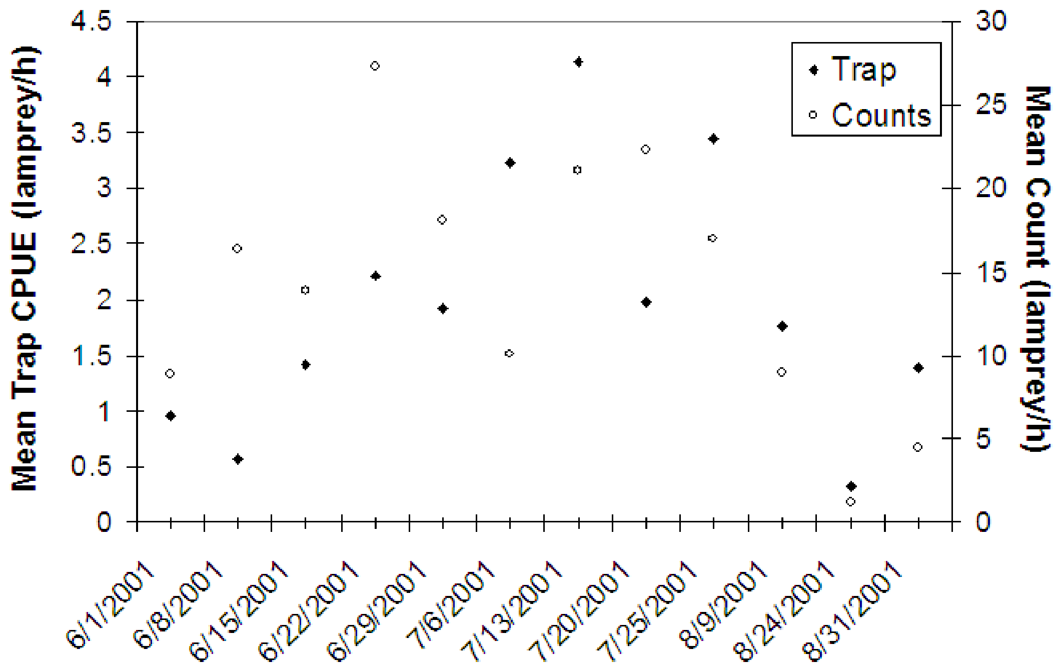

Figure 7. Comparison of weekly trap CPUE (lamprey/h) and weekly counts at the Washington-shore count station (lamprey/h) in 2001.

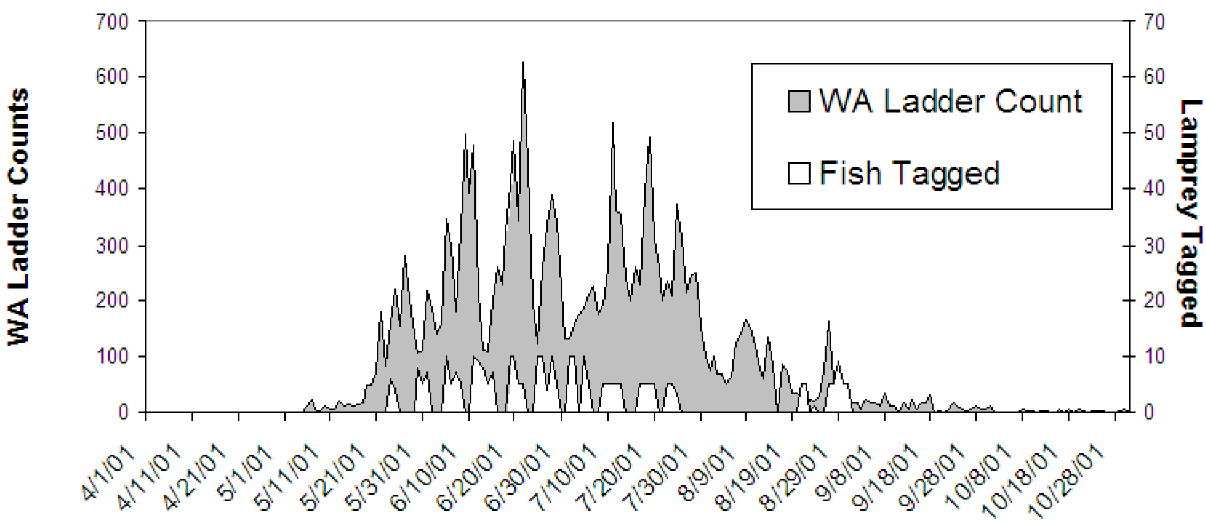

Figure 8. Daily lamprey counts at the Washington-shore count station and release dates for radio-tagged lamprey in 2001.

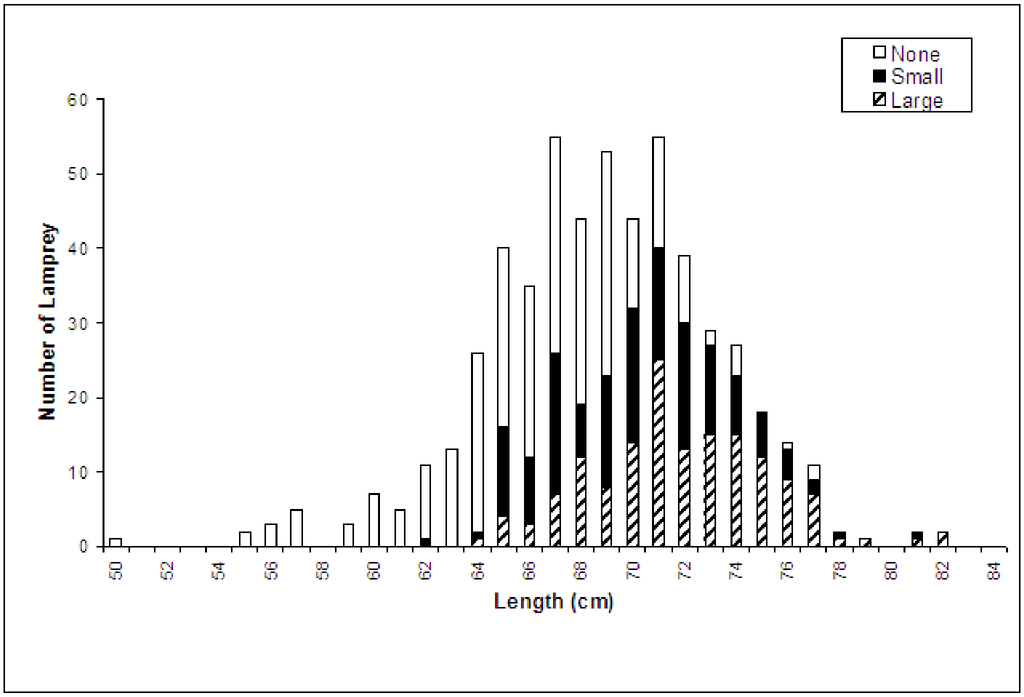

Figure 9. Length distribution of lamprey tagged (small tags in black, large tags in hatched) and not tagged (white) in 2001.

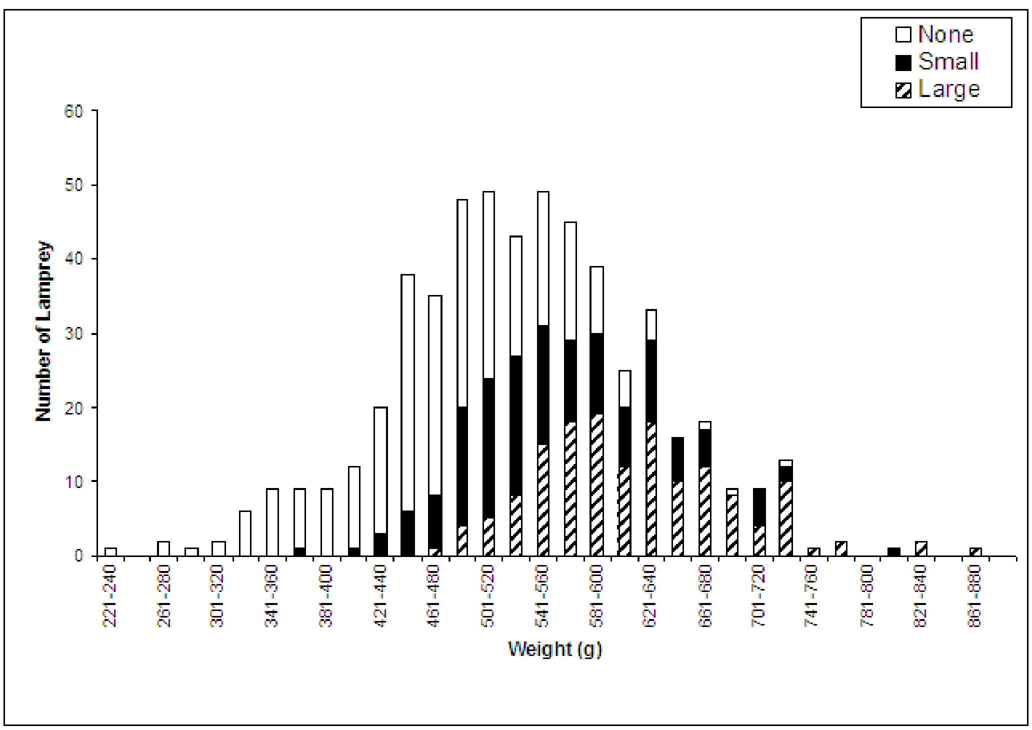

Figure 10. Weight distribution of lamprey tagged (small tags in black, large tags in hatched) and not tagged (white) in 2001.

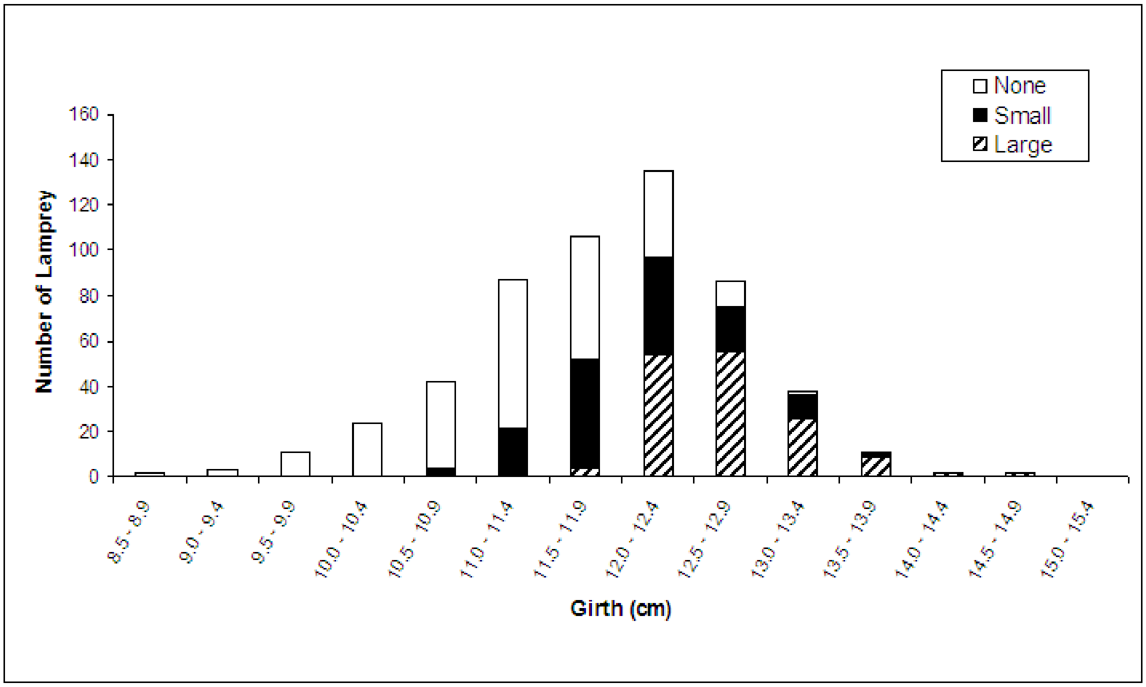

Figure 11. Frequency distribution of girth (measured at the insertion of first dorsal fin) for lamprey tagged (small tags in black, large tags in hatched) and not tagged (white) in 2001.

Table 1. Sizes and the median travel time from release to first approach at a Bonneville Dam fishway entrance for adult Pacific lamprey radio tagged and released below Bonneville Dam in 1997-2001.

	1997	1998	1999	2000	2001
Number released	147	205	199	299	298
Mean length, cm	70	70	71	70	77.4
(range)	(60-80)	(59-79)	(65-78)	(62-80)	(62-82)
Mean weight, g	-	545	571	570	588
(range)	>450	(420-830)	(475-755)	(405-825)	(380-880)
Number detected at Bonneville Dam	129	182	183	260	278
(%)	(88%)	(89%)	(92%)	(87%)	(93%)
Travel time to dam, median days	7.8	4.0	5.2	6.4	4.3
(range)	(0.5-40.5)	(0.1-28.2)	(0.1-53.5)	(0.3-111.2)	(0.1-111.3)
standard deviation	7.5	4.8	7.3	13.0	11.9

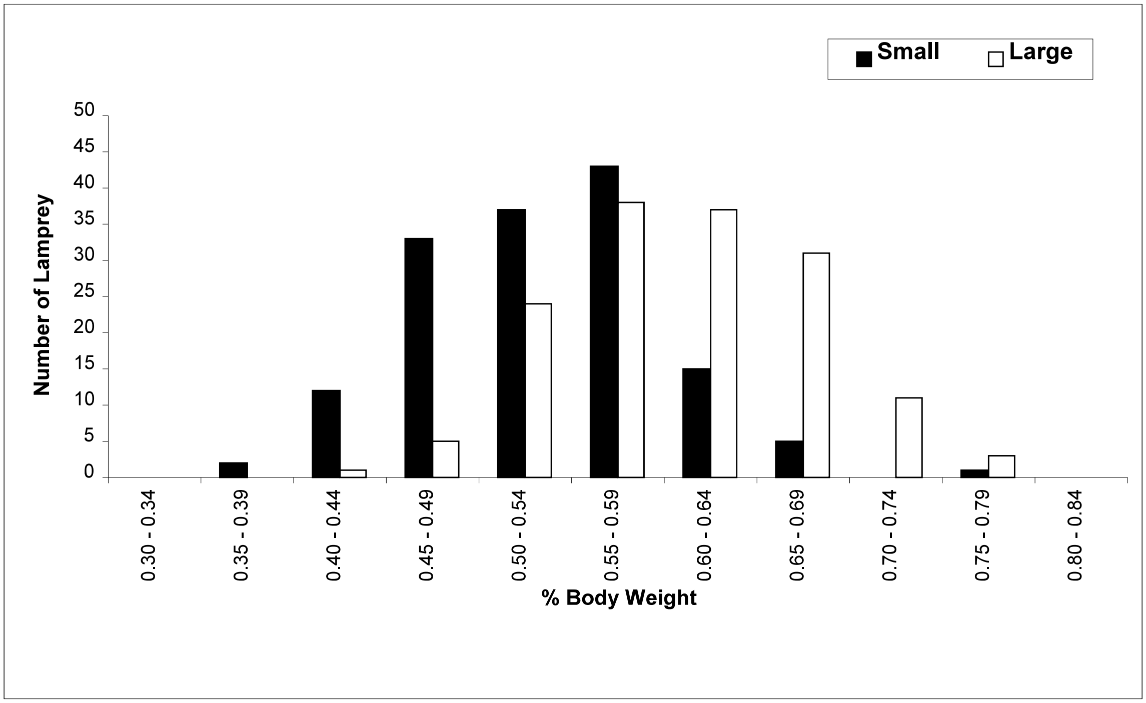

Figure 12. Frequency distribution of percent lamprey body weight for each tag size.

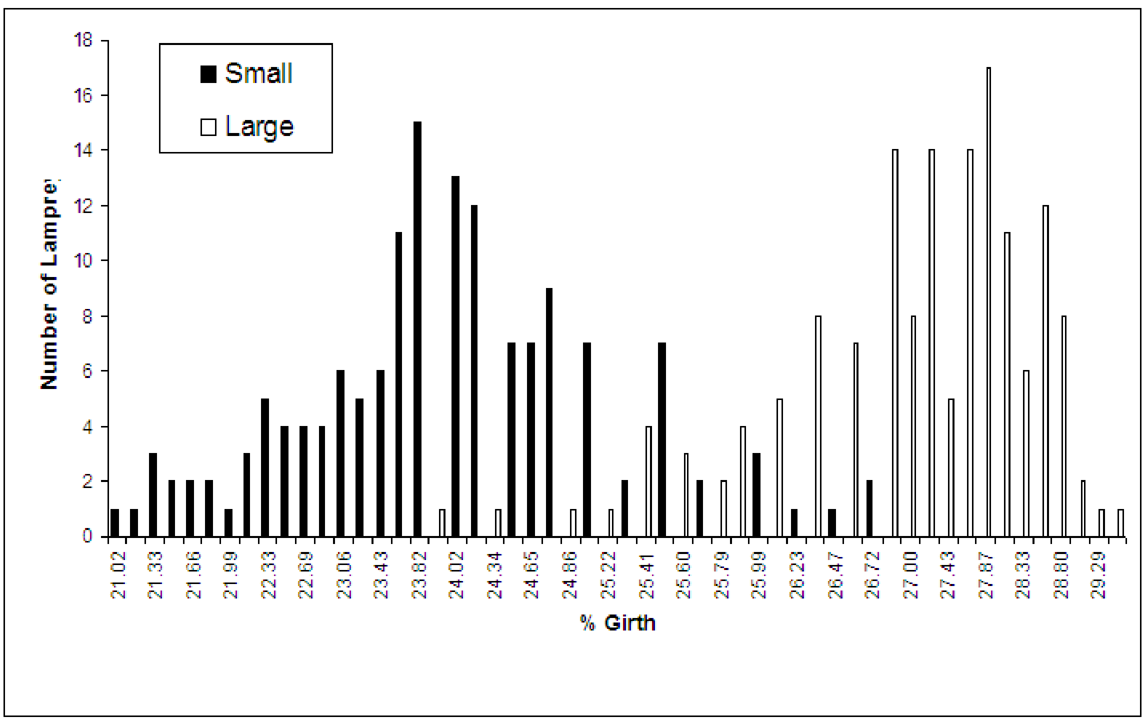

Figure 13. Frequency distribution of percent lamprey girth for each tag size.

Bonneville Dam

Of the 298 fish released below Bonneville Dam, 20 (7%) did not approach the dam and were only detected at the release site. The rest of the fish were detected at Bonneville Dam (93%), and this is the highest percentage of radio-tagged lamprey that have returned to the dam during our tracking studies (Table 1). In addition, the median travel time from release to first detection at a Bonneville Dam fishway entrance was 4.3 days, lower than most previous years of study (Table 1).

There was no apparent effect of tag type (small or large) on the percentage of fish that was not detected at the dam: 11 (7%) of the 150 fish with large tags were not detected and 9 (6%) of the 148 fish with small tags were not detected. However, median travel times from release to first detection at the dam were shorter (3.1 d) for fish tagged with small tags than for fish bearing the large tags (5.5 d). Further analysis indicated that the longest travel times were recorded for fish bearing tags that were greater than 0.7% of body weight (Fig. 14). Lamprey with tags that represented the largest percent girth in each treatment group also had longer travel times (Fig. 15).

To determine whether lamprey were differentially attracted to Powerhouse 1 (PH1), Powerhouse 2 (PH2), or spillway entrances when they initially approached Bonneville Dam, we divided the number of fish that first approached each of these sections by the total number of lamprey that approached the dam (n = 278). In many cases individual lamprey approached the entrances more than once and/or were detected at entrances in more than one section. For this analysis, we used only the very first approach by a given fish. In 2001, 59% of the radio-tagged lamprey made their initial approach at PH2, a higher percentage than in any other year, and the percentage that approached at PH1 (26%) was lower than in any other year (Fig. 16).

Entrance efficiency (the number of lamprey that entered a fishway entrance divided by the number of lamprey that approached that entrance) varied among the powerhouses and spillway (Table 2). As in other years of study, entrance efficiency was lowest at the spillway entrances (65%), intermediate at PH1 entrances (74%), and highest at the PH2 entrances (77%). However, entrance efficiency improved at the spillway entrances relative to previous years of study. Also, entrance efficiency at PH2 entrances was low relative to previous years.

Examination of entrance efficiency at individual entrances revealed that, as in previous years, lamprey generally had lower entrance success at orifice entrances than at main entrances (Fig. 17). However, entrance efficiency at PH1 gates 34, 58, and 62 was higher in 2001 than in previous years of monitoring. We also noted relatively low entrance efficiency at the northernmost PH2 entrances (Fig. 17)

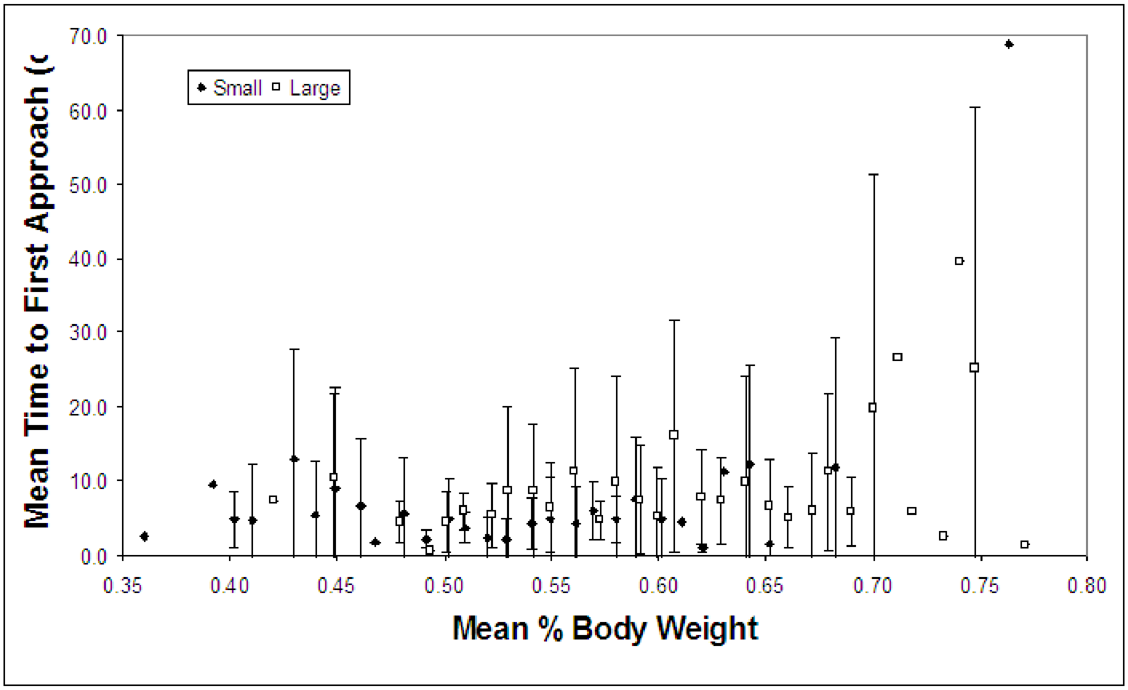

Figure 14. Mean travel time (d) from release to first detection at Bonneville Dam for lamprey bearing large and small tags of increasing mean % body weight.

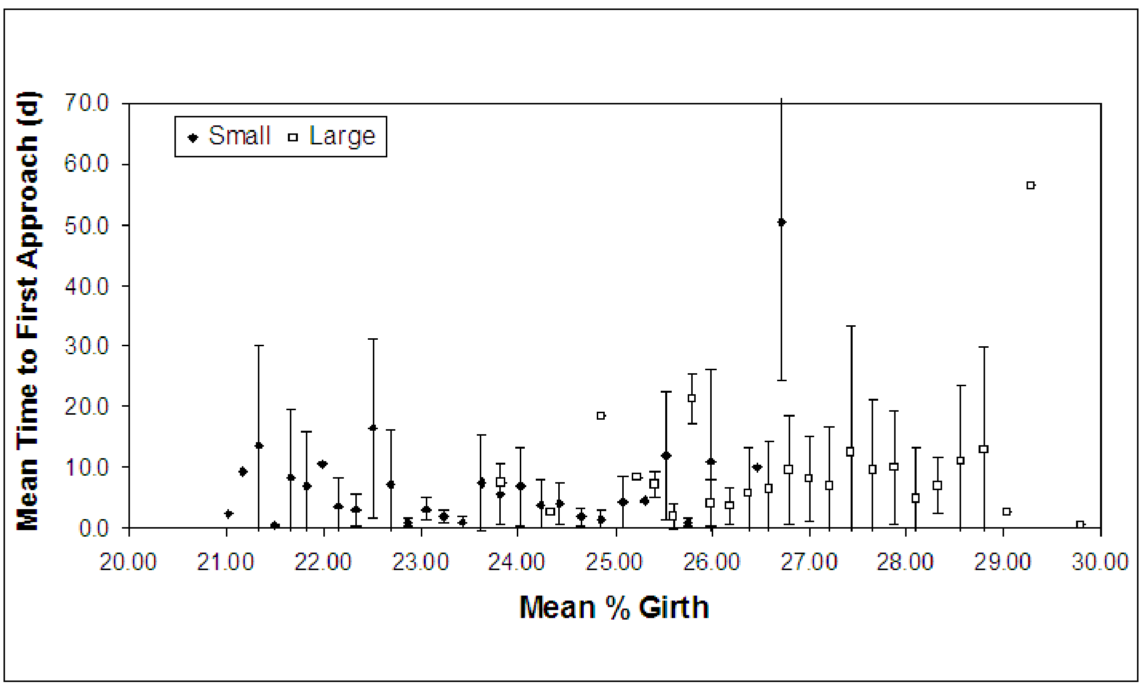

Figure 15. Mean travel time (d) from release to first detection at Bonneville Dam for lamprey bearing large and small tags of increasing mean % girth.

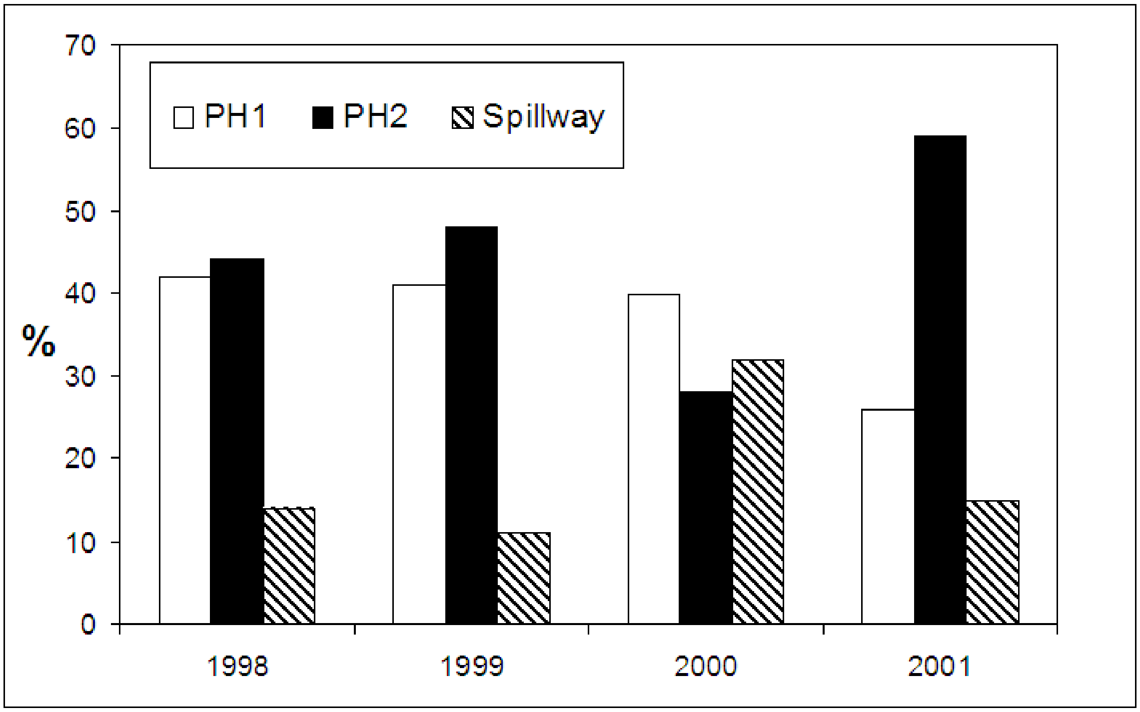

Figure 16. Percent (%) of radio-tagged lamprey that made their initial approach at the fishways at PH1, PH2, or the spillway at Bonneville Dam in 1998-2001.

Table 2. The number of radio-tagged lamprey that passed through each area within each fishway at Bonneville Dam in 1997-2001. Passage efficiency (the number of fish that passed through the area / the number that approached that area × 100) is in parenthesis.

Fishway	Area	1997	1998	1999	2000	2001
PH1	Entrance	47 (60%)	78 (80%)	63 (72%)	97 (74%)	71 (74%)
	Collection	36 (77%)	63 (81%)	55 (87%)	85 (88%)	59 (83%)
	Transition	32 (89%)	61 (97%)	50 (91%)	82 (96%)	58 (98%)
	Ladder	27 (75%)	59 (97%)	49 (98%)	71 (86%)	52 (90%)
	Count station	21 (78%)	37 (63%)	38 (78%)	63 (89%)	45 (86%)
PH2	Entrance	50 (69%)	78 (81%)	100 (85%)	87 (80%)	157 (77%)
	Collection	30 (60%)	50 (64%)	79 (79%)	63 (72%)	94 (60%)
	Transition	25 (83%)	32 (64%)	43 (54%)	43 (68%)	72 (77%)
	Ladder	24 (96%)	29 (91%)	43 (100%)	38 (88%)	71 (99%)
	Count station	21 (88%)	25 (86%)	35 (81%)	32 (84%)	57 (80%)
Spillway	Entrance	33 (54%)	35 (44%)	41 (57%)	69 (60%)	55 (65%)
	Collection	19 (58%)	21 (60%)	22 (54%)	63 (91%)	53 (96%)
	Transition	14 (74%)	12 (57%)	11 (50%)	37 (59%)	39 (74%)
	Ladder	11 (79%)	11 (92%)	10 (91%)	32 (86%)	36 (92%)
	Count station	6 (54%)	9 (82%)	8 (80%)	24 (75%)	26 (72%)

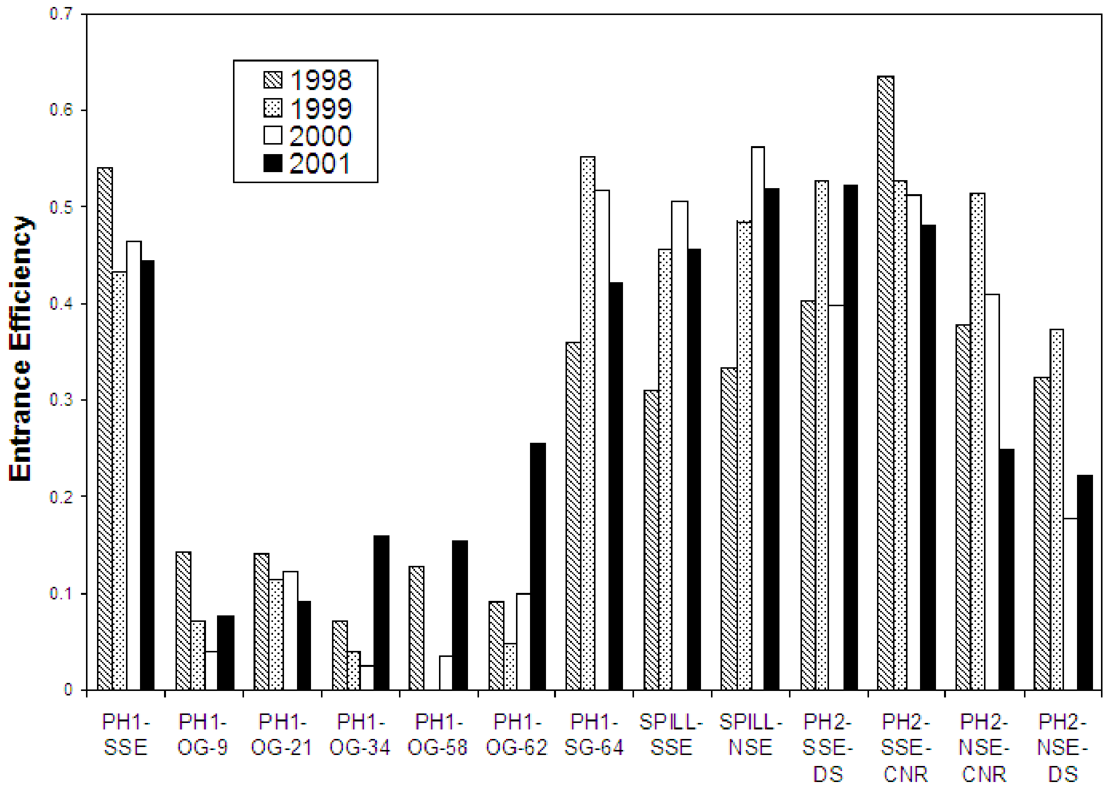

Figure 17. Entrance efficiency (percentage of lamprey that successfully entered of those that approached) at each of the Bonneville Dam fishway entrances from south to north along Powerhouse 1 (PH1), the spillway (SPILL), and Powerhouse 2 (PH2) in 1998-2001. Orifice and sluice gate entrances at PH1 are denoted by OG and SG, respectively (orifice entrances were not monitored at PH2 in 2000). Main entrances at PH2 include those downstream (DS) and in the corners (CNR).

Overall entrance efficiency increased at the spillway entrances but decreased at the individual entrances in 2001. This apparent discrepancy resulted from the tendency for lamprey to move between the two spillway entrances prior to entering. As in previous years, entrance efficiency at the northern spillway entrance (Cascades Island, SPILL-NSE) was higher than at the southern spillway entrance (Bradford Island B-Branch, SPILL-SSE)(Fig. 17).

In 2001, water velocity testing at the spillway entrances was conducted without the benefit of computer control (i.e., the testing relied on dam operators to manually manipulate valves that controlled head at these entrances). We measured head levels at the two entrances at 2300 h on randomly selected nights and found that there was either no difference in water level at the entrances (67% of the time) or that the high head treatment was in place at the wrong entrance (22% of the time). Consequently, velocity treatments in 2001 were considered unreliable.

As a more general test of the effect of lowering water velocity on lamprey entrance success, we compared the entrance efficiency of lamprey that approached the spillway entrances during the scheduled velocity testing period (1 June-29 August) to entrance efficiency of lamprey that approached these entrances during other times of the year. Of the 76 lamprey that approached the spillway entrances during the testing period, 47 (62%) entered. A total of 10 lamprey approached the spillway entrances outside of the velocity testing period and 7 (70%) entered.

Lamprey passage through the PH2 collection channel was lower than through the PH1 collection channel. While this pattern has emerged in previous years of tracking, passage at the PH2 collection channel was also markedly lower than in the two previous years (Table 2).

In contrast, lamprey passage efficiency improved at the PH2 transition area relative to previous years (Fig. 18). Passage through the transition areas in PH2 and spillway fishways was still lower than passage through the transition area at PH1. Lamprey passage efficiency through the ladders was 90% or higher in all fishways at Bonneville Dam (Table 2).

We intensively monitored the fates of radio-tagged lamprey that approached the count windows at the tops of both the Washington-shore and the Bradford Island fishways. Of the 73 lamprey that approached the count window on Bradford Island, 3 went through the picketed lead and into the makeup water channel (MWC). Two of these fish fell back downstream and one entered the serpentine weir area without passing the count window and then fell back downstream.

Of the 70 fish that passed the Bradford Island count window, 9 did not exit at the top of the ladder (Fig. 19). Five of these 9 fell back downstream, passing the count window, and 4 entered the MWC via grates in the wall. Of the four that passed into the

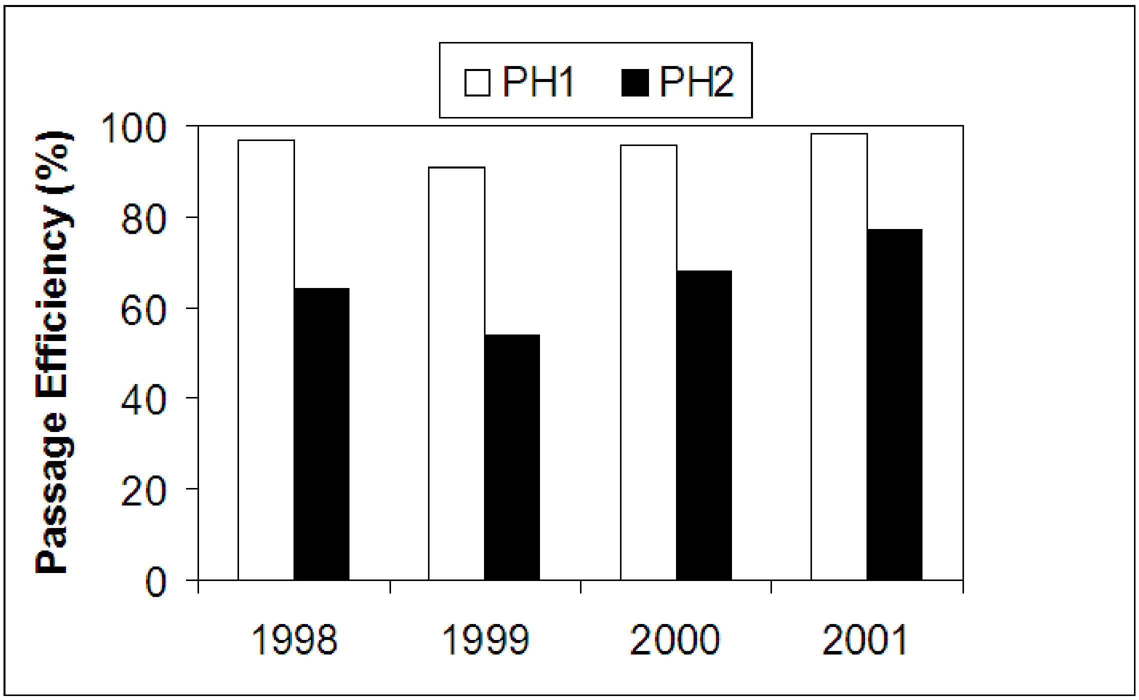

Figure 18. Transition area passage efficiency (percentage of lamprey that passed through the transition area of those that approached this area) at the Bonneville Dam fishways (Bradford Island = PH1, Washington-shore = PH2) in 2001 (after installation of metal plates over diffuser grating at PH2) as compared to the period before installation of attachment plates (1998-2000).

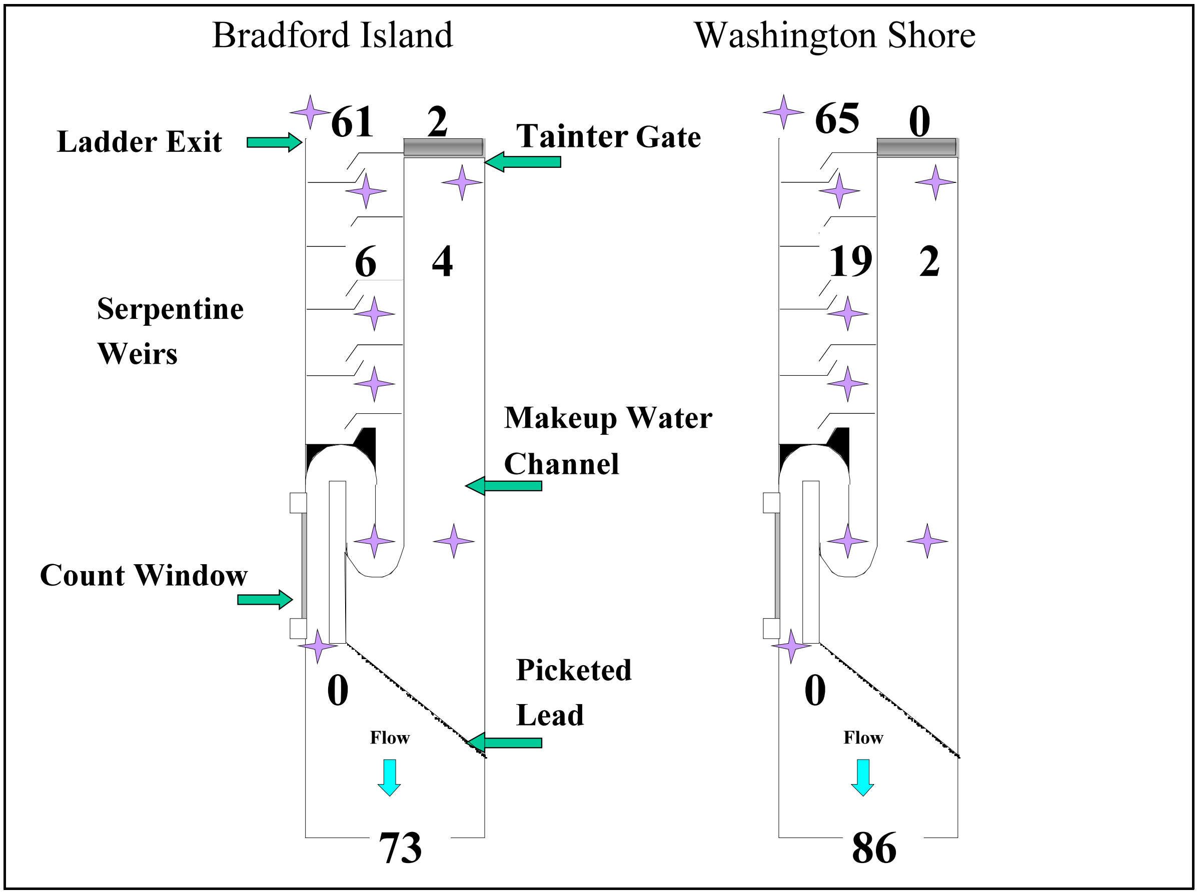

Figure 19. Diagram of the count station areas at the tops of the Bradford Island and Washington-shore fish ladders. Numbers in the fishways indicate the number of lamprey that fell back downstream at each location of the 73 fish that approached the Bradford count window and the 86 fish that approached the Washington-shore count window. Numbers above each diagram indicate the number of lamprey that successfully exited into the forebay. Stars indicate antenna locations.

MWC, two fell back downstream and two passed upstream and into the dam forebay via the Tainter gate. The last position of each fish prior to falling back downstream is shown on Figure 19.

At the top of the Washington-shore ladder, 85 lamprey passed the count window and 1 passed through the picketed lead and into the MWC. This fish eventually fell back downstream through the picketed lead. All of the remaining 85 fish passed the count window and entered the serpentine weir section. However, 20 of these did not exit at the top of the ladder. One fish moved through the wall grating and into the MWC and eventually fell back downstream through the picketed lead. The other 19 lamprey fell back downstream past the count window. The last position where lamprey were recorded before falling back downstream is shown on Figure 19.

Lamprey tended to hold for extended periods in the Bradford Island makeup water channel, compared to the highly variable, but generally lower residence times observed in the serpentine weir section (Fig. 20). At both counting station areas, lamprey were delayed or obstructed at the serpentine weir areas (particularly those farthest upstream) more than at the counting window (Figs. 19-21).

Of the 278 lamprey that approached Bonneville Dam, 128 passed over the dam via the fishways and 1 passed upstream through the navigation lock, for a total passage efficiency of 46%. Passage efficiency dropped from around 50% to around 25% for fish bearing large tags that represented greater than 59% of their body weight (Fig. 22). In addition, lamprey with small tags that were greater than 25% of lamprey girth had lower passage efficiency (less than 30%) than lamprey with small tags that were less than 25% of their girth (greater than 40% passage efficiency). Similarly, lamprey with large tags that were over 27% of the girth measurement exhibited lower passage efficiency (less than 30%) than lamprey bearing tags that were less than 27% of their girth (passage efficiencies greater than 40%)(Fig. 23).

Median passage time from the first approach at Bonneville Dam fishway entrances to the last detection when the lamprey exited the fishway into the forebay was 11.1 d (range = 0.4-96.6 d, SD 14.5 d). There was no clear effect of tag size (either % of body weight or % of girth) on passage time of lamprey that successfully passed over the dam (Figs. 24 and 25). Moreover, we found that females (n = 78) had only slightly shorter passage times (median = 10.7 d, range = 0.4-71.1 d, SD = 12.7) than males (median = 11.7 d, range = 0.4-96.6 d, SD = 17.5 d, n = 44).

In 2001, 16 (12%) of the radio-tagged lamprey that passed over Bonneville Dam were subsequently detected downstream from the dam; i.e., they fell back downstream via an unknown route. In addition, one fish fell back downstream through the Washington-shore ladder. Of the 17 fallbacks, only one fish reapproached the dam. This individual attained the top of the ladder, but did not pass over the dam and subsequently exited the fishway and did not reascend.

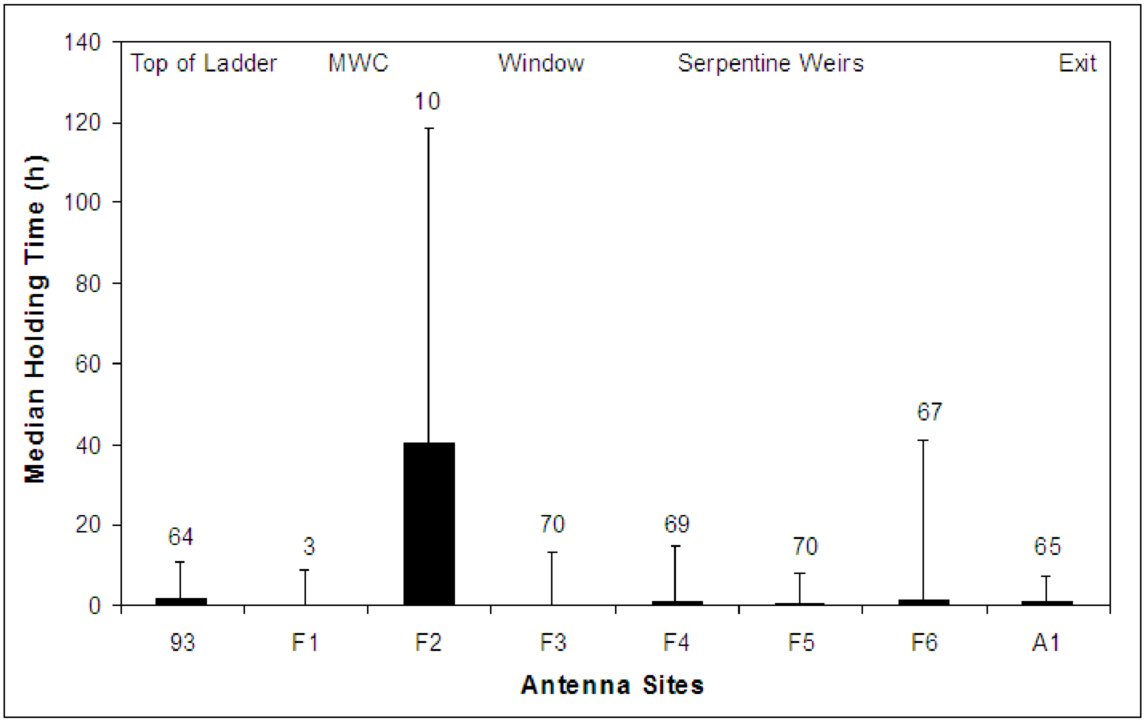

Figure 20. Median holding time at each antenna site (Fig. 5) for the Bradford Island count station area (i.e., median hours from first detection at an antenna site to the first detection at the next upstream antenna site with standard deviation denoted by error bars and sample size over each bar). Features of each site are indicated at the top of the plot (e.g., F1 and F2 are the antennas inside the makeup water channel (MWC), A1 is at the exit, etc.).

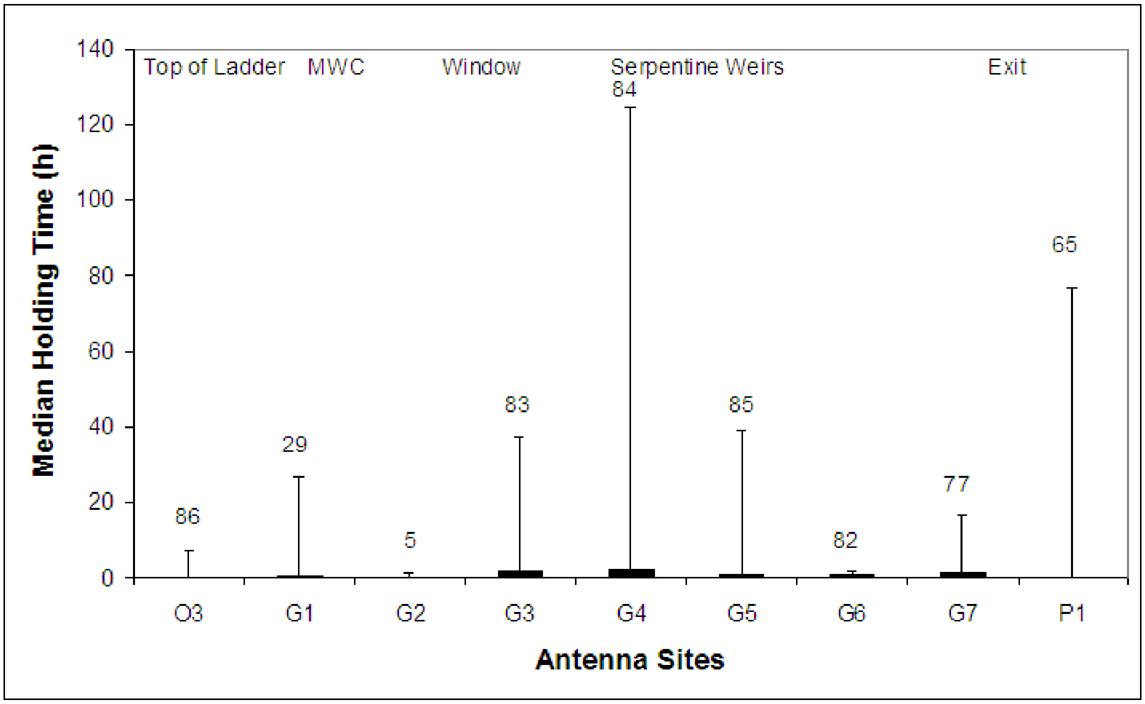

Figure 21. Median holding time at each antenna site (Fig. 6) for the Washington-shore count station area (i.e., median hours from first detection at an antenna site to the first detection at the next upstream antenna site with standard deviation denoted by error bars and sample size over each bar). Features of each site are indicated at the top of the plot (e.g., G3 is the antenna at the count station window, P1 is at the exit, etc.).

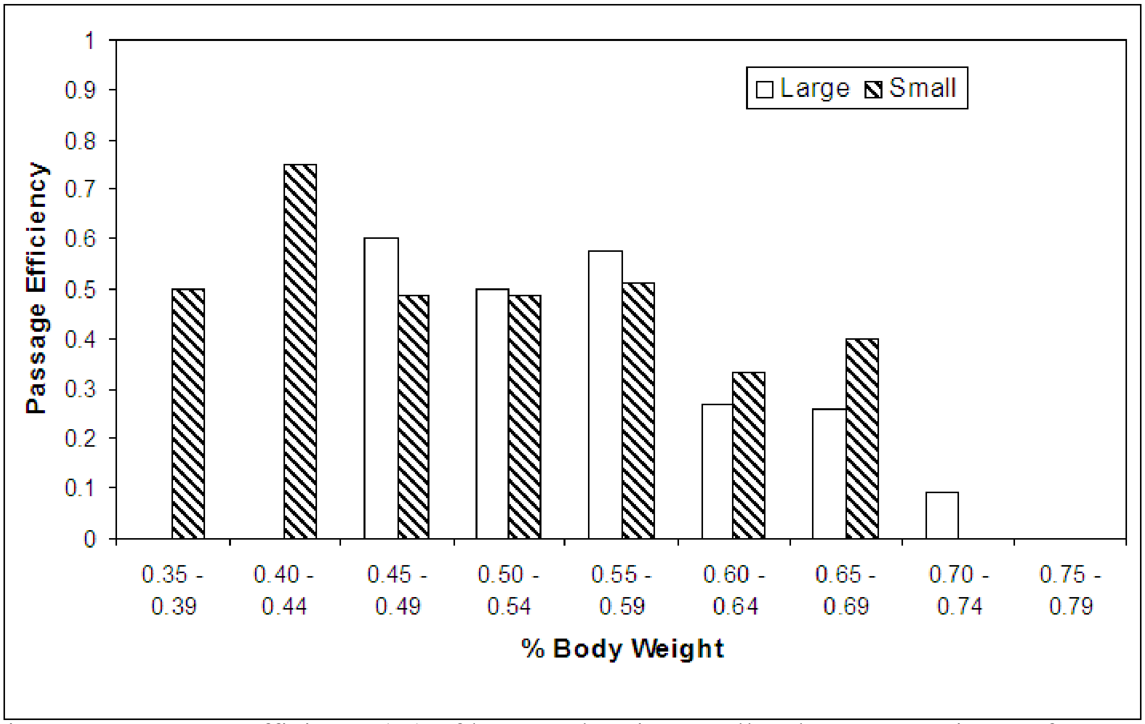

Figure 22. Passage efficiency (%) of lamprey bearing small or large transmitters of increasing percentages of lamprey body weight.

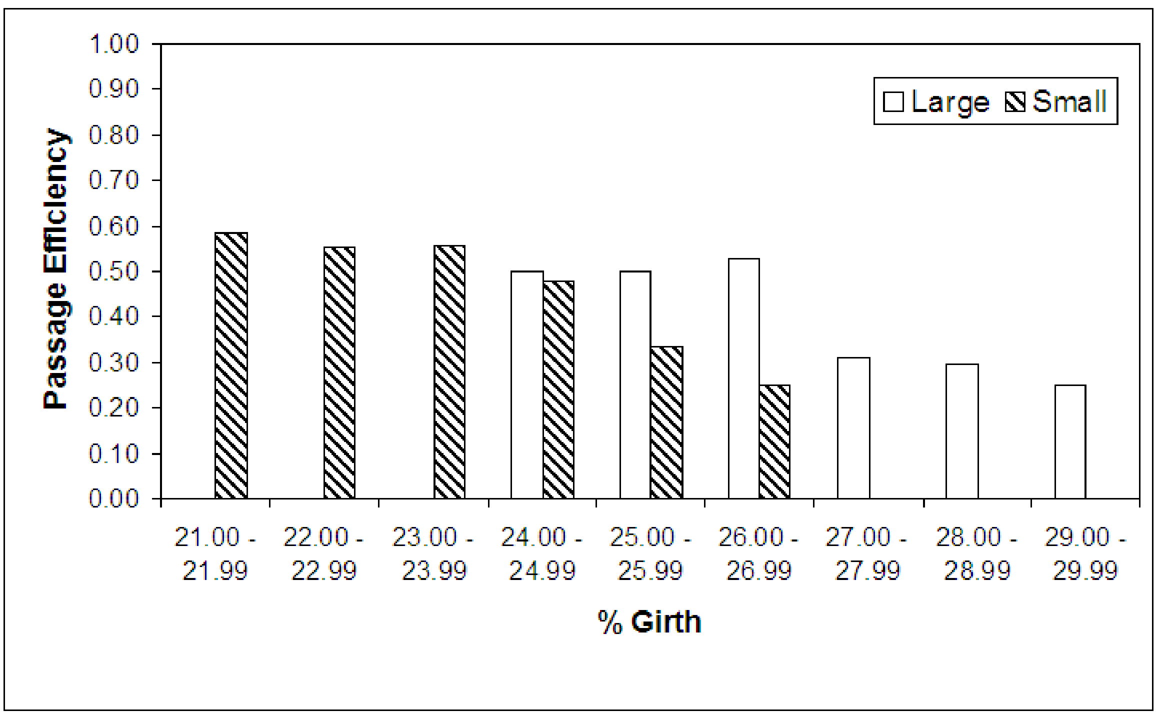

Figure 23. Passage efficiency (%) of lamprey bearing small or large transmitters of increasing percentages of lamprey girth.

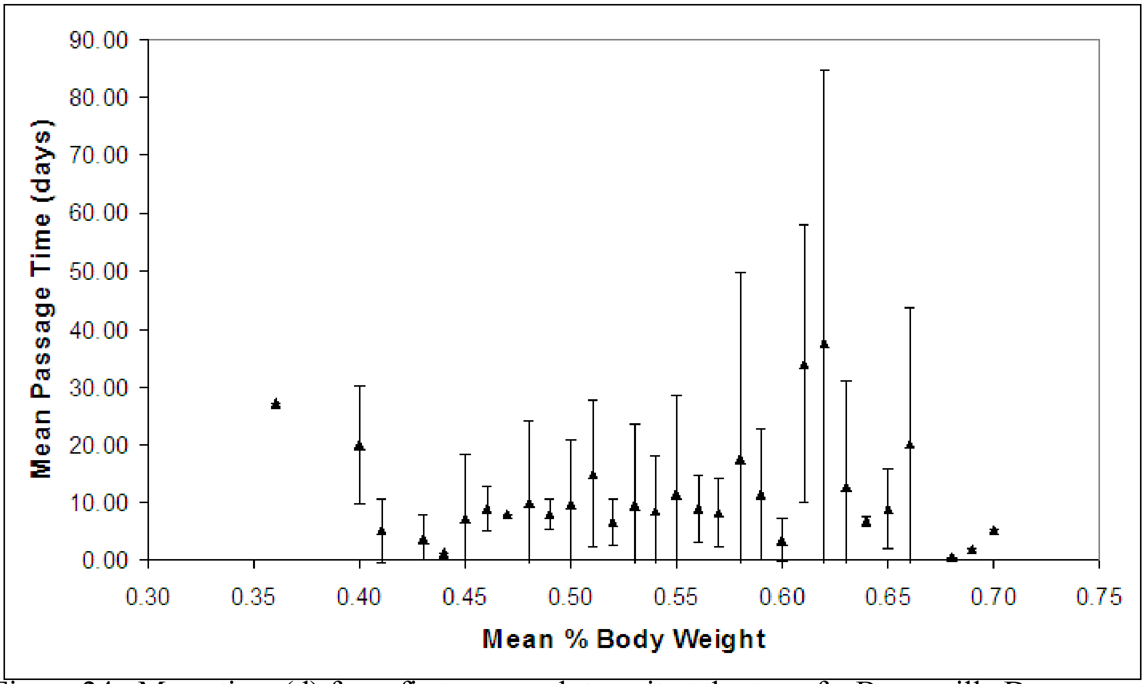

Figure 24. Mean time (d) from first approach to exit at the top of a Bonneville Dam fishway for lamprey with transmitters of increasing % body weight.

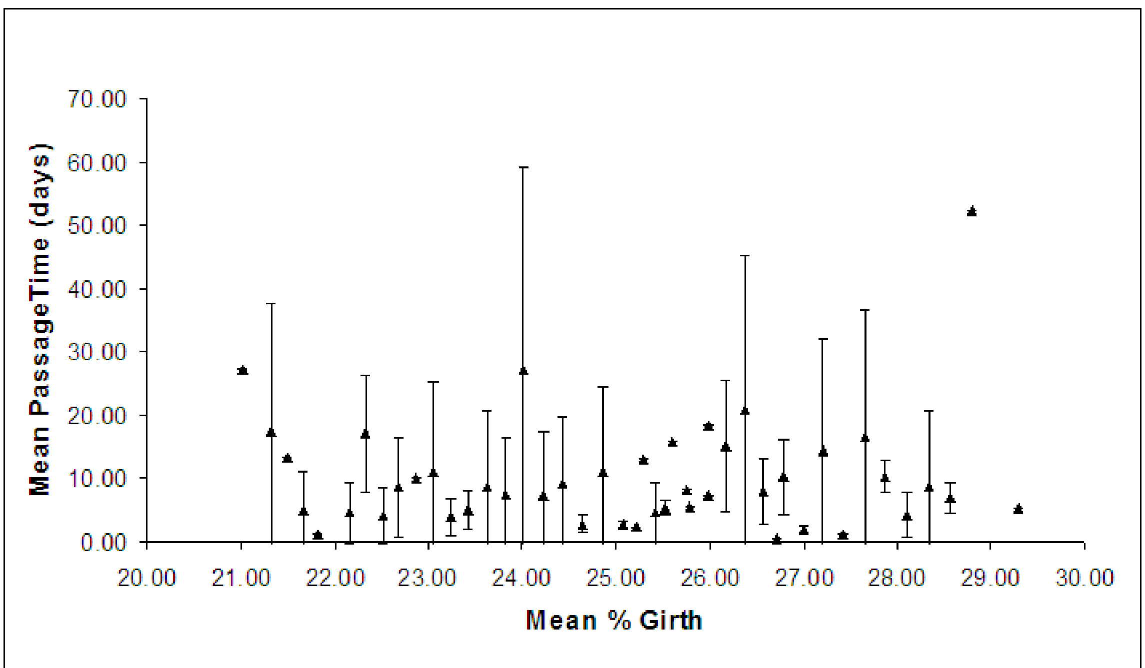

Figure 25. Mean time (d) from first approach to last detection at a Bonneville Dam fishway exit for lamprey with transmitters of increasing % girth.

The Dalles Dam

Of the 129 radio-tagged lamprey that passed over Bonneville Dam, we detected 94 in the vicinity of The Dalles Dam tailrace, and 93 of these fish approached entrances to the fishways. More lamprey approached the powerhouse fishway system on the Oregon shore (Fig. 2, East, n = 80) than the fishway adjacent to the spillway on the north shore (Fig. 2, North, n = 44). Entrance efficiency at the North Fishway entrance was lower than that recorded in either 1998 or 2000 (Table 3).

While overall entrance efficiency was also lower at the North Fishway entrance than at the East Fishway entrances (Table 3), individual entrance efficiency was higher at the North Fishway entrance than at each of the individual East Fishway entrances due to the fact that lamprey use was spread across all the East Fishway entrances (Fig. 26). Among the East Fishway entrances, lamprey had the highest entrance efficiency at the east end of the fishway (i.e., the entrances located closest to the fish ladder).

In 2001, 48 of the 80 fish that approached the East Fishway system successfully passed over (60%), while 20 of the 44 that approached the North Fishway passed over (45%). Two of the lamprey that successfully passed through the North Fishway fell back over the dam and successfully passed through the North Fishway a second time. As in previous years, passage time (the time from first approach at a fishway entrance to last detection at the fishway exit) through the North Fishway was greater than passage time through the East Fishway (Fig. 27).

As in previous years of monitoring, lamprey had the lowest passage efficiencies at The Dalles Dam transition areas, but greater than 90% efficiency through the collection channels, the ladder, and count station areas (Table 3). Passage through the transition areas in both fishways was lower in 2001 than in most other years of study.

Overall passage efficiency at The Dalles Dam was 73% (68 of the 93 fish that approached The Dalles Dam passed over). Median passage time for lamprey at The Dalles Dam was 2.1 d (minimum = 0.2 d, maximum = 48.0 d, SD = 8.6 d). Median passage time for females was slightly lower (2.0 d) than for males (2.5 d). Five radio-tagged lamprey (7% of those that passed over The Dalles Dam) fell back over The Dalles Dam and were detected downstream from the dam.

Table 3. The number of radio-tagged lamprey that passed through each area within each fishway at The Dalles Dam in 1997, 1998, 2000, and 2001. Passage efficiency (the number of lamprey that passed through the area / the number that approached that area × 100) is in parentheses.

Fishway	Area	1997	1998	2000	2001
East	Entrance	41 (85%)	22 (73%)	52 (87%)	71 (89%)
	Collection	34 (83%)	21 (95%)	47 (90%)	67 (94%)
	Transition	27 (79%)	12 (57%)	41 (87%)	52 (78%)
	Ladder	24 (89%)	12 (100%)	38 (93%)	50 (96%)
	Count station	24 (100%)	12 (100%)	37 (97%)	48 (96%)
North	Entrance	18 (67%)	15 (94%)	44 (94%)	34 (77%)
	Collection	14 (78%)	15 (100%)	42 (95%)	34 (100%)
	Transition	11 (79%)	13 (87%)	36 (86%)	24 (71%)
	Ladder	11 (100%)	12 (92%)	33 (92%)	22 (92%)
	Count station	11 (100%)	12 (100%)	33 (100%)	22 (100%)

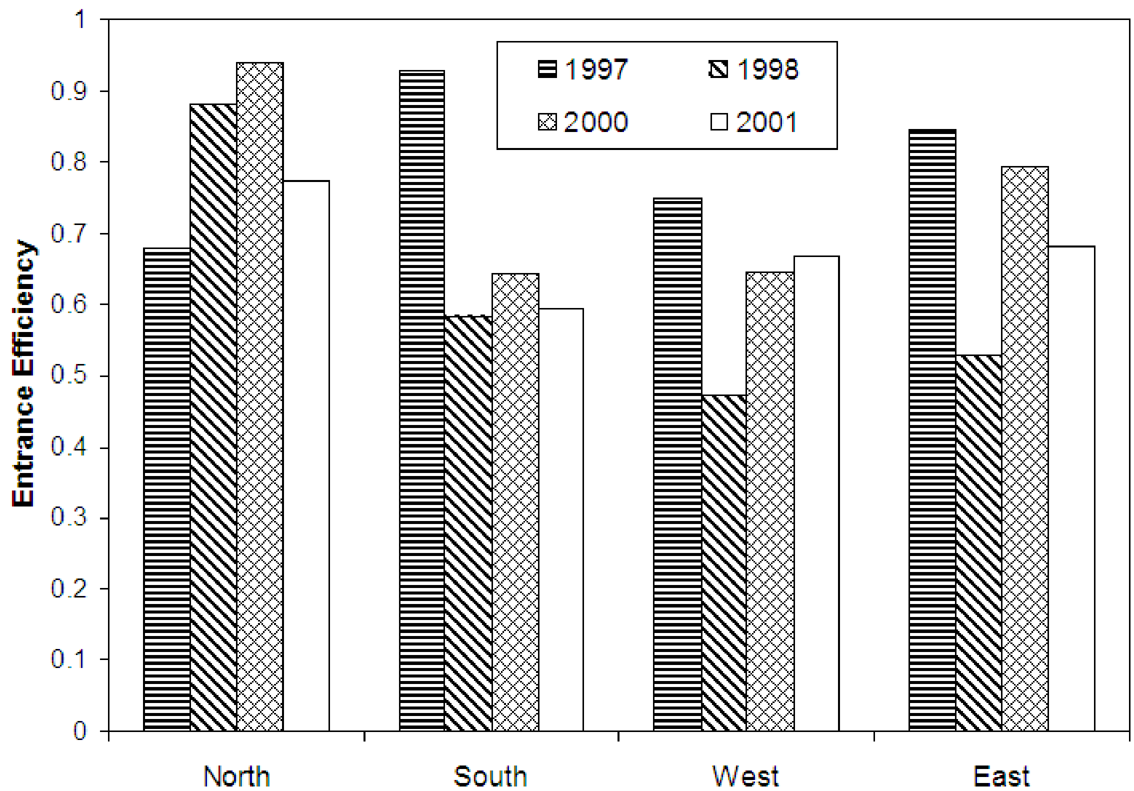

Figure 26. Entrance efficiency (proportion of lamprey that successfully entered of those that approached) at each of The Dalles Dam fishway entrances: the North Fish Ladder entrance on the Washington shore (North), the East Fish Ladder entrance at the south end of the spillway (South), the East Fish Ladder entrance at the west end of the powerhouse (West) and the East Fish Ladder entrance at the east end of the powerhouse (East) in 1997, 1998, 2000, and 2001.

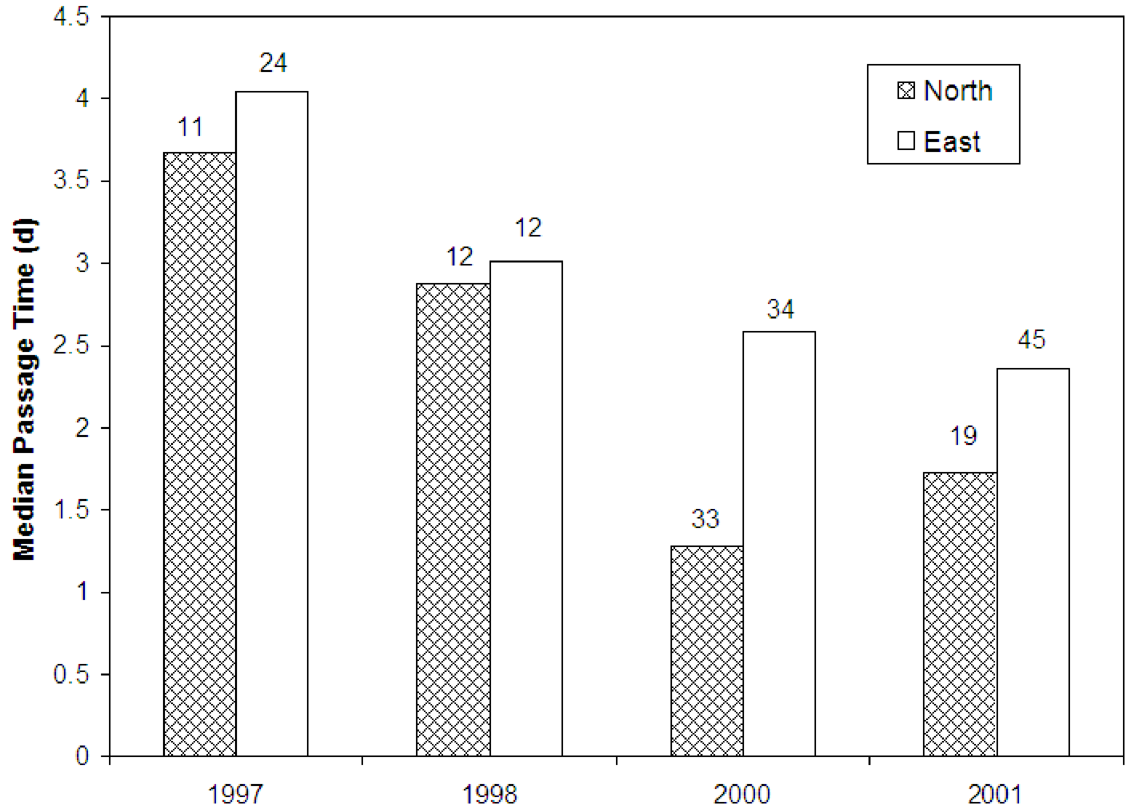

Figure 27. Median passage time (days from first detection outside a fishway entrance to last detection at the top of the fish ladder) for fish that used the North and East fishways at The Dalles Dam. Only fish with known times of first approach at an entrance and known times of exit into the forebay were used for this analysis (numbers of fish in each year for each fishway are indicated at the tops of the bars).

John Day Dam

Of the 68 radio-tagged lamprey that passed over The Dalles Dam, we detected 51 in the vicinity of the John Day Dam tailrace and 47 approached entrances to the fishways. Far more fish approached entrances to the powerhouse fishway system on the Oregon shore (Fig. 3, South, n = 46) than entrances to the fishway on the Washington shore (Fig. 3, North, n = 11). Overall entrance efficiency at the North Fishway was lower (73%) than at the South Fishway (96%)(Table 4). However, most fish that approached the South Fishway actually used the entrance closest to the South Fish Ladder (entrance efficiency = 90%). Entrance efficiency at the entrances closest to the spillway (North Collection System entrances) was lower (19 and 67%).

Passage efficiencies differed among areas within the John Day Dam fishways. Relatively high passage efficiencies were recorded through the collection channel and transition areas in 2001. However, passage efficiencies through the ladders were 68 and 50% for the South and North fishways, respectively, at John Day Dam (Table 4), in contrast to much higher passage efficiencies through the ladders at other dams we monitored. Of the 44 lamprey that approached the South Fishway, 22 ultimately passed over the dam (50%). Of the 11 lamprey that approached the North Fishway, 3 used this fishway to pass over the dam (27%). Overall passage efficiency at John Day Dam was 53% and median passage time was 1.3 d (n = 25, range = 0.3 to 7.4 d, SD = 1.65 d). We noted that median passage time for females (1.5 d, n = 14) was greater than that for males (0.9 d, n = 8).

As in 2000, we found that a high percentage (36%) of the lamprey that passed over John Day Dam were later detected downstream from the dam (i.e., they fell back). Of the nine fish that fell back, three never re-approached the dam, three reentered the fishways but did not pass over the dam, and three reascended the fishways and were detected in the forebay. One of the three fish that passed over a second time was later detected below the dam, having fallen back a second time. It did not reapproach the fishways.

Overall Passage Patterns and Tributary Use

Overall passage efficiency differed among dams (Fig. 28). In 2001, passage efficiency declined slightly at Bonneville Dam for the first time during our radiotelemetry investigations. Declines in passage efficiency relative to 2000 at The Dalles and John Day Dams were also noted (Fig. 28). In addition to lower passage efficiency at Bonneville Dam in 2001, we found that median passage time at this dam was approximately double that recorded in previous years (Fig. 29). In contrast, passage times in 2001 at The Dalles and John Day Dams were similar or slightly lower than in 2000.

In 2001, nine radio-tagged lamprey approached McNary Dam, and seven of these (78%) successfully passed over the dam. All seven successful fish passed through the

Table 4. The number of radio-tagged lamprey that passed through each area within each fishway at John Day Dam in 1997, 1998, 2000, and 2001. Passage efficiency (the number of lamprey that passed through the area / the number that approached that area × 100) is in parentheses.

Fishway	Area	1997	1998	2000	2001
John Day South	Entrance	20 (87%)	6 (60%)	48 (73%)	44 (96%)
	Collection	13 (65%)	6 (100%)	39 (81%)	41 (93%)
	Transition	13 (100%)	6 (100%)	30 (77%)	34 (83%)
	Count station	12 (92%)	6 (100%)	21 (70%)	34 (100%)
	Ladder	9 (75%)	4 (67%)	21 (100%)	23 (68%)
John Day North	Entrance	3 (75%)	3 (75%)	18 (67%)	8 (73%)
	Collection	1 (33%)	3 (100%)	18 (100%)	8 (100%)
	Transition	0	2 (67%)	17 (94%)	6 (75%)
	Ladder	0	2 (100%)	7 (41%)	3 (50%)
	Count station	0	0	7 (100%)	3 (100%)

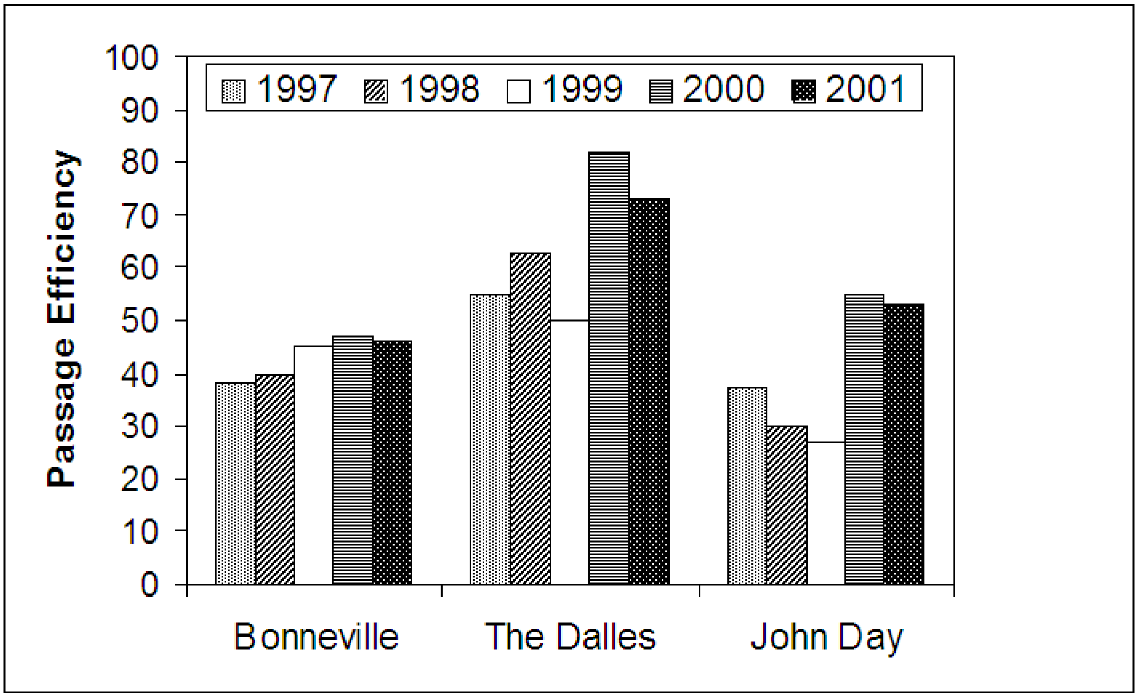

Figure 28. Overall passage efficiency (the number of lamprey that passed over each dam divided by the number that approached it) for Bonneville, The Dalles, and John Day Dams in 1997-2001.

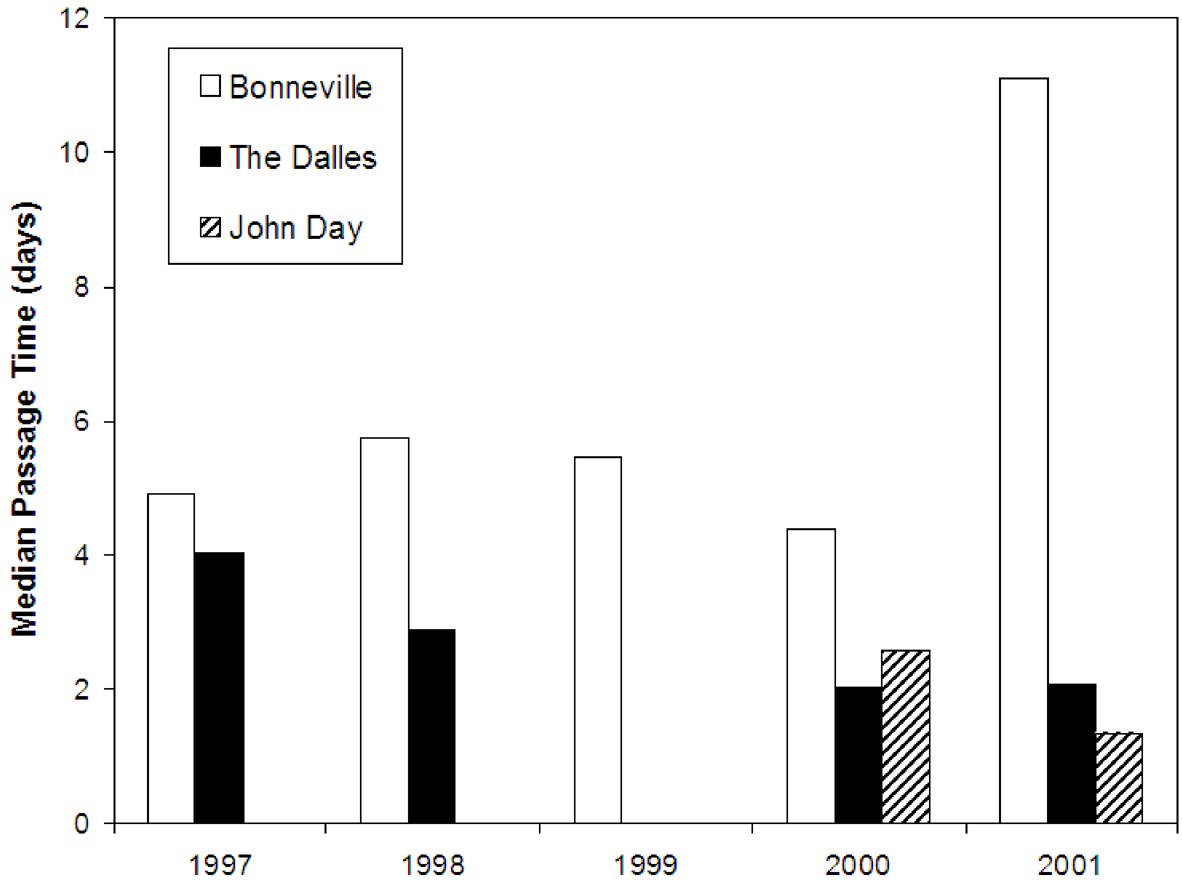

Figure 29. Median passage time (days from first detection outside a fishway entrance to last detection at the top of the fish ladder) for fish that passed Bonneville, The Dalles, and John Day Dams in 1997-2001. Only fish with known times of first approach at an entrance and known times of exit into the forebay were used for this analysis.

South Fishway (Oregon shore). The 2 fish that did not pass upstream approached at both fishways and were able to enter, but did not move any farther up. Three of the seven fish that passed over McNary Dam were later detected at Priest Rapids Dam (RKm 639) on the mid-Columbia River.

Tributary Use and Seasonal Distribution

We monitored the mouths of all major tributaries between Bonneville Dam and McNary Dam and were able to identify lamprey entrances into each tributary. In 2001, we detected lamprey in two Columbia River tributaries: the Deschutes and John Day Rivers. We found eight lamprey in the Deschutes River (which enters the Columbia River 20 km upstream from The Dalles Dam) and one of these fish was eventually detected on our receiving station at Shearars Falls (396 km from the mouth of the Columbia River, 68 km from the mouth of the Deschutes River). One of the eight lamprey was also relocated approximately 1 km upstream from Twin Springs (390 km from the mouth of the Columbia River, 62 km from the mouth of the Deschutes River). In addition, we detected four radio-tagged lamprey as they entered the John Day River (which enters the Columbia River 3 km upstream from John Day Dam).

From November 2001 to May 2002, we conducted monthly standardized surveys for radio-tagged lamprey using a portable receiver and an antenna mounted on a vehicle (mobile tracking). During this period, we detected 56 (19%) of the lamprey tagged in 2001. The mean time at large (the number of days between the last detection in May-October (2001 tracking year) and the last detection after October 31 (2002 tracking year)) was 172 d with a minimum of 79 d and a maximum of 271 d (Table 5).

We found that 28 of the fish we detected in 2002 were at the same site (±0.5 km) on the last relocation date in 2002 as they were on the last relocation date in the 2001 tracking year (Table 5). However, a number of these fish were detected at other sites in the interim, indicating that they were alive and making short local movements during the winter.

Thirteen of the lamprey moved 0.8-47.3 km downstream from their last known position in 2001. Four of these fish moved downstream from John Day Dam, one moved downstream from The Dalles Dam, and the rest moved downstream from Bonneville Dam. The fish that moved the farthest downstream from Bonneville Dam (47.3 km) had entered and exited the Bonneville Dam fishways during the summer. Four fish apparently fell back over Bonneville Dam during the winter.

Fourteen lamprey moved upstream short distances (1-3 km) during the winter and all of these movements occurred below Bonneville Dam. Only one fish moved more than 20 km upstream during the winter (from Wishram, Washington to the base of John Day Dam). However, this fish had also been detected at John Day Dam fishway entrances during the summer of 2001. We did not detect any lamprey moving upstream through the fishways in 2002; however, the transmitter battery life only allowed detection through April 2002.

Table 5. The last date and location in the 2001 tracking year of individual radio-tagged lamprey, the last date and location in the 2002 tracking year, time at large (days from last 2001 detection to last 2002 detection) and the distance (km) between 2001 and 2002 positions.

		2001		2002			
Channel	Code	date	site	date	site	Time	Distance
1	192	10/14/01	232.3	03/09/02	235.1	146	2.8
1	194	09/30/01	235.1	03/07/02	235.1	158	0
1	204	10/31/01	235.1	03/06/02	232.6	126	-2.5
1	205	08/22/01	232.3	01/08/02	232	139	-0.3
1	207	08/22/01	232.3	03/07/02	235.1	197	2.8
1	212	09/07/01	308.1	02/04/02	308	151	-0.1
2	192	08/29/01	232.3	03/09/02	235.1	192	2.8
2	197	09/24/01	235.1	12/11/01	235.1	79	0
2	200	09/12/01	232.3	03/06/02	232.6	175	0.3
2	204	09/26/01	346.9	03/04/02	346.1	159	-0.8
2	205	09/11/01	235.1	03/07/02	235.1	177	0
2	208	10/24/01	235.1	03/06/02	187.8	133	-47.3
2	209	08/31/01	232.3	01/10/02	235.1	132	2.8
2	212	10/26/01	235.1	04/08/02	235.1	164	0
9	10	10/31/01	232.3	03/06/02	232	126	-0.3
9	18	10/31/01	232.3	03/06/02	235.1	127	2.8
9	19	10/23/01	232.3	02/05/02	230.7	106	-1.6
9	21	07/10/01	235.1	03/07/02	235.1	240	0
9	24	07/02/01	232.3	03/07/02	235.1	248	2.8
9	25	07/14/01	232.3	01/10/02	234	180	1.7
9	27	06/11/01	235.1	11/06/01	235.1	148	0
9	33	07/03/01	232.3	03/07/02	235.1	247	2.8
9	35	07/04/01	232.3	12/11/01	234	160	1.7
9	41	06/23/01	235.1	02/05/02	235	228	-0.1
9	42	07/05/01	232.3	03/07/02	235.1	245	2.8
9	51	08/24/01	235.1	03/07/02	235.1	195	0
9	53	08/29/01	235.1	05/27/02	235.1	271	0

Table 5. Continued.

		2001		2002			
Channel	Code	date	site	date	site	Time	Distance
9	54	06/29/01	232.3	11/06/01	235.1	130	2.8
9	57	07/24/01	235.1	03/07/02	235.1	226	0
9	59	06/29/01	235.1	03/06/02	235.1	251	0
9	66	07/27/01	235.1	12/11/01	235.1	137	0
9	84	09/19/01	232.3	03/06/02	214.6	168	-17.7
9	98	08/31/01	346.9	01/07/02	336.6	130	-10.3
9	100	10/31/01	232.3	03/06/02	232	126	-0.3
9	102	09/04/01	293	03/06/02	286.9	184	-6.1
9	111	07/13/01	235.1	03/07/02	235.1	237	0
9	112	07/19/01	235.1	03/07/02	235.1	231	0
9	114	07/05/01	235.1	03/06/02	235.1	245	0
9	117	10/05/01	235.1	03/07/02	235.1	153	0
9	119	08/31/01	235.1	03/07/02	235.1	188	0
9	137	07/11/01	235.1	11/06/01	235.1	118	0
9	142	07/11/01	232.3	12/11/01	235.1	154	2.8
9	143	10/26/01	235.1	03/25/02	235.1	150	0
9	147	07/18/01	235.2	03/07/02	235.1	232	-0.1
9	150	08/01/01	325.3	03/04/02	346.1	215	20.8
10	2	08/05/01	232.3	11/06/01	235.1	93	2.8
10	19	07/14/01	235.1	01/08/02	232	178	-3.1
10	34	07/12/01	235.1	02/05/02	235.1	209	0
10	40	07/30/01	345	01/07/02	336.6	162	-8.4
10	51	07/10/01	235.1	11/06/01	235.1	119	0
10	59	07/19/01	232.3	12/11/01	235.1	146	2.8
10	61	07/11/01	235.1	02/25/02	219	229	-16.1
10	70	10/31/01	232.3	03/07/02	232	127	-0.3
10	86	08/13/01	327.1	02/04/02	323.7	176	-3.4
10	99	09/17/01	325.3	02/04/02	323.7	141	-1.6
10	110	08/20/01	235.1	01/09/02	219	142	-16.1

DISCUSSION

Conditions and dam operations in the lower Columbia River differed radically in 2001 from previous years of study. Low water conditions resulted in extremely low flow (Fig. 30) and essentially no spill (Fig. 31) during the study period in 2001 at Bonneville Dam. In addition, priority for power generation was at Bonneville Powerhouse 2 in 2001 (Fig. 31), while Powerhouse 1 had priority during the study period in 2000 (Fig. 32) and previous years of study.

The change in river conditions and dam operations apparently affected lamprey use of the fishways at Bonneville Dam. A higher percentage of lamprey made their initial approach at PH2 in 2001 than in 2000. We also noted a lower number of initial approaches at the spillway in 2001 compared to 2000. Overall passage efficiency of lamprey at Bonneville Dam decreased for the first time since monitoring began in 1997, perhaps due to the fact that lamprey generally have more difficulty negotiating PH2 fishways than those at PH1 (Moser et al. 2002b). Also, we recorded more fallbacks at Bonneville Dam in 2001 than in any other year.

Our trap CPUE was higher in 2001 relative to 2000, probably due to the larger number of lamprey using the PH2 fishway system where the trap is located. However, total lamprey counts at both of the Bonneville Dam counting windows indicated that overall lamprey abundance at Bonneville Dam in 2001 was lower than in 2000 (USACE 2001). We found no correlation between the weekly trap CPUE and weekly lamprey counts at the Washington-shore count station in 2001. Moser and Close (2003) reported a similar lack of relationship for 2000 trap data and suggested that this was due to error in lamprey counts.

In 2001, a very high percentage of the tagged lamprey (93%) returned to the base of Bonneville Dam and did so in less time than in most previous years of study. This may have been due to the fact that we tagged larger lamprey in 2001 than in previous years. We found that size of the transmitters relative to lamprey body size (i.e., percent of body weight and girth) affected both travel time from release to the base of Bonneville Dam and the overall passage efficiency. In 2000, we found no effects of tag size; however, in that year we were unable to tag large lamprey with small tags to test the effects of relative tag size. Based on the results from 2001, we recommend that only lamprey with girth greater than 11.5 cm should be tagged with the 4.5-g transmitter used in this study and that only lamprey with a girth of greater than 12.8 cm should be tagged with the 7.7-g transmitter used in this study.

In 2001, we continued to test the effects of structural and operational modifications on lamprey performance at the fishway entrances. Overall entrance efficiency at the spillway entrances improved relative to previous years, but entrance efficiency at the individual entrances was actually lower than in 2000 due to the fact that lamprey moved readily between the spillway entrances prior to entering.

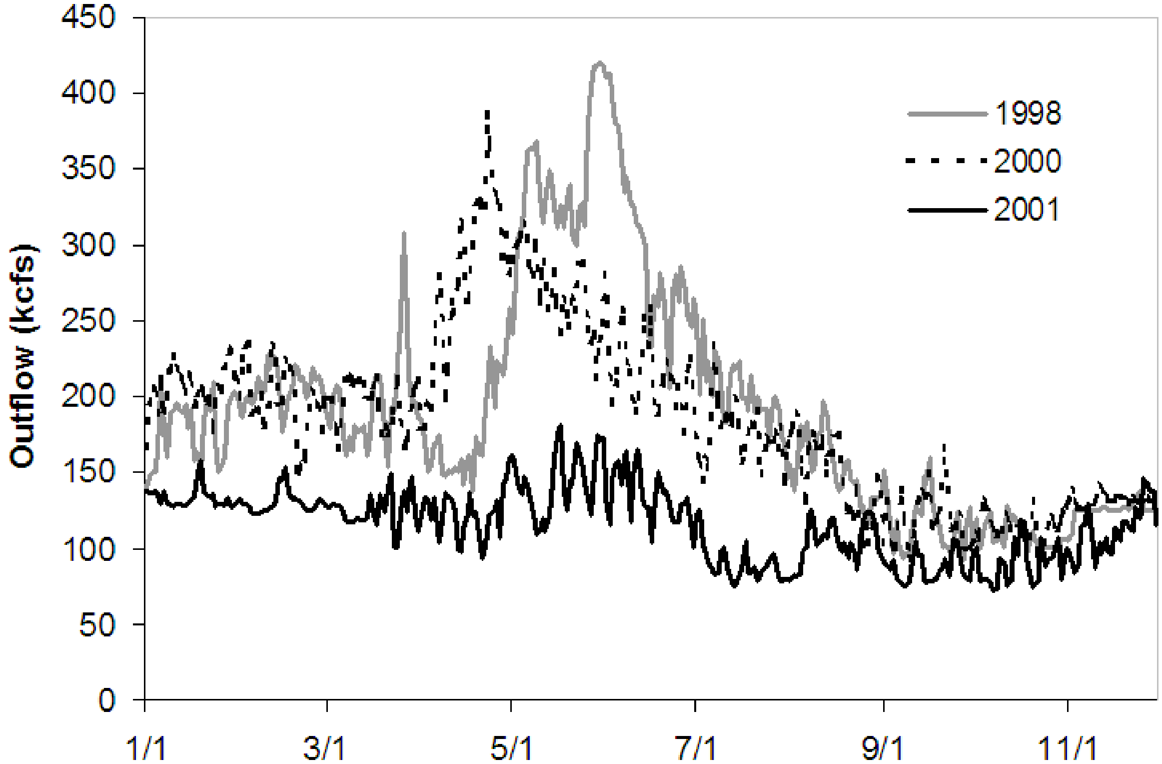

Figure 30. Outflow (kcfs) measured at the Bonneville Dam tailrace in 1998, 2000, and 2001.

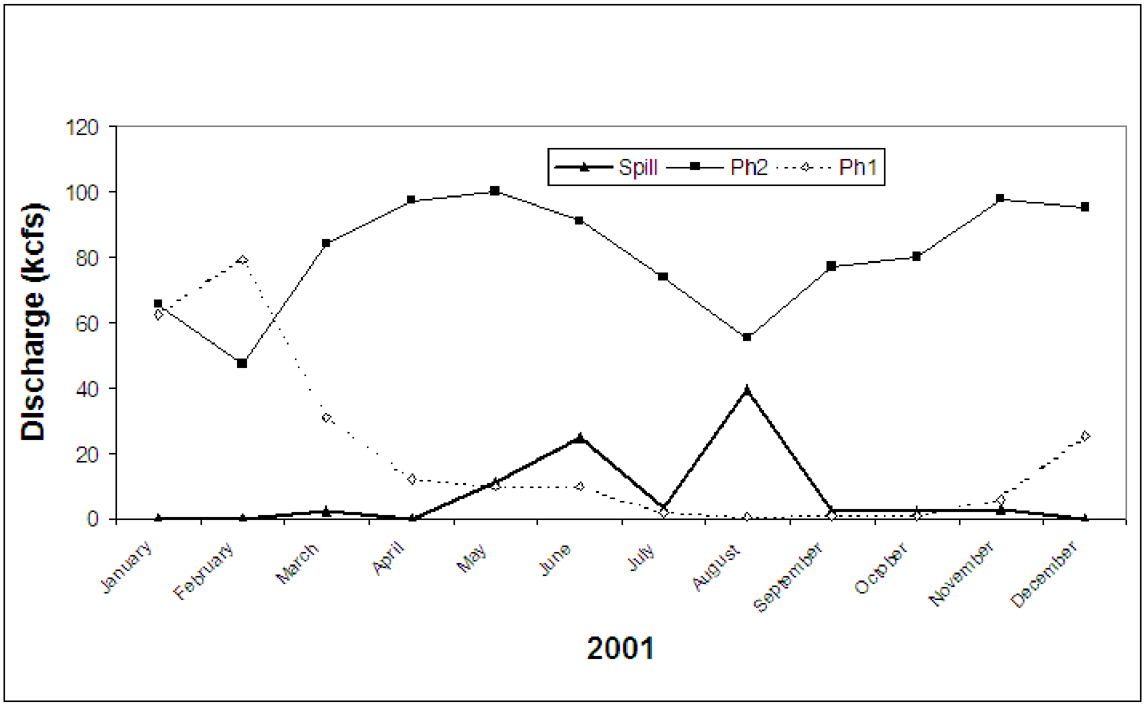

Figure 31. Mean monthly discharge (kcfs) at PH1, PH2, and the spillway in 2001.

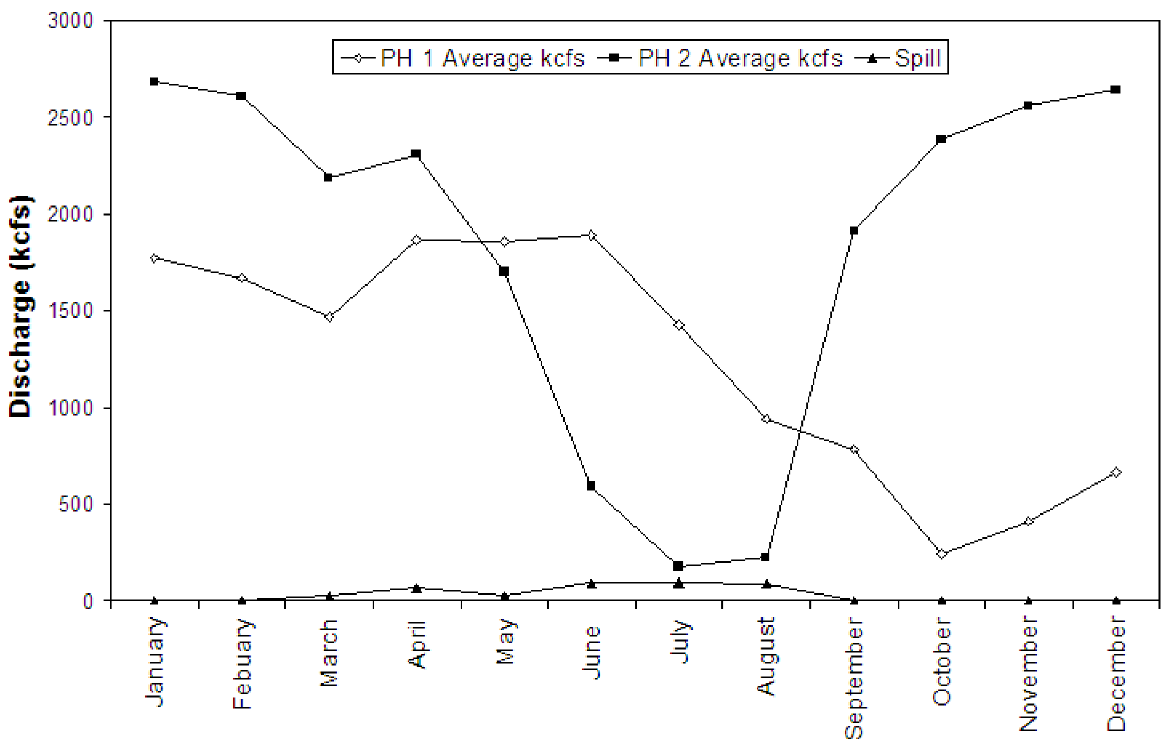

Figure 32. Mean monthly discharge (kcfs) at PH1, PH2, and the spillway in 2000.

Improved spillway entrance performance in 2001 could be due to several different factors: 1) structural improvements to the bulkheads adjacent to the entrances, 2) reduced velocity testing at the spillway entrances, or 3) reduced spill during the study period. While we found that the velocity testing schedule was not performed reliably, we were able to compare spillway entrance success during the velocity testing period to other times of the year. We concluded, as in 2000, that lamprey entrance efficiency was not increased substantially during low velocity treatments. However, the comparison in 2001 was based on the behavior of only 10 fish that approached the spillway entrances during the known control condition.

As in previous years, lamprey entrance efficiency was lower at Bonneville Dam orifice entrances than at main entrances. However, entrance efficiency at some of the PH1 orifice entrances (34, 58, and 62) was higher than in other years. It is unclear what produced this change. We found no obvious effect of orifice gate closure at PH1 in 2000, but the 2000 test was conducted during PH1 priority. It is possible that the combined effects of reduced flows at PH1 and the orifice closure schedule both contributed to increased lamprey performance at the northernmost PH1 orifices in 2001.

The ability to find attachment sites is key to the success of lamprey passage through areas of high velocity, such as fishway entrances (Moser et al. 2002a). We observed lamprey in the fishways and noted that, when confronted with high-velocity conditions, they typically hold fast with the suctorial oral disc and then surge ahead to reattach. In all years of study, radio-tagged lamprey had relatively poor passage efficiency through collection channels and transition areas (Moser et al. 2002b). We hypothesized that gratings on the floors and walls in these areas limit lamprey attachment and reduce passage success. For example, collection channels and transition areas at the PH1 fishway have less floor grating than at PH2 fishways, and lamprey passage success is consistently higher through these areas in PH1 fishways than through similar areas in PH2 fishways.

One objective of our work in 2001 was to test the efficacy of providing attachment sites for lamprey moving through the PH2 transition area. We found that lamprey passage through this area in 2001 (77% of those that approached the PH2 transition area moved through) was higher than in all previous years except 1997. Consequently, the addition of attachment plates apparently benefitted lamprey passage in this area.

Pacific lamprey have difficulty passing through the count station area at the top of the Bonneville Dam (Moser et al. 2002b). We intensively monitored the progress of lamprey that approached this area in 2001. At both the Bradford Island and Washington-shore count stations, all lamprey that approached the count window were later detected above the window and in the serpentine weir area. As in 2000, we found that some lamprey were either delayed or obstructed by the serpentine weirs, particularly at the top of the Washington-shore ladder. Moreover, lamprey that made their way into the makeup water channel adjacent to the serpentine weirs could remain in this area for several days before either escaping upstream via the Tainter gate (this was only noted at the Bradford Island site) or falling back downstream.

As in previous years of study, overall lamprey passage at Bonneville Dam was low relative to salmonid passage (Moser et al. 2002b). Lamprey passage efficiency at Bonneville Dam never exceeded 50% during 1997-2000 and was 46% in 2001. Adult Pacific lamprey that successfully passed over Bonneville Dam also took longer than salmonids (Moser et al. 2002b). In 2001, median lamprey passage times at Bonneville Dam were even longer than normal: 11.1 d as opposed to 4-6 days in other years.

Travel times to the base of Bonneville Dam after release were less than in previous years, so it is unlikely that the longer passage times at the dam were related to handling. It is possible that decreased flow, the lack of spill, or Powerhouse 2 priority in 2001 contributed to lamprey delay. More comprehensive analysis of factors contributing to lamprey delay (i.e., time of day, temperature, flow, spill) will permit identification of causative factors.

Lamprey passage efficiency at The Dalles Dam was higher than at Bonneville Dam in all years of study, including 2001. However, overall lamprey passage efficiency at The Dalles Dam was lower in 2001 than in 2000. This may have been due to lower entrance efficiency recorded at the North Fishway (Washington-shore). Lower attraction of lamprey to the north shore in 2001 may have been due to the lack of spill. Entrance efficiency at the East Fishway was similar to 2000. Orifice gates were closed at The Dalles in 2000 and 2001, which may have contributed to relatively high entrance success at the main entrances in those years.

As in other years, passage time through The Dalles Dam fishways was considerably shorter than passage time at Bonneville Dam. However, lamprey took longer to negotiate The Dalles Dam fishways in 2001 than in previous years. We recorded faster passage at the North Fishway than at the longer and more complex East Fishway, as in 2000. It is unclear what contributed to delay at The Dalles Dam in 2001. Additional analysis is needed to confirm which factors (such as spill, flow, temperature, and time of year) affect lamprey delay.

Lamprey passage efficiency at John Day Dam was similar to that recorded in 2000, but median passage time at John Day Dam was actually less in 2001 than in 2000. As in previous years, we found that lamprey had greatest difficulty moving through the ladders at John Day Dam. These areas typically are not an obstacle to lamprey at the other dams. More lamprey fell back over John Day Dam in the 2001 tracking season (36%) than at any other dam or in any other year. We also noted a higher fallback rate at John Day Dam in 2000 than at the other dams. It is unclear why lamprey tend to fall back more at John Day Dam than at other locations. Perhaps the absence of olfactory cues from waters upstream from John Day Dam causes lamprey to fall back at this point.

As in 2000, few lamprey were detected at the base of McNary Dam in 2001; however, they exhibited relatively high passage efficiency (78%). Interestingly, three of the lamprey that passed McNary Dam were later detected at Priest Rapids Dam, but none were detected at the Snake River dams. A radiotelemetry study at Priest Rapids Dam in 2001 indicated that passage efficiency of adult Pacific lamprey was 70% in that year and that median passage time was 1.1 d (Nass et al. 2002).

In the winter and spring of 2001-2002, we relocated 56 (19%) of the lamprey tagged in the previous summer. The tags used in 2001 only had a 7-month battery life and limited range, reducing our ability to detect them during monthly mobile tracking surveys. However, we were able to document that most lamprey made short local movements during the winter and that four fell back over Bonneville Dam during the winter.

We did not detect any lamprey passing upstream over a dam during the winter or spring. Further study is needed to determine whether a significant percentage of the radio-tagged lamprey are able to get to spawning areas in their second year in fresh water and to determine the fate of the large number of fish that are not relocated after making an unsuccessful attempt to pass over Bonneville Dam.

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