Migration Behavior of Adult Pacific Lamprey in the Lower Columbia River and Evaluation of Bonneville Dam Modifications to Improve Passage, 2002.

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EXECUTIVE SUMMARY

Adult Pacific lamprey (*Lampetra tridentata*) encounter various obstacles to upstream migration at lower Columbia River hydropower dams. In particular, radiotelemetry studies indicate that lamprey have the greatest difficulty negotiating fishway entrances, collection channels, transition areas, and areas at the top of fishways. In 2002, we continued a study to evaluate the areas at dams where lamprey passage could be improved. Specific objectives of our research were to:

1) Evaluate passage efficiency of radio-tagged adult Pacific lamprey at Bonneville, The Dalles, and John Day Dams on the lower Columbia River.

2) Evaluate effects of structural and operational modifications on passage of adult lamprey at the lower Columbia River dams.

3) Determine fates of radio-tagged adult lamprey that do not pass Bonneville Dam.

4) Develop and evaluate a structure to pass adult lamprey from makeup water channels to the forebay at Bonneville Dam.

We radio-tagged 201 adult lamprey (101 with a 4.5-g transmitter and 100 with a 7.7-g transmitter) and released them approximately 3 km downstream from Bonneville Dam. Ninety-six percent of the radio-tagged lamprey were detected at Bonneville Dam and the median time from release to first detection at the dam was 4.5 d.

Passage efficiency at Bonneville Dam in 2002 (48%) was slightly higher than in 2001 (46%) and 2000 (47%). As in 2001, more lamprey initially approached fishway entrances at Powerhouse 2 (PH2) than at the spillway or Powerhouse 1 (PH1). In addition, median passage time (the time from first detection outside a fishway entrance to the last detection at the fishway exit) was substantially longer in 2002 (9 d) than in 1997-2001 (4-6 d). We conclude that the delay exhibited in 2002 was probably due in part to higher lamprey use of PH2 fishways.

While rounding the edges at the spillway entrance bulkheads improved lamprey entrance efficiency, addition of attachment plates in the PH2 transition area produced equivocal results. Lamprey passage efficiency through the PH2 transition area decreased relative to 2001 (the first year that attachment plates were added). Orifice gates at PH1 were open in 2002, and lamprey passage efficiency through this area was lower than in

2000 and 2001 (when orifice gates were periodically closed). This result provides some indication that closing orifice gates may help to retain lamprey in PH1 collection channels by reducing the number that exit the PH1 collection channel via the orifice gates.

As in previous years, lamprey were delayed and/or obstructed by the serpentine weir sections at the tops of both fish ladders at Bonneville Dam. However, tests of two prototype bypass structures in the adjacent makeup water channel (MWC) at Bradford Island indicated that it may be possible to provide passage for up to 50 lamprey/night or 18% of those in the MWC. While MWC bypass structures showed promise, further refinement is needed to improve lamprey collection.

CONTENTS

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). However, in recent years adult Pacific lamprey fisheries in the Columbia River drainage have 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. Lamprey abundance has historically been monitored by visually counting adults as they pass counting stations in fishways at hydropower dams. While these adult 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 resulted in a petition to list this species under the U.S. 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. Our previous radiotelemetry studies determined that lamprey passage at lower Columbia River dams is poor relative to 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. 2002b), whereas passage efficiency for salmonids during this period was typically greater than 90% (Bjornn et al. 2000a,b).

In previous studies, we identified specific obstacles to adult Pacific lamprey passage within the fishways at Bonneville, The Dalles, and John Day Dams using radiotelemetry. Over the past decade an extensive array of fixed-site radio receivers and antennas has been installed 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. Lamprey were obstructed or delayed at 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 2002 was to assess lamprey passage and the efficacy of actions taken to improve passage at Bonneville Dam, the first mainstem dam that adult lamprey encounter on their spawning migration in the Columbia River. Specific objectives were:

1) Evaluate passage efficiency of radio-tagged adult Pacific lamprey at Bonneville, The Dalles, and John Day Dams on the lower Columbia River.

2) Evaluate effects of structural (rounding entrance bulkheads and adding plates over diffuser grating) and operational (orifice gate closure) modifications on passage of adult lamprey at lower Columbia River dams.

3) Determine fates of radio-tagged adult lamprey that do not pass Bonneville Dam.

4) Develop and evaluate a structure to enable adult lamprey to pass from makeup water channels to the forebay at Bonneville Dam.

METHODS

Study Area

We collected and radio tagged adult lamprey at the Adult Collection and Monitoring Facility on the Washington shore of Bonneville Dam, Columbia 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 the navigation locks; however, we monitored lamprey passage via this route only at Bonneville Dam (Fig. 1).

Lamprey passage was monitored by fixed-site receivers located on and around 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 $\leq$9 m) to receive transmissions on a number of frequencies simultaneously.

The 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, and ladders as 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. At the counting stations, a picketed lead crowds fish into a narrow, brightly-lit

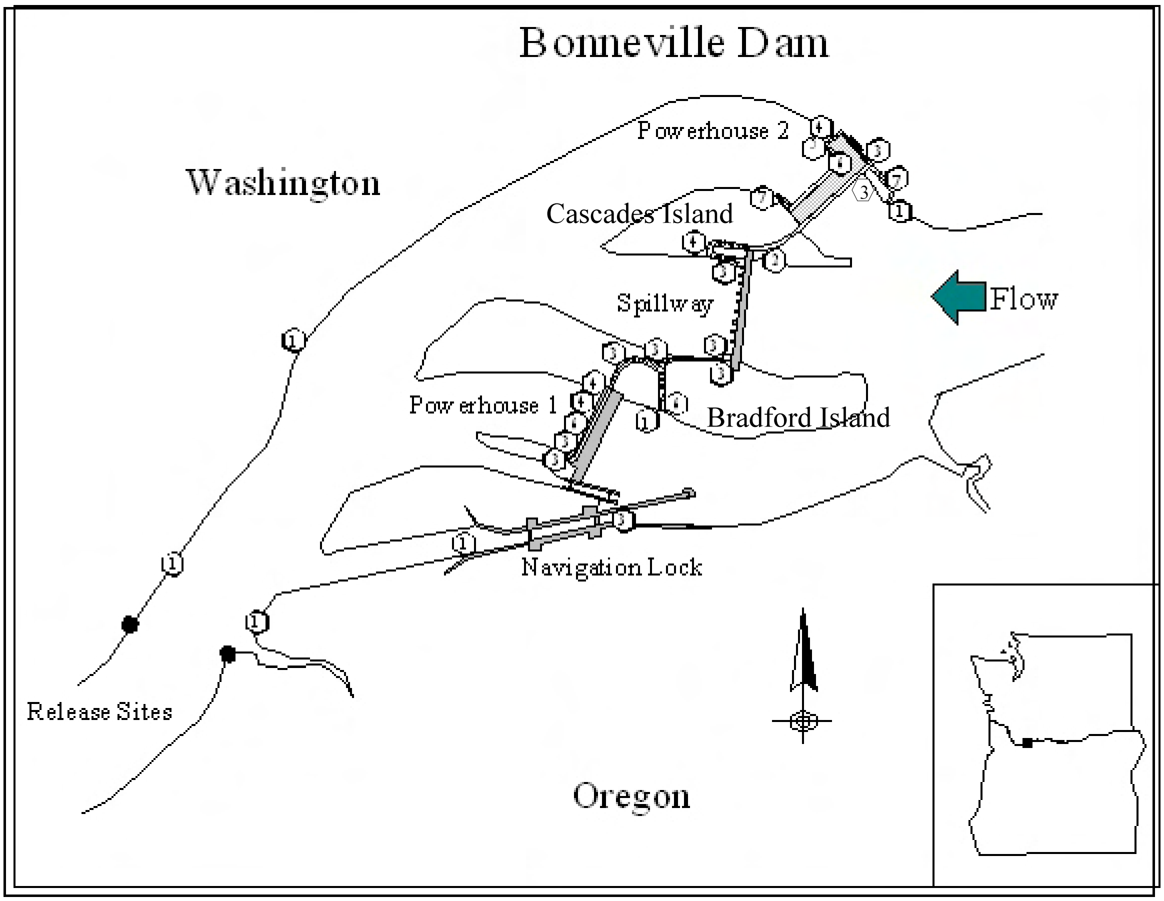

Figure 1. Study area at Bonneville Dam on the lower Columbia River (solid square in insert). Release sites used in 2002 are indicated by solid dots. Radio receiver sites (with the number of antennas used at each site) are indicated by hexagons.

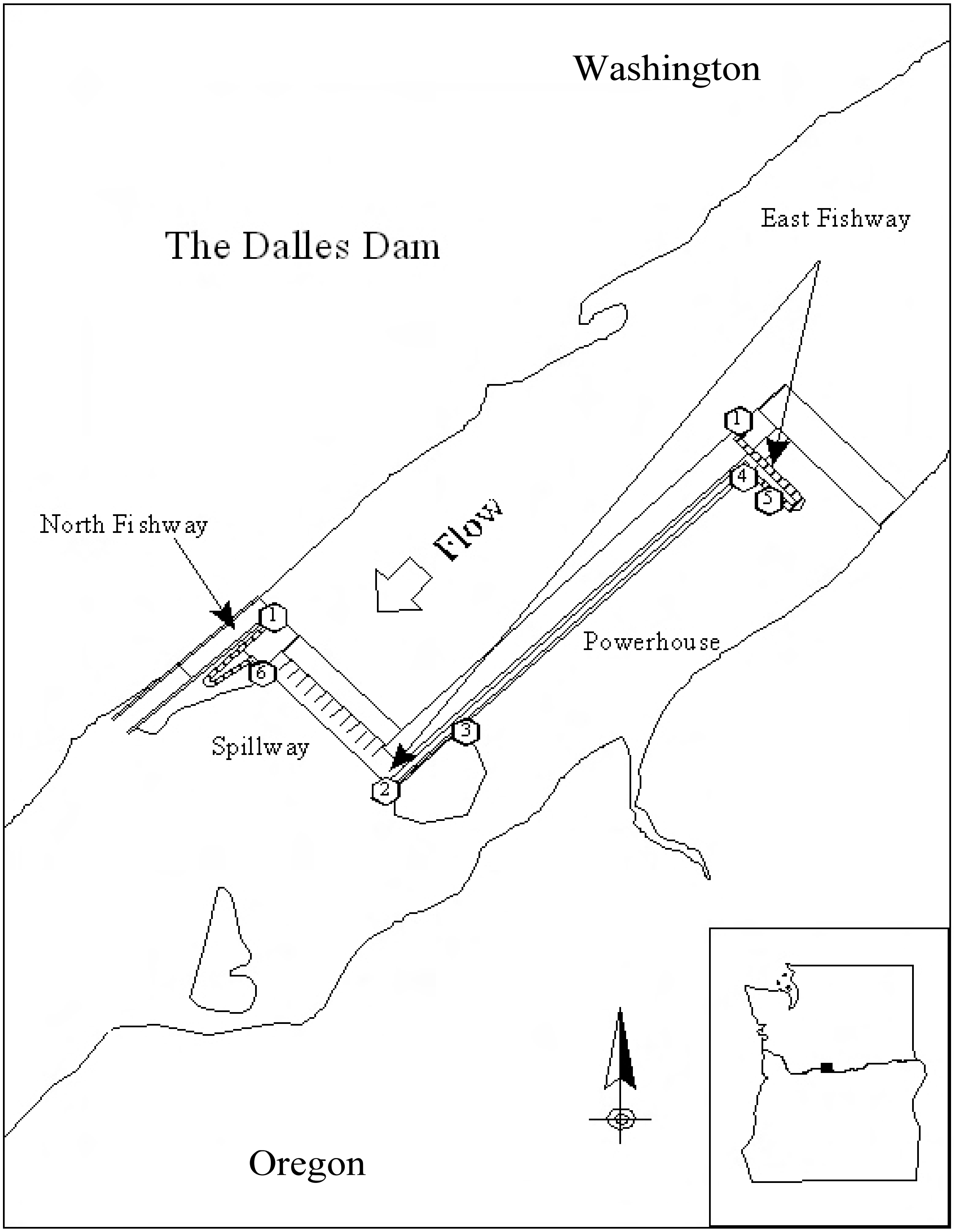

Figure 2. Study area at The Dalles Dam on the lower Columbia River (solid square in insert). Radio receiver sites (with the number of antennas at each site) are indicated by hexagons.

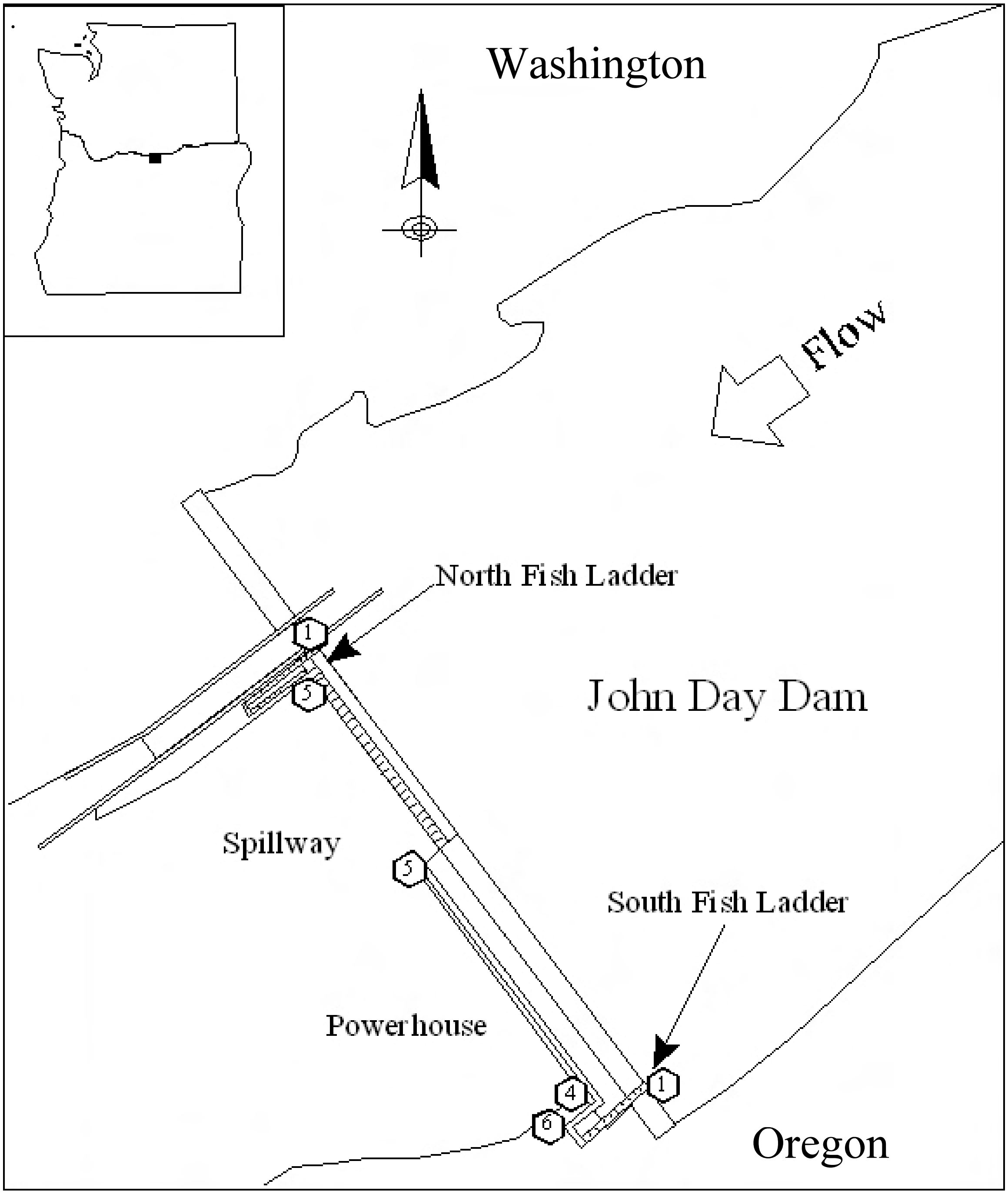

Figure 3. Study area at John Day Dam on the lower Columbia River (solid square in insert). Radio receiver sites (with the number of antennas at each site) are indicated by hexagons.

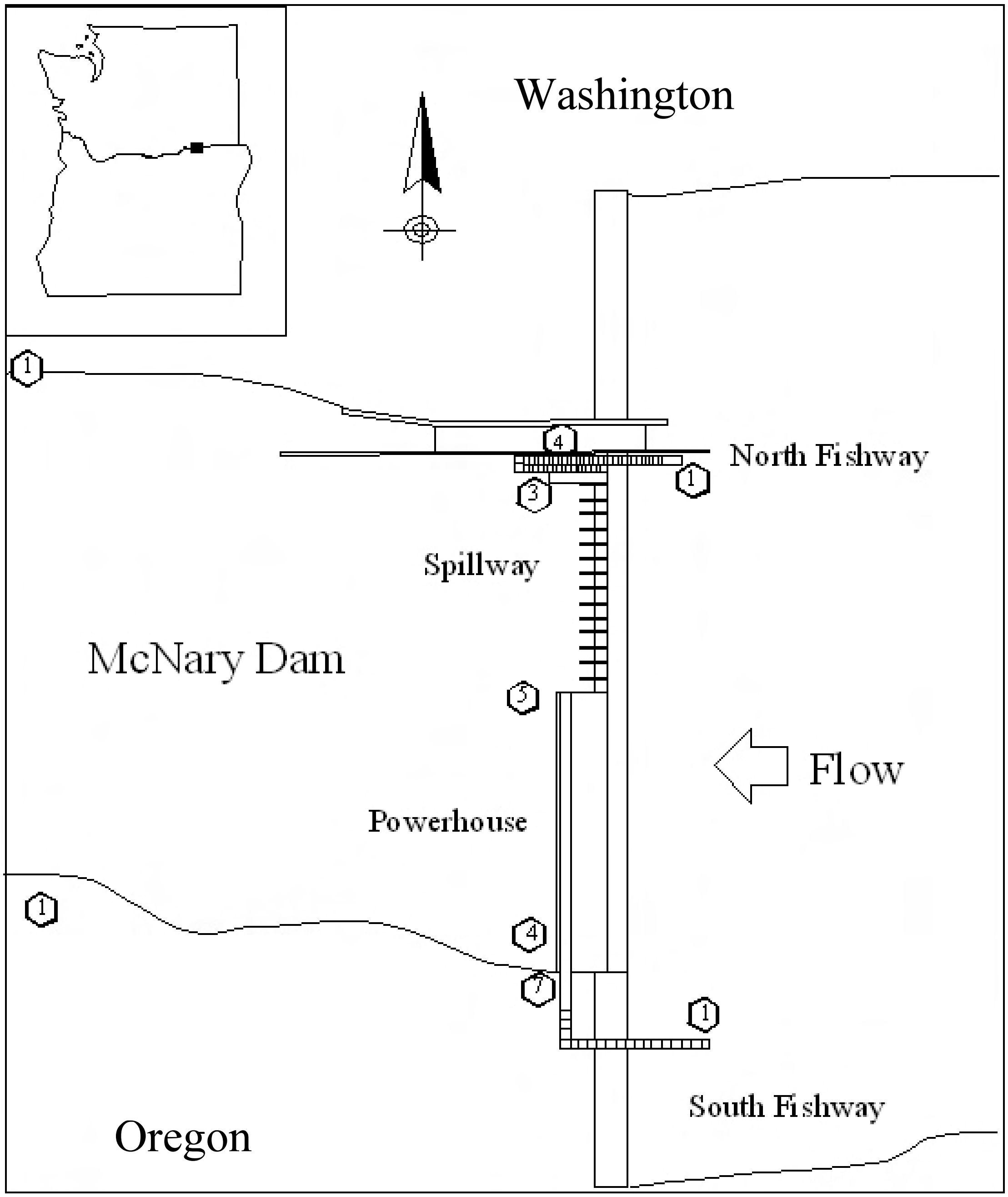

Figure 4. Study area at McNary Dam on the lower Columbia River (solid square in insert). Radio receiver sites (with the number of antennas at each receiver) are indicated by hexagons.

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 2002, 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, antennas were positioned immediately downstream and upstream from the count window (Fig. 5). Four more antennas were used to monitor progress through the serpentine slot weirs above the count window: one antenna below and above each of two consecutive weirs (Fig. 5). One antenna was also positioned at the fishway exit into the forebay and three were located in the makeup water channel (MWC), which runs parallel to the serpentine weir area (Fig. 5). A similar configuration was used at the top of the Washington-shore fishway, except that only one antenna was used to monitor movements into the MWC (Fig. 5).

In 2002, we tested the efficacy of structural and operational modifications at fishway entrances by comparing entrance efficiency at specific entrances 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 more easily attach 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. In addition, in 2002 the orifice gates at Bonneville Dam PH1 were left open throughout the tracking period (closure of these orifice gates was tested in 2000 and 2001). As in 2000 and 2001, orifice gates at The Dalles Dam were closed during the 2002 tracking period.

We also tested the efficacy of adding attachment plates for lamprey in areas where extensive diffuser grating covered the floor of the fishway. In 2001 a metal plate was fixed over the diffuser grating at the PH2 transition area to test whether it would increase attachment sites for lamprey and thereby 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 (Fig. 6). This treatment was applied from the first to the tenth weirs in the Washington-shore fishway. We tested whether lamprey approaching the first weir were more likely to ascend to the tenth weir than in years prior to addition of the attachment plates. In 2002, attachment plates that were the same width as orifice openings were also added to alternating pools (those with diffuser grating) in the PH2 fishway between weirs 18 and 21 (Fig. 6).

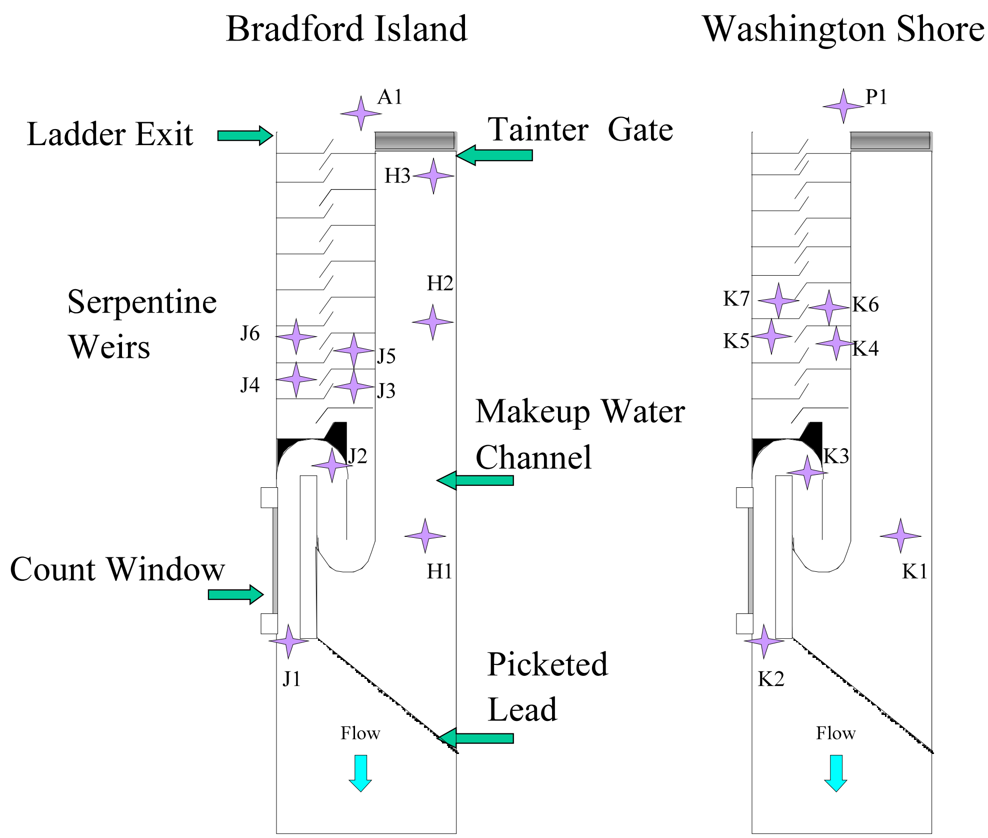

Figure 5. Individual underwater antennas (denoted by stars) at the top of the Bradford Island and Washington-shore fishways in 2002 (diagram is not to scale).

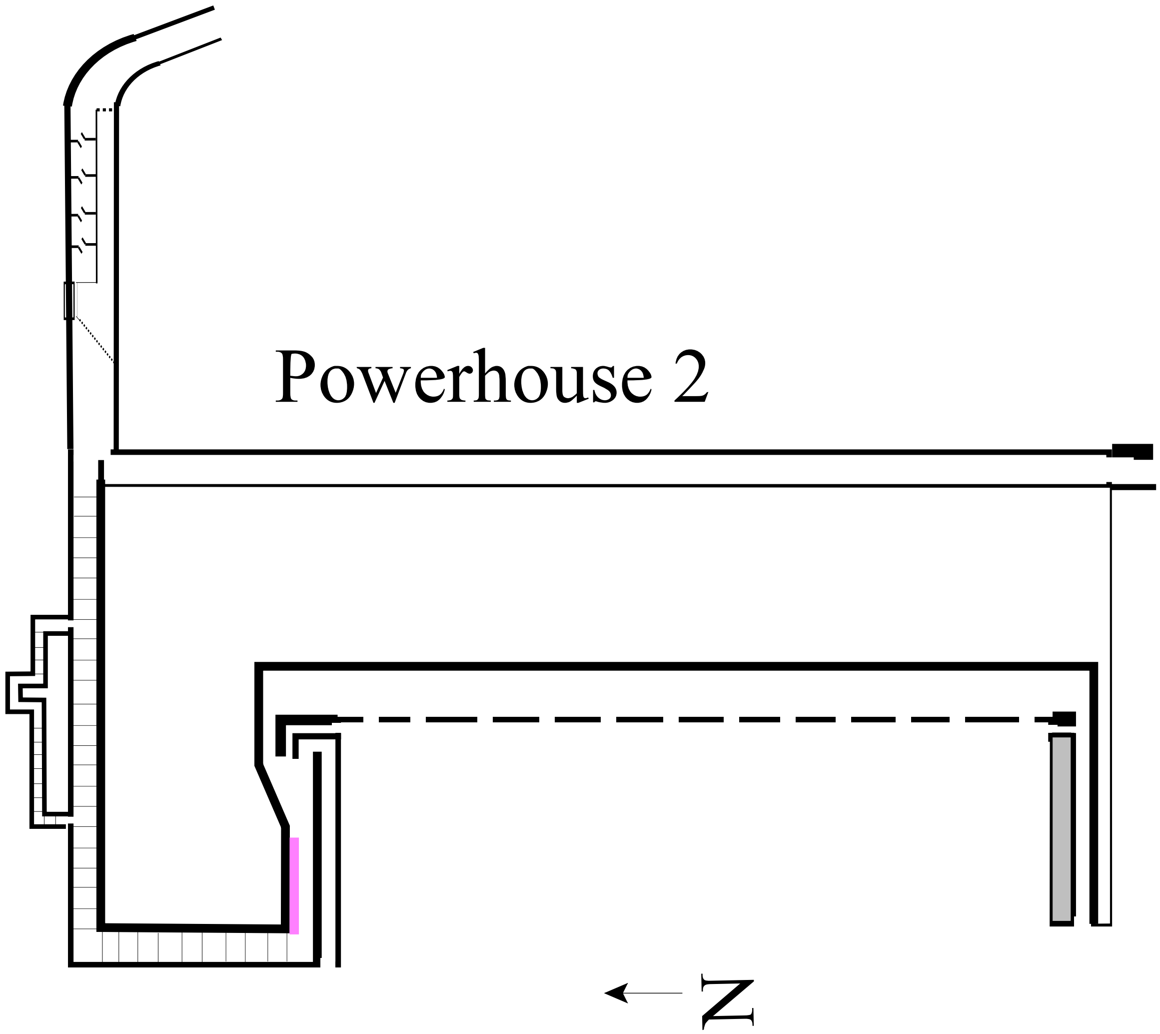

Figure 6. Location of attachment plates (shaded bars) at the transition area of the Washington shore fishway.

Finally, in 2002 we designed, built, and tested two bypass structures to collect lamprey from the Bradford Island MWC. If successful, these structures would be extended to allow lamprey passage directly from the MWC into the forebay of Bonneville Dam. Bypass structures were deployed on the west wall at the upstream end of the MWC. Guides were put in place during winter dewatering and were positioned so that the entrance to the bypass structures could be located either 8 or 15 m downstream from the Tainter gate (i.e., the entire bypass device could be oriented either in the same direction as flow or in the opposite direction).

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 (Ocker et al. 2001). Lamprey were anaesthetized, measured (length and girth to the nearest mm) and weighed (nearest g). A radio transmitter representing less than 0.7% 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. The battery life was 7 months for large transmitters and 12 months for small transmitters.

Fish to be tagged were anaesthetized and transferred to a surgery cradle partly submerged in a 16-L bath of 60 ppm clove oil solution. 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 three to 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 3000 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 h prior to release.

Radio-tagged lamprey were detected via mobile tracking (using a portable receiver from a vehicle or vessel) and 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 an area and the proportion that successfully passed through that area (passage efficiency). Lamprey moved both upstream and downstream in the fishways (Matter et al. 2000). For analysis, we determined the farthest upstream position attained by each fish, even if it required several attempts to reach this position.

At Bonneville Dam count station areas, we 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, regardless of whether the fish left the count station area. We also compared passage through the straight slots and angled slots (those bounded by the ends of weirs) (Fig. 7). At the Bradford Island fishway, the straight slot we tested was between antennas J4 and J5 (Fig. 5), and at the Washington-shore fishway it was between antennas K5 and K6 (Fig. 5). We tested the angled slots at Bradford Island between J3 and J4 and between J5 and J6 (Fig. 5). At the Washington-shore fishway, the angled slots we tested were between K4 and K5 and between K6 and K7 (Fig. 5)

Figure 7. Photo of serpentine weirs (angled slot on left and straight slot on right) taken when the fishway was dewatered.

Bypass Structure Development and Testing

We designed, built, and tested two different bypass prototypes in 2002 (Fig. 8). The first featured a closed rectangular tube (15.2 cm high × 20.3 cm wide) of schedule 40 aluminum that extended from the bottom of the MWC to the trap box (an elevation of 3.2 m) at a slope of 1.4:1.0. The entire bypass was 6.6 m in length, which included a 0.7-m wide collector that rested on the bottom (Fig. 9). Ambient Columbia River water was supplied to the trap box via a 10.2-cm diameter flexible corrugated pipe from two, 3-hp submersible pumps. Flow into the trap box was regulated to maintain a 3-cm depth in the rectangular tube. Attraction flow could be provided at the top of the collector via a 5.1-cm diameter pipe connected to one of the 3-hp submersible pumps.

The second design incorporated an open ramp that extended from the bottom of the MWC to the level of the trap box (3.2-m elevation). Lamprey could enter the ramp at any depth in the water column. A heavy rubber flange was used to create a seal against the wall and floor of the MWC and to help guide lamprey onto the ramp (Fig. 10). After ascending the 4.4-m long ramp (at a slope of 1:1), lamprey entered a 1.2-m long rectangular aluminum tube (15.2 cm high × 20.3 cm wide) with an open top that emptied into the trap box (Fig. 8). Ambient Columbia River water was supplied to the trap box via a 10.2-cm diameter flexible corrugated pipe from two, 3-hp submersible pumps. Flow into the trap box was regulated to maintain a 3-cm depth in the rectangular tube.

To test the efficacy of the bypass structures, we deployed a trap box at the upstream end of each structure (Fig. 11). The trap could be retrieved and re-deployed without moving the rest of the structure, and it was checked each morning and evening. The time of day and number of lamprey captured were recorded for each sample, and then the lamprey were released into the forebay of the dam. Catch per unit effort (CPUE) was defined as the number of lamprey caught during each deployment divided by the number of hours the trap was operating.

Mean CPUE was determined for four treatments: 1) the closed tube with attraction flow provided at the collector, 2) the closed tube with no attraction flow, 3) the open ramp oriented with the collector at the downstream end of the MWC, and 4) the open ramp oriented with the collector at the upstream end of the MWC (near the Tainter gate where lamprey tend to accumulate). The first two treatments (closed tube with and without the attraction flow) were alternated each day. The open ramp was then tested first oriented downstream and then oriented upstream.

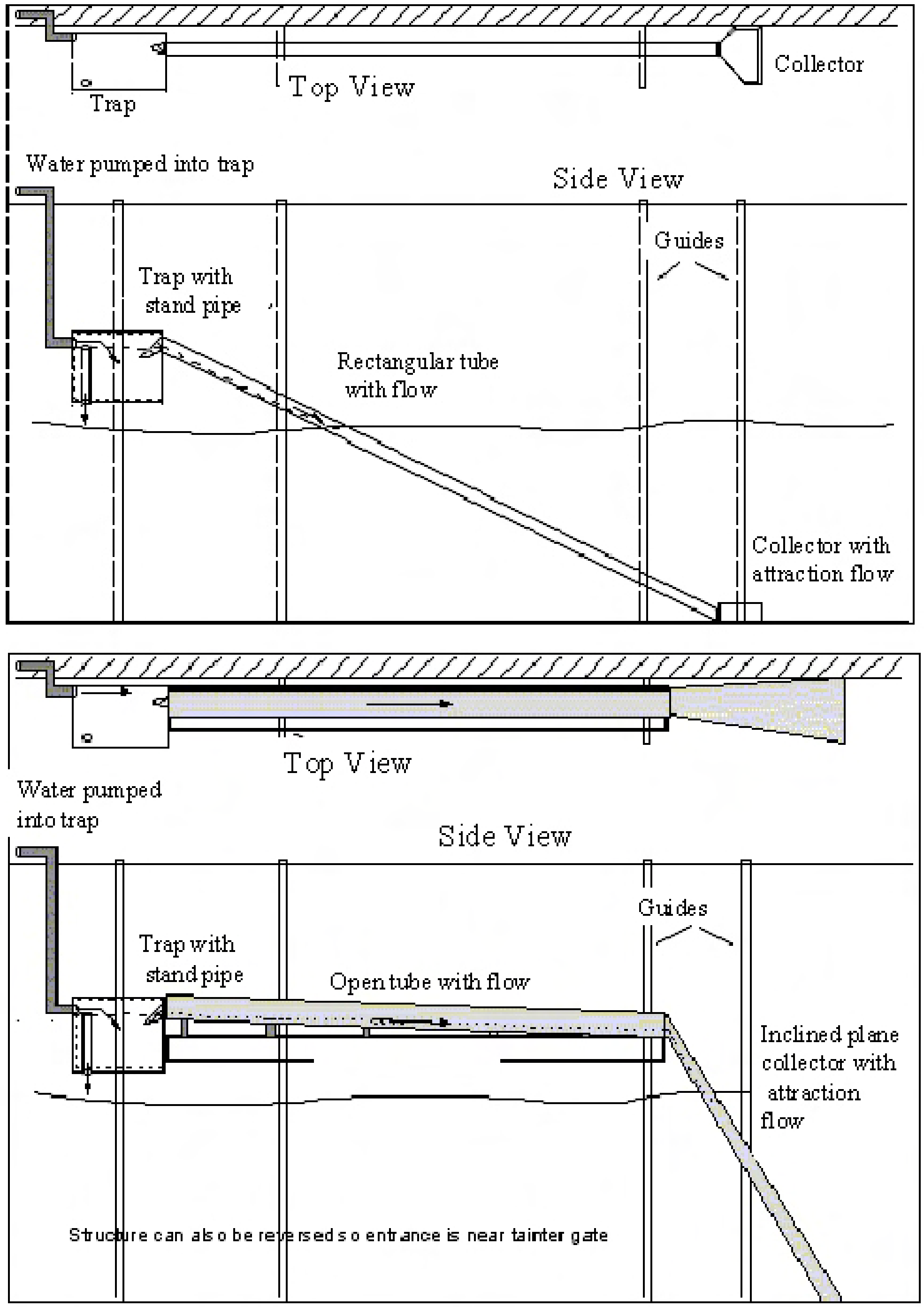

Figure 8. Top and side views of the closed tube bypass design (upper panel) and the open ramp bypass design (bottom panel) at the Bradford Island MWC in 2002.

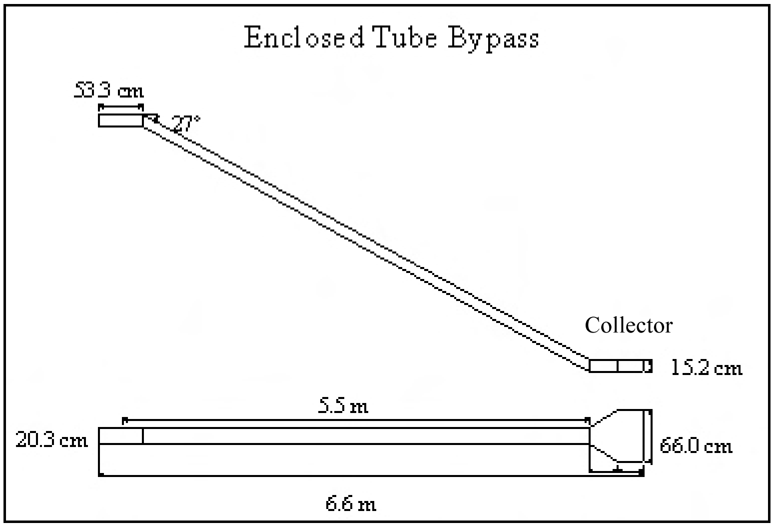

Figure 9. Dimensions of the closed tube bypass design (side view above and top view below) installed at the Bradford Island MWC in 2002.

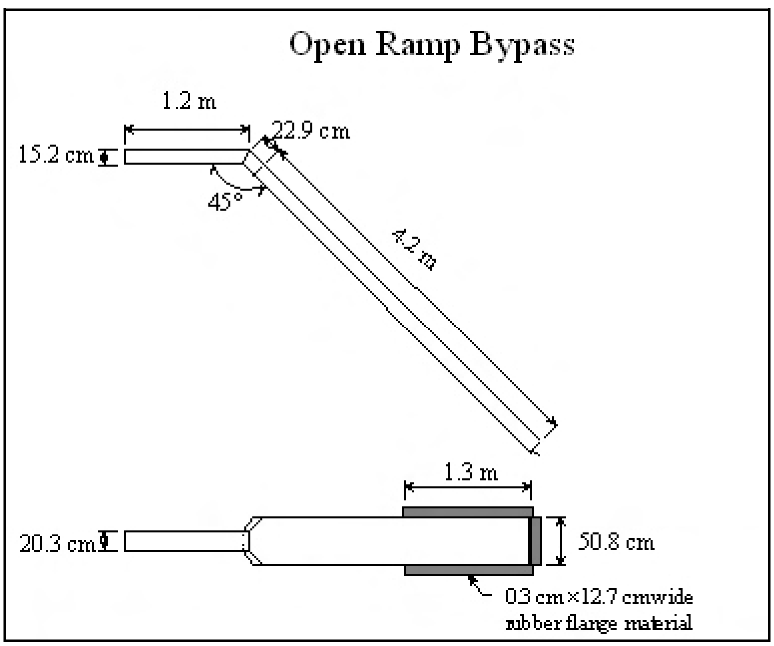

Figure 10. Dimensions of the open ramp bypass design (side view above and top view below) installed at the Bradford Island MWC in 2002.

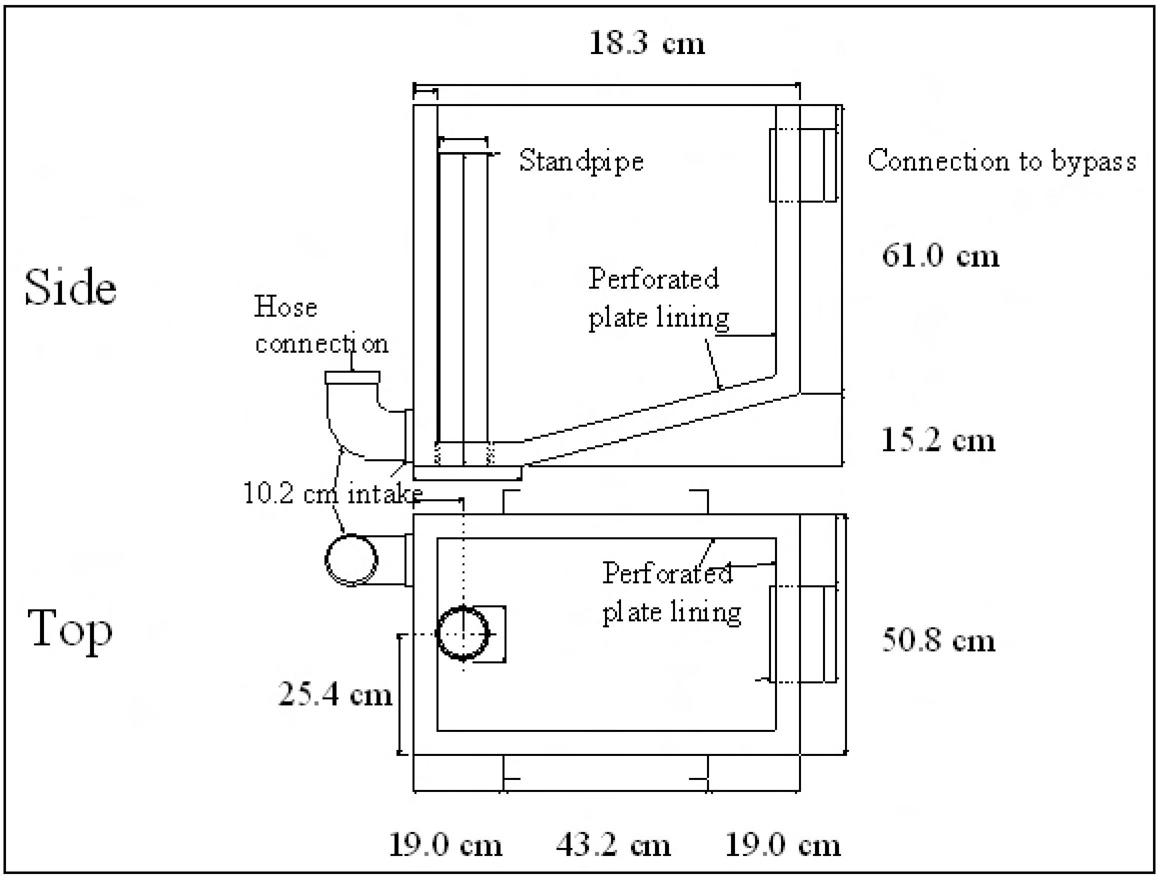

Figure 11. Dimensions of trap box (side view above and top view below).

To test the efficiency of each structure, we also conducted a mark-recapture experiment using lamprey collected at the Adult Fish Collection and Monitoring Facility (described in the previous section) that were not used for radio tracking or other research. These fish were collected each day, anaesthetized using 60 ppm clove oil, and marked with a unique silver nitrate brand, so that their time at large could be determined. They were then released into the Bradford Island MWC at a position immediately downstream from the Tainter gate (Fig. 5).

The efficiency of each of the four treatments was computed by dividing the number of marked lamprey that we recaptured by the number of marked lamprey that were in the MWC during each treatment. During the first week of experimentation we released 10 marked lamprey into the bypass trap to ensure that they were not able to escape after entering the trap. All 10 marked lamprey were still in the trap the following day.

We were also able to estimate efficiency for each treatment using the counts at the Bradford Island counting station. Numbers of lamprey in the MWC during each treatment were estimated by expanding counts made at the Bradford Island counting station using results from radiotelemetry. Efficiency of each treatment was determined by dividing the total number of fish trapped during each treatment by the estimated number of lamprey that were in the MWC during that treatment.

RESULTS

Trapping and Tagging

The trapping period for lamprey was from 28 May to 18 September 2002, and a total of 2,732 lamprey were caught in 817 hours of trapping (CPUE = 3.34 lamprey/hour). This was over three times the CPUE that we achieved in previous years using the same methods (Moser and Close 2003). The higher CPUE was probably partly due to the larger lamprey run in 2002. At Bonneville Dam, 100,476 lamprey were counted in 2002 (USACE 2002), as compared to 27,947 in 2001 and 19,002 in 2000 (Moser and Close 2003). As in previous years, counts at Bonneville Dam peaked in June, with a peak at The Dalles Dam approximately one month later (Fig. 12). The counts of lamprey in the Washington-shore fishway (where our trap was located) peaked at the end of June.

We radio tagged 201 lamprey from the beginning of June until the beginning of August (Fig. 13). We also took blood samples from 159 of these lamprey for U.S. Geological Survey researchers. Blood samples were taken from 62 males, 91 females, and 6 of undetermined sex. Due to the abundance of lamprey in 2002, we selected the largest fish to minimize tag effects (Fig. 14-16). Nevertheless, the mean length of the lamprey we tagged in 2002 was actually shorter than in 2001, and similar to the length tagged in previous years of radiotelemetry (Table 1). Mean weights of the fish tagged in 2002 were greater than in all previous years. The females used for tagging in 2002 (n = 116) were slightly larger (mean length = 72.5 cm, mean weight = 627 g) than the males (n = 75, mean length = 71.5 cm, mean weight = 590 g).

Based on results from 2001, we used the small transmitter only on lamprey having a girth of at least 11.5 cm (n = 101) and the large transmitter on lamprey having a girth of at least 12.5 cm (n = 100) to minimize tag effects. In this study, the small radio tag (wet weight) ranged from 0.40 to 0.66% of the lamprey body weight and 21.0 to 24.9% of girth (Figs. 17 and 18). The large tag was 0.47-0.67% of body weight and 23.3-27.0% of girth (Figs. 17 and 18).

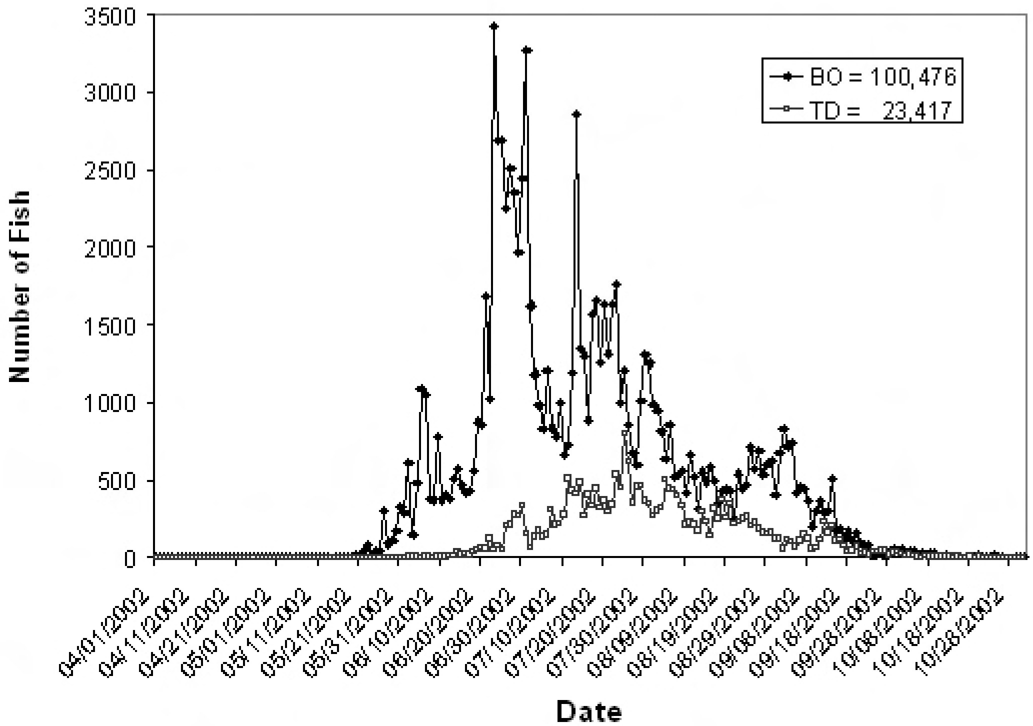

Figure 12. Number of lamprey counted at Bonneville Dam (diamonds) and The Dalles Dam (squares) count stations in 2002.

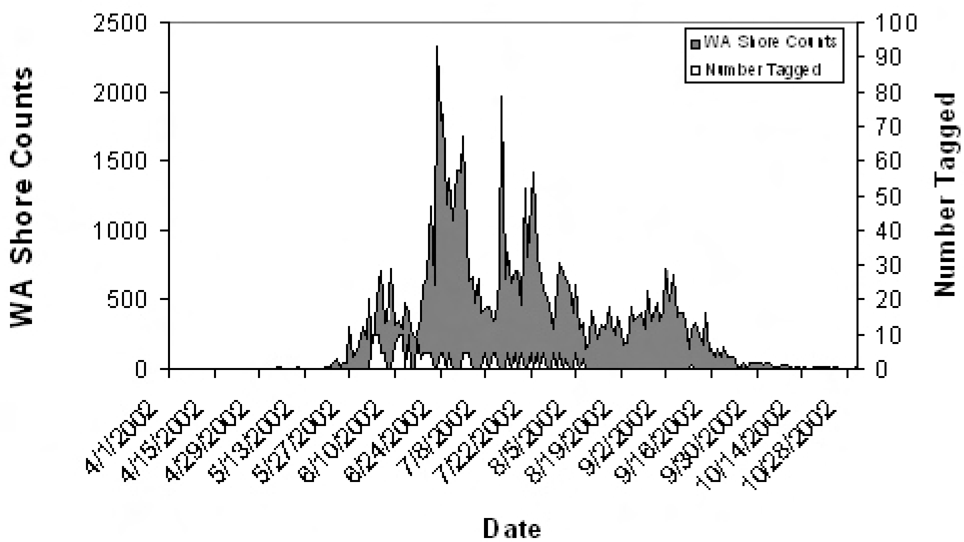

Figure 13. The number of lamprey counted at the Washington-shore count station (shaded area) and the number tagged with radio transmitters (open area).

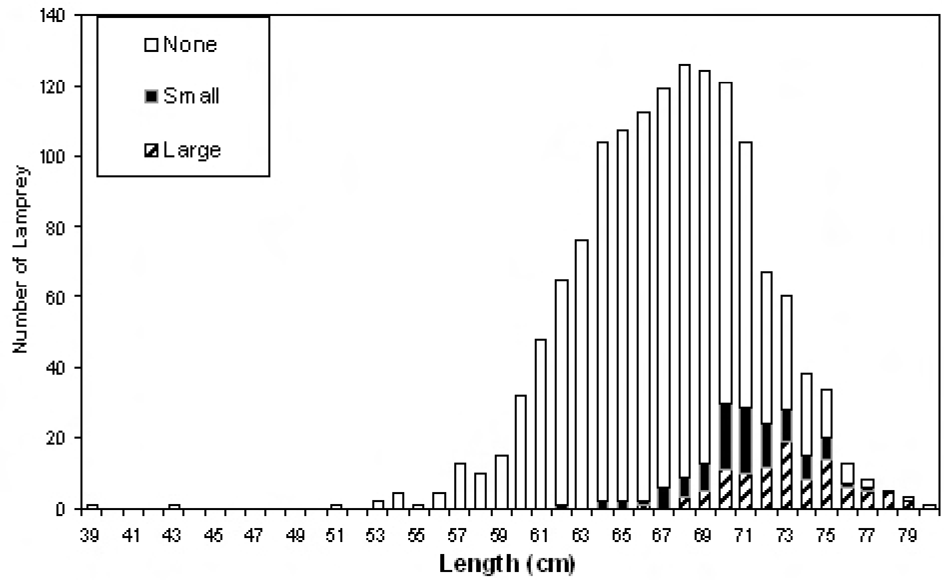

Figure 14. Length distribution of lamprey captured and not tagged (open bars), tagged with small tags (solid bars), and tagged with large tags (hatched bars).

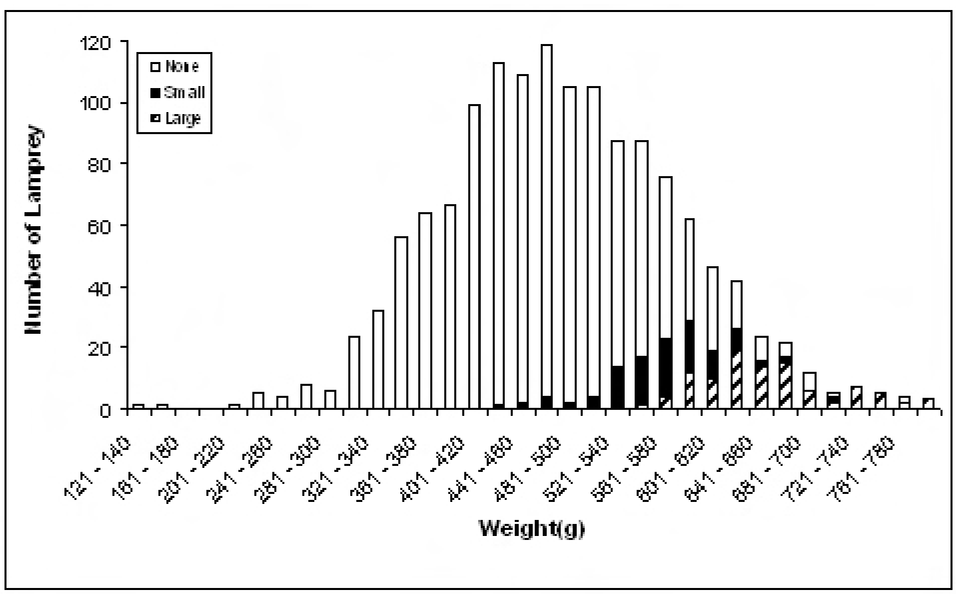

Figure 15. Weight distribution of lamprey captured and not tagged (open bars), tagged with small tags (solid bars), and tagged with large tags (hatched bars).

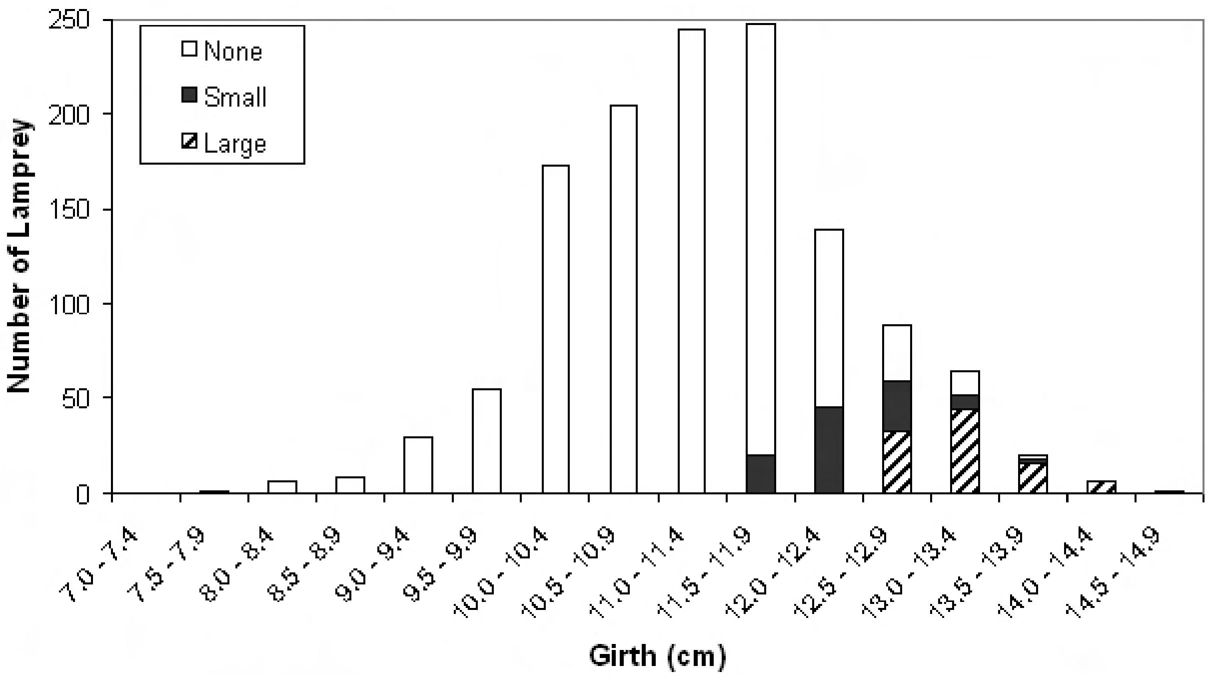

Figure 16. Distribution of lamprey girth measurements (taken just anterior to dorsal fin insertion) for lamprey captured and not tagged (open bars), tagged with small tags (solid bars), and tagged with large tags (hatched bars).

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 1997-2002.

	1997	1998	1999	2000	2001	2002
Number released	147	205	199	299	298	201
Mean length (cm)	70	70	71	70	77	72
(range)	(60-80)	(59-79)	(65-78)	(62-80)	(62-82)	(62-80)
Mean weight (g)	-	545	571	570	588	612
(range)	> 450	(420-830)	(475-755)	(405-825)	(380-880)	(440-790)
Number detected at Bonneville Dam	129 (88%)	182 (89%)	183 (92%)	260 (87%)	278 (93%)	193 (96%)
Travel time to dam, median (d)	7.8	4.0	5.2	6.4	4.3	4.5
(range)	(0.5-40.5)	(0.1-28.2)	(0.1-53.5)	(0.3-111.2)	(0.1-111.3)	(0.3-53.4)
Standard deviation	7.5	4.8	7.3	13.0	11.9	7.3

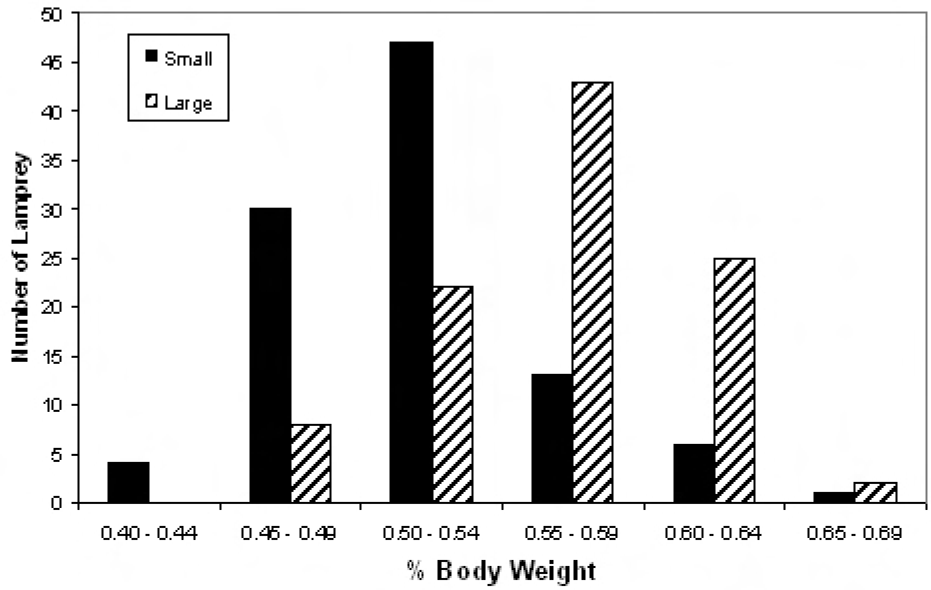

Figure 17. Frequency distribution of percent body weight for each transmitter size (small = 4.5 g, large = 7.7 g).

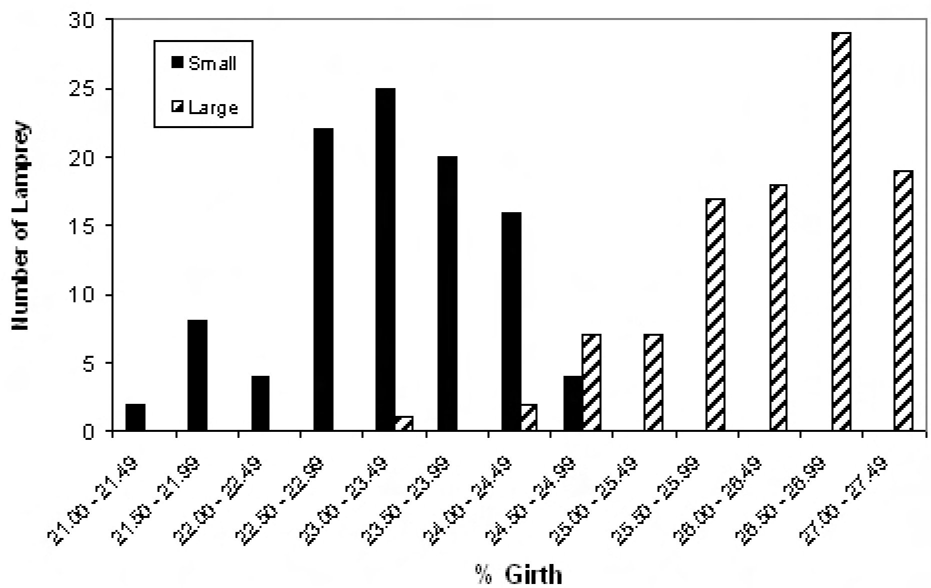

Figure 18. Frequency distribution of percent girth for both transmitter sizes (small = 4.5 g, large = 7.7 g).

Bonneville Dam

We released all 201 lamprey below Bonneville Dam: 112 near the Washington shore and 89 near the Oregon shore. Ninety-six percent (n = 193) of these fish were later detected at Bonneville Dam fishway entrances, the highest percentage that have returned to the dam after release among all years we have studied lamprey migration (range = 87-96%, Table 1). Median time from release to first detection at the Bonneville Dam fishway entrances was 4.5 d and was similar to or lower than other years of study (range = 4.0-7.8 d, Table 1). There was no apparent effect on travel time to the dam of either absolute tag size or the size of the tags relative to lamprey size (measured as both a percentage of body weight and girth; Figs. 19 and 20).

To determine what part of the dam the radio-tagged lamprey initially approached, we divided the number that initially approached each section (PH1, Spillway, and PH2) by the total number that approached the dam. For this analysis we used only the location where lamprey were first detected at a fishway entrance. The results were similar to those recorded in 2001, with more lamprey initially approaching at PH2 than at either PH1 or the spillway (Fig. 21).

Overall, of the 193 radio-tagged lamprey that approached Bonneville Dam in 2002, 169 successfully entered the fishways (88%). The number of lamprey that successfully entered a fishway of those that approached the fishway (entrance efficiency) was determined for each section of the dam: PH1, PH2, and spillway entrances (Table 2). Overall entrance efficiency in 2002 was similar to that found in other years of study and indicated that lamprey have higher entrance efficiency at the powerhouse fishway entrances than at the spillway entrances (Table 2). However, examination of entrance efficiency at the individual entrances indicated that lamprey success at the Bradford Island spillway entrance (SPILL-SSE, Fig. 22) was higher (52%) in 2002 than in previous years. Entrance efficiency at the Cascades Island spillway entrance (SPILL-NSE, Fig. 22) in 2002 was also similar to or higher than that recorded in previous years (56%).

As in other years of study, entrance efficiency at the orifice gates at PH1 was lower than at main entrances (Fig. 22). As in 2001, we noted that entrance efficiency at the northernmost PH2 main entrance (PH2-NSE-CNR, Fig. 22) was low relative to previous years. In addition, we found that entrance success at the southernmost entrance at PH1 was only 25% in 2002. This represented a substantial drop from entrance efficiencies at this location in 1998-2001, which ranged from 43 to 54% (PH1-SSE, Fig. 22).

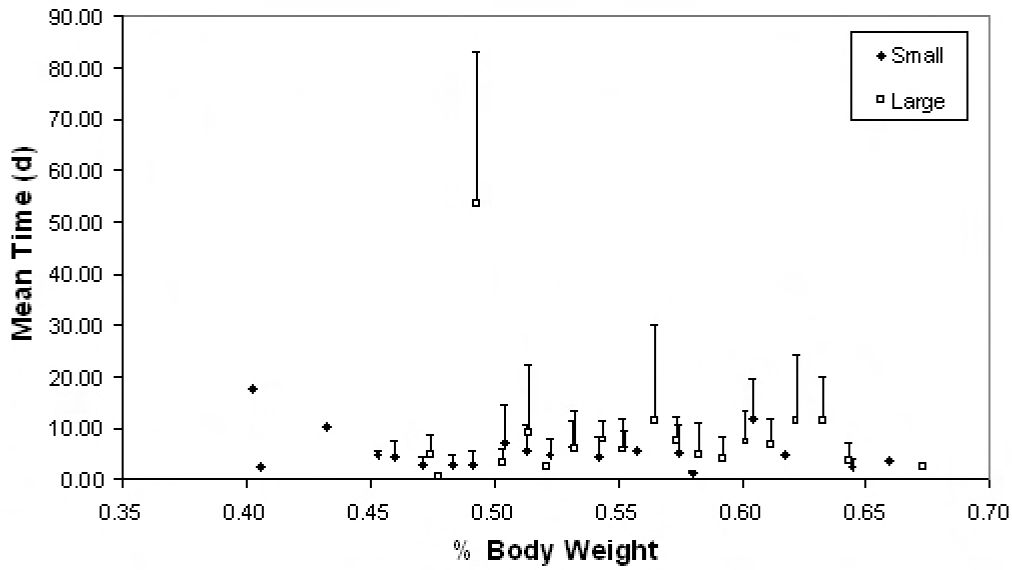

Figure 19. Mean travel time (standard deviation indicated by error bars) from release to first detection at Bonneville Dam for lamprey bearing tags of increasing percent body weight. Diamonds indicate lamprey with small tags (4.5 g) and open squares indicate lamprey with large tags (7.7 g).

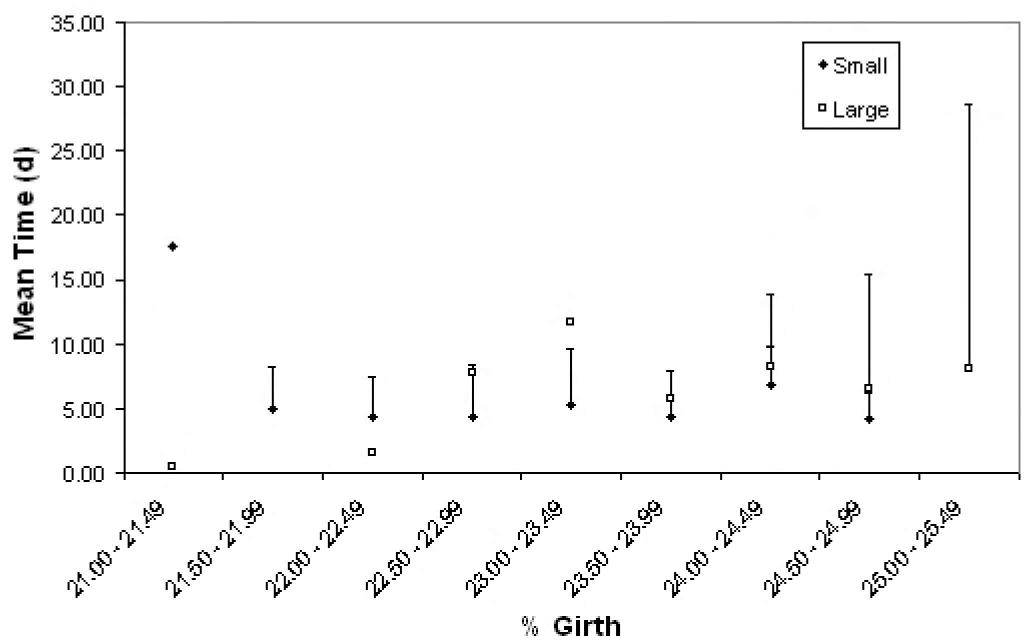

Figure 20. Mean travel time (standard deviation indicated by error bars) from release to first detection at Bonneville Dam for lamprey bearing tags of increasing percent girth. Diamonds indicate lamprey with small tags (4.5 g) and open squares indicate lamprey with large tags (7.7 g).

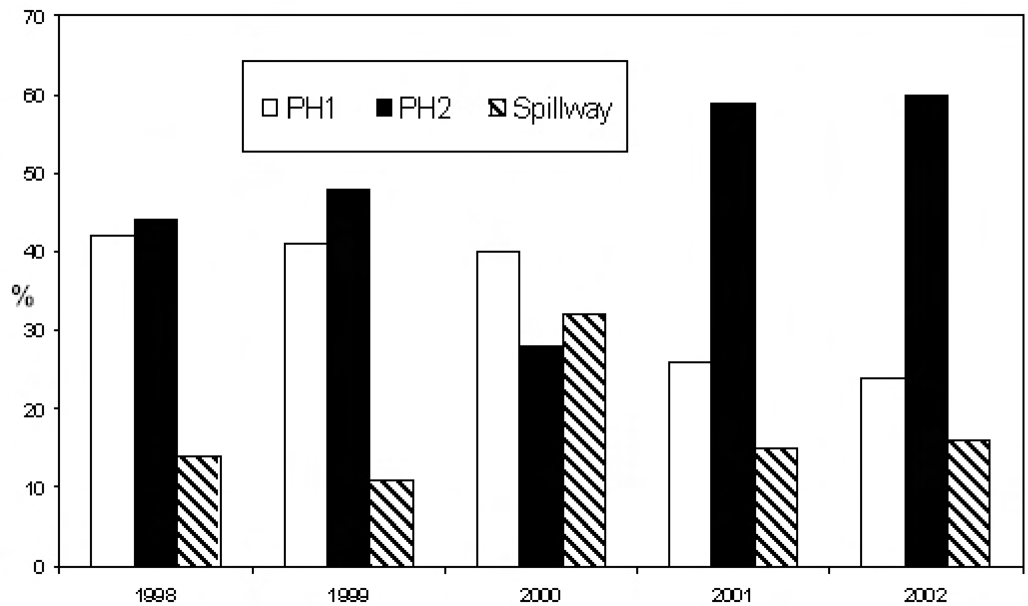

Figure 21. Percent of radio-tagged lamprey that made their initial approach at the fishways at PH1 (open bars), PH2 (solid bars), and the spillway (hatched bars) in 1998-2002.

Table 2. The number of radio-tagged lamprey that passed through each area within each fishway at Bonneville Dam in 1997-2002. Passage efficiency (the number of fish that passed through the area / the number that approached that area × 100) is in parenthesis.

Area	1997	1998	1999	2000	2001	2002
			PH1			
Entrance	47 (60%)	78 (80%)	63 (72%)	97 (74%)	71 (74%)	54 (76%)
Collection	36 (77%)	63 (81%)	55 (87%)	85 (88%)	59 (83%)	41 (76%)
Transition	32 (89%)	61 (97%)	50 (91%)	82 (96%)	58 (98%)	38 (93%)
Ladder	27 (75%)	59 (97%)	49 (98%)	71 (86%)	52 (90%)	35 (92%)
Count station	21 (78%)	37 (63%)	38 (78%)	63 (89%)	45 (86%)	25 (71%)
			PH2			
Entrance	50 (69%)	78 (81%)	87 (80%)	109 (78%)	100 (85%)	157 (77%)
Collection	30 (60%)	50 (64%)	79 (79%)	63 (72%)	94 (60%)	84 (77%)
Transition	25 (83%)	32 (64%)	43 (54%)	43 (68%)	72 (77%)	54 (64%)
Ladder	24 (96%)	29 (91%)	43 (100%)	38 (88%)	71 (99%)	52 (96%)
Count station	21 (88%)	25 (86%)	35 (81%)	32 (84%)	57 (80%)	42 (81%)
			Spillway			
Entrance	33 (54%)	35 (44%)	41 (57%)	69 (60%)	55 (65%)	66 (62%)
Collection	19 (58%)	21 (60%)	22 (54%)	63 (91%)	53 (96%)	59 (89%)
Transition	14 (74%)	12 (57%)	11 (50%)	37 (59%)	39 (74%)	37 (63%)
Ladder	11 (79%)	11 (92%)	10 (91%)	32 (86%)	36 (92%)	35 (95%)
Count station	6 (54%)	9 (82%)	8 (80%)	24 (75%)	26 (72%)	25 (71%)

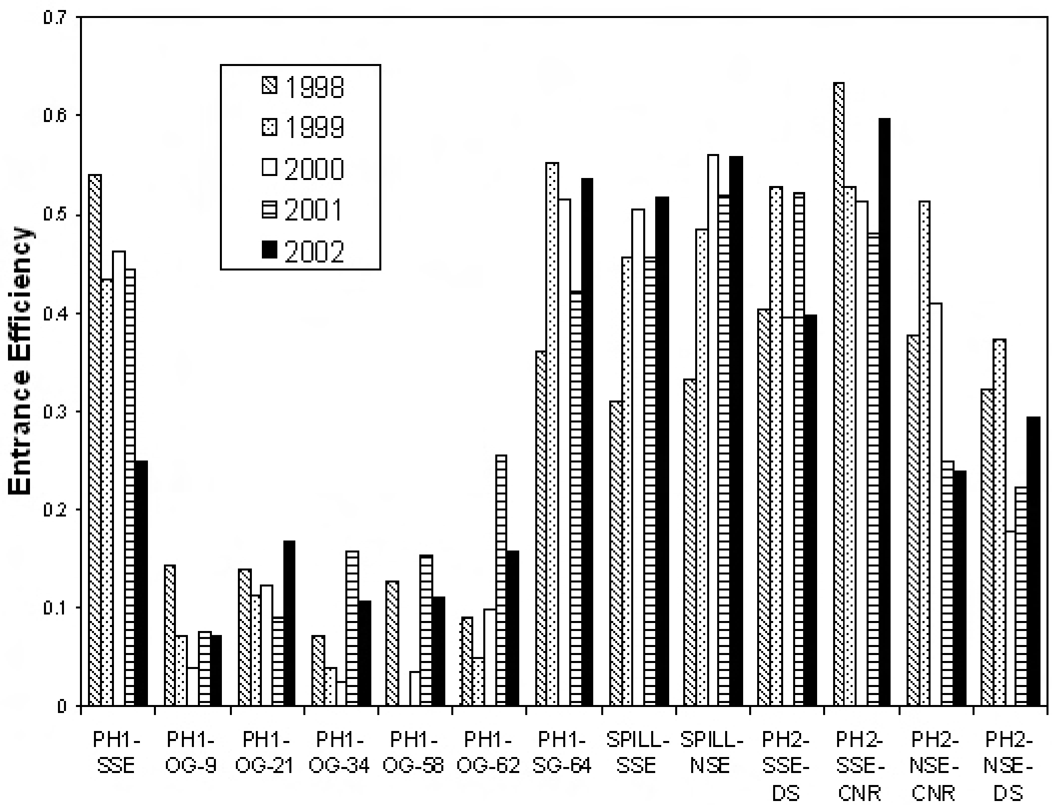

Figure 22. Entrance efficiency (percentage of lamprey that successfully entered of those that approached) at each of the Bonneville Dam fishway entrances from south to north along Powerhouse 1 (PH1), the spillway (SPILL), and Powerhouse 2 (PH2) in 1998-2002. orifice gates (OG) and sluice gates (SG) were open in 2002, but were only monitored at PH1. Main entrances at PH2 include those downstream (DS) and in the corners (CNR).

We compared lamprey passage through the transition area at PH2 among years to assess the efficacy of attachment plates installed in this area. Using the same definitions of passage success as in previous years, we found that passage through this area was actually lower in 2002 than in either 2000 or 2001 (Fig. 23). However, this was due in part to a slight change in the antenna configuration in this area in 2002. An antenna that detected some of the lamprey entering the transition area via the northwesternmost PH2 collection channel was removed in 2002. When we examined only the area from weirs 1 to 23, we found that passage efficiency through this area was 72% in 2000 (prior to plate installation), 82% in 2001 (after installation of plates at weirs 1-10) and 74% in 2002 (when plates were added above weir 10). This analysis also revealed that the area immediately downstream of weir 1 is the most problematic part of the PH2 transition area for radio-tagged lamprey.

As in previous years, lamprey exhibited very high passage efficiency (>90%) through the ladder areas (pools and weirs not influenced by tailwater), but were less successful at counting station areas at the tops of the fishways (Table 2). We intensively monitored this area to document the fates of lamprey that approached the counting stations.

In 2002, 52 radio-tagged lamprey approached the Bradford Island counting station (Fig. 24). One of these went through the picketed lead and directly into the makeup water channel (1 of 3 lamprey detected in the MWC). This fish eventually fell back downstream and then passed the counting station again, but did not get past the serpentine weirs and instead fell back and out of the fishway altogether. One of the 52 fish did not get past the counting station, and another did not enter the serpentine weir section (Fig. 24). Thirty-five lamprey (67% of those that approached the counting station) exited at the top of the fishway.

Fourteen lamprey were obstructed in the Bradford Island serpentine weir area and either fell back past the counting station (n = 12, 23%) or crossed from the serpentine weir section into the makeup water channel via grates in the wall (n = 2, 4%). As indicated in Fig. 24, most of these lamprey were detected at the uppermost serpentine weirs (at or upstream from antenna J5, Fig. 5) or near the ladder exit. In fact, 5 fish were detected at the ladder exit but did not successfully exit the ladder and fell back downstream through the serpentine weirs.

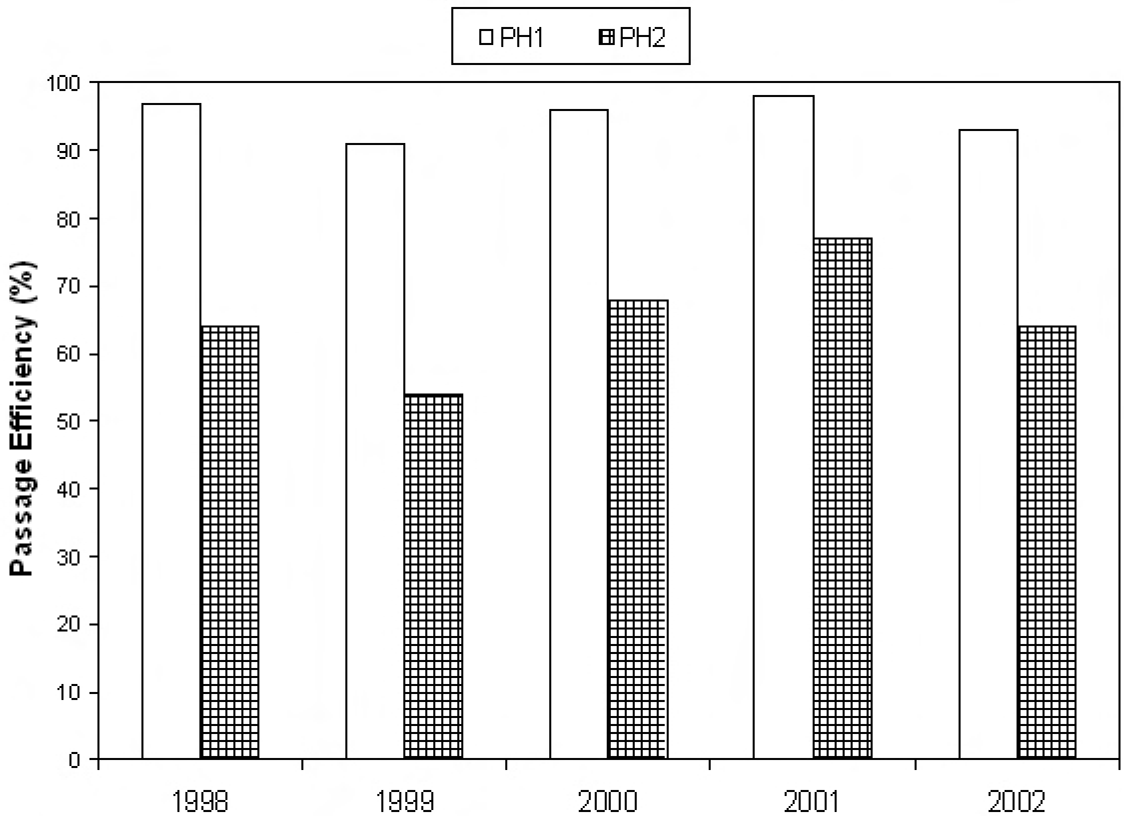

Figure 23. Transition area passage efficiency (percent of lamprey that passed through the transition area of those that approached this area) at Bonneville Dam fishways (Bradford Island = PH1, Washington-shore = PH2) in 2001and 2002 after installation of metal plates over diffuser grating at PH2. There were no plates in this area in 1998-2000.

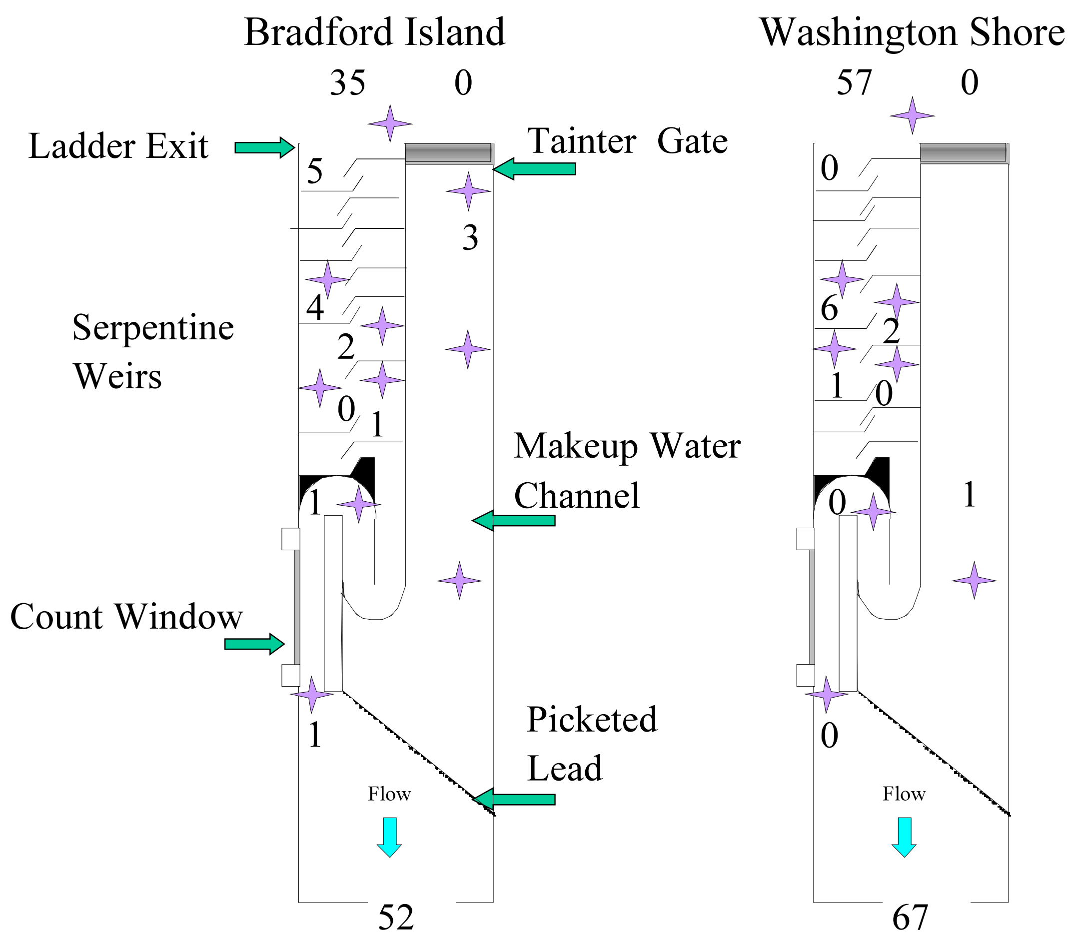

Figure 24. Fates of the radio-tagged lamprey that approached the count stations at the top of the Bradford Island (left panel) and Washington-shore (right) fishways in 2002. The numbers at each location indicate the number of lamprey for which that antenna was the furthest upstream point of detection and the stars indicate the position of antennas. Numbers at the top of the diagrams indicate the number of lamprey that successfully exited each fishway.

At the Washington-shore ladder, all 67 lamprey that approached the counting station passed it and successfully entered the serpentine weir section. Ten (15%) of these fish were last detected in the serpentine weir area before either moving back downstream (n = 9) or crossing into the makeup water channel through grates in the wall (n = 1). The other 57 lamprey exited at the top of the fishway.

Six of the nine lamprey that fell back in the serpentine weir section of the Washington-shore ladder did so upstream from antenna K7 (Fig. 5), indicating that they were obstructed in the upper section of the serpentine weirs (Fig. 24). However, in contrast to the results at Bradford Island, all lamprey detected at the Washington-shore exit successfully entered the forebay.

In the serpentine weir areas of both fishways, we found that lamprey moved through the straight slots more rapidly than through the angled slots (Figs. 25 and 26). At Bradford Island, lamprey required a median of 7.8 min to pass through the straight slot but a median of 12.6 and 21.6 min to pass through the angled slots that were immediately downstream and upstream of the straight slot. Similarly, at the Washington-shore fishway lamprey required less time to pass through the straight slot (median = 12.6 min) than the angled slots (medians = 25.2 and 18 min).

Lamprey that did not ultimately pass the dam did not exhibit the same patterns of delay in the serpentine weirs as lamprey that passed successfully (Figs. 25 and 26). Median holding times of the unsuccessful fish at the downstream-most serpentine weirs were longer than those of fish that eventually exited. For the weirs farther upstream (antennas J4-J 6 at Bradford Island, Fig. 25; antennas K5-K7 at the Washington-shore, Fig. 26) there was little difference between these two groups.

The few lamprey that entered the MWC resided there for extended periods (median = 26 h at Bradford Island and median = 61 h at the Washington-shore fishway). None of these fish were collected in the bypass device deployed in the MWC at Bradford Island (see following section).

Of the 193 lamprey that approached the fishways at Bonneville Dam, 92 passed over the dam via the fishways, for a passage efficiency of 48%. No radio-tagged lamprey were detected in the navigation lock during 2002. Passage efficiency was lower for fish bearing tags greater than 0.6% of body weight (Fig. 27) or 27% of girth (Fig. 28).

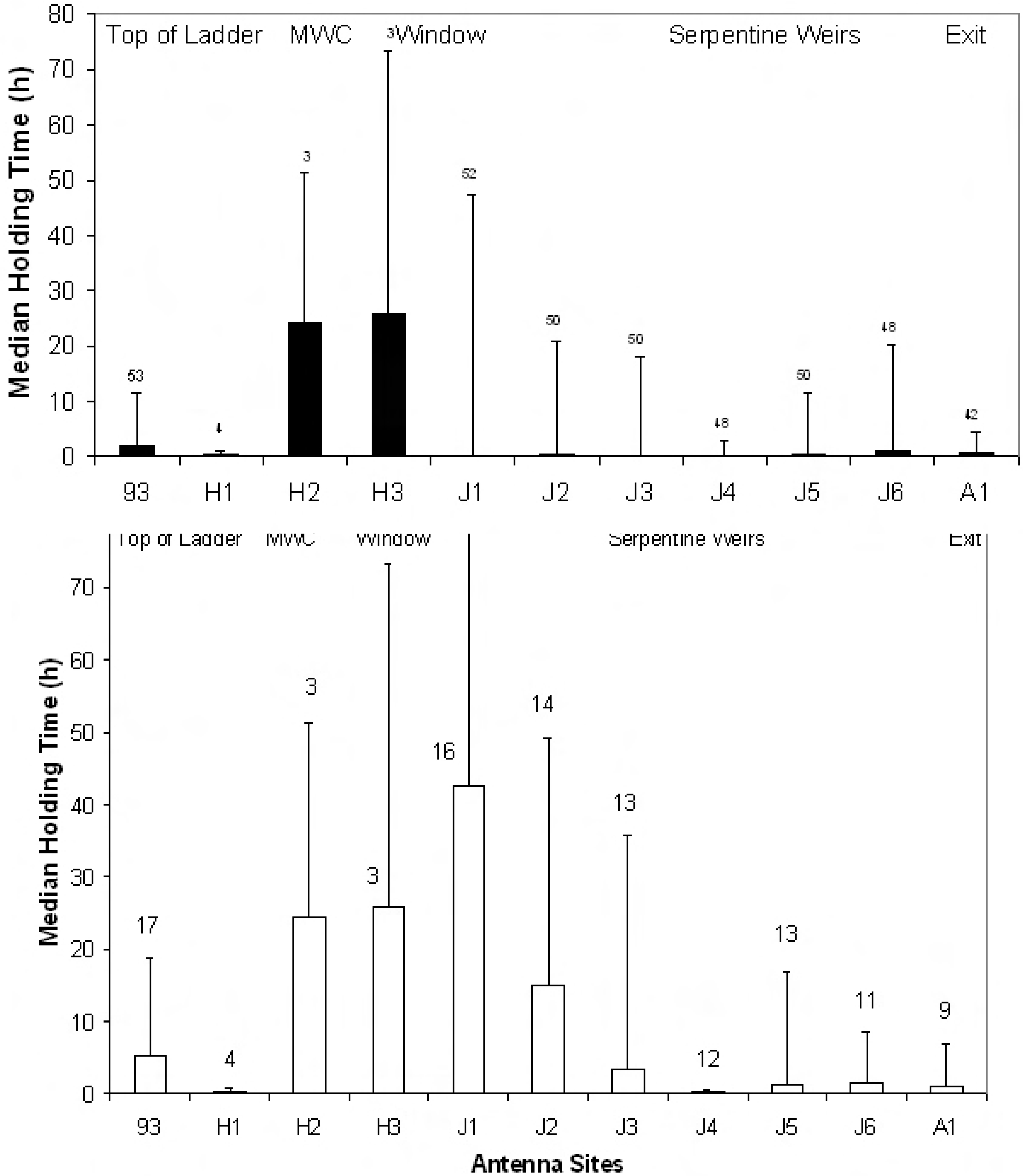

Figure 25. Median holding time for each antenna site (see Fig. 5) at the top of the Bradford Island fishway (i.e., the median time from first detection at an antenna to the first detection at the next upstream antenna with standard deviation error bars and sample size over each bar. Data for all lamprey in top panel (solid bars), and for those that did not successfully exit the fishway in bottom panel (open bars).

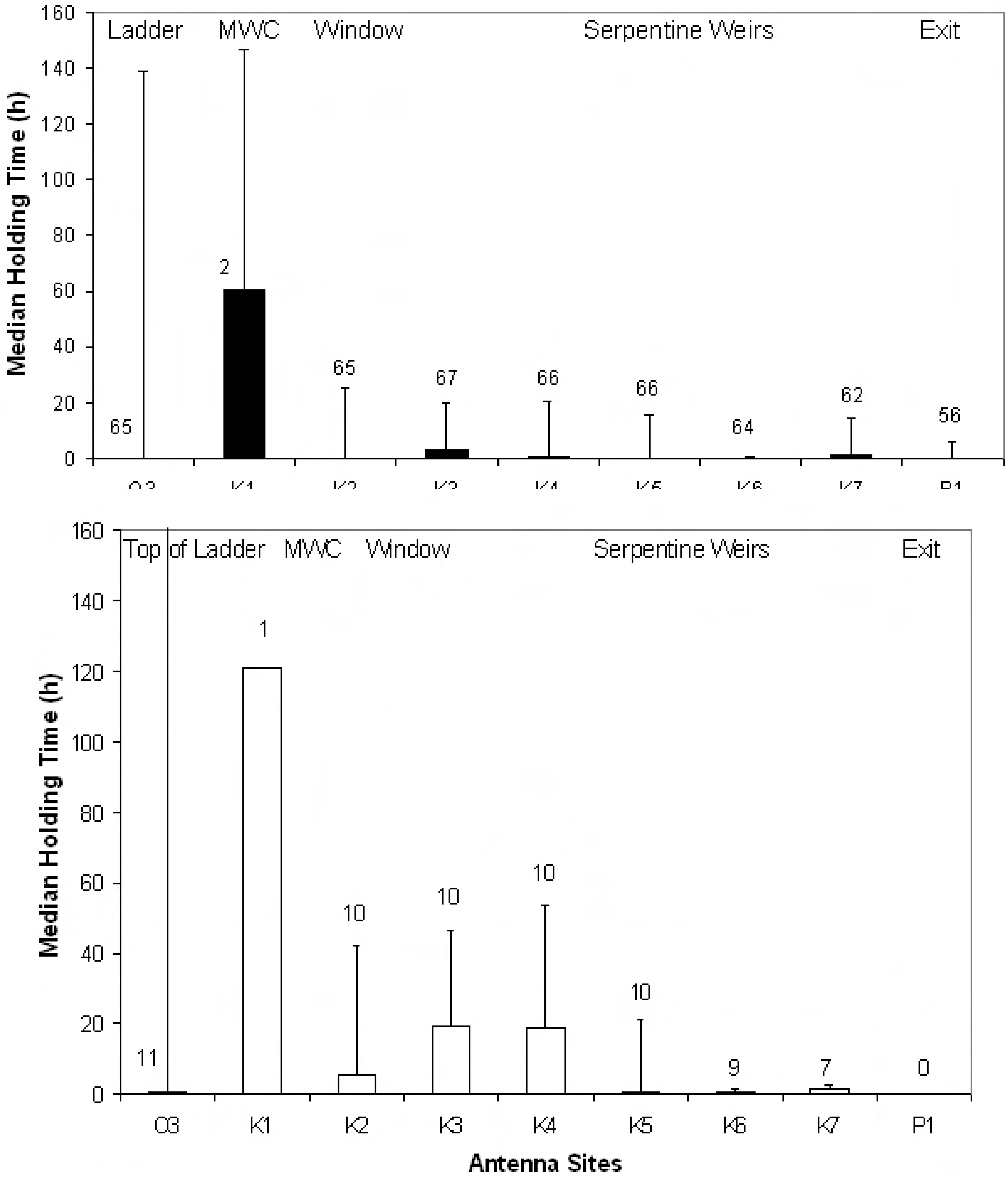

Figure 26. Median holding time at each antenna (see Fig. 5) at the top of the Washington-shore fishway (i.e., median hours from first detection at an antenna to the first detection on the next upstream antenna with standard deviation bars and sample size indicated above the bars). Data for all lamprey in top panel (solid bars), and for those that did not successfully exit the fishway in the bottom panel (open bars).

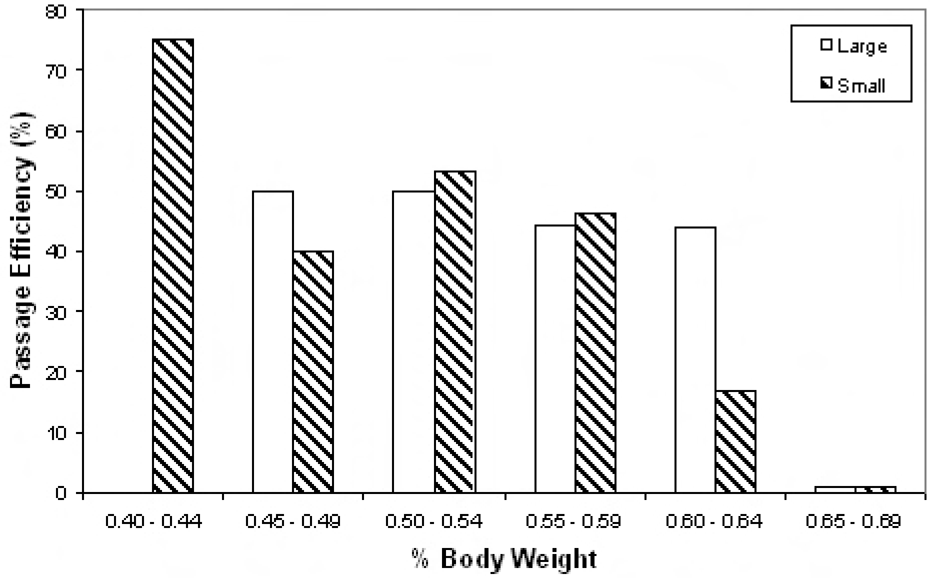

Figure 27. Passage efficiency (percent of lamprey that successfully passed over Bonneville Dam of those that approached the dam) of lamprey bearing small (hatched bars) or large (open bars) radio tags of increasing percentages of lamprey body weight.

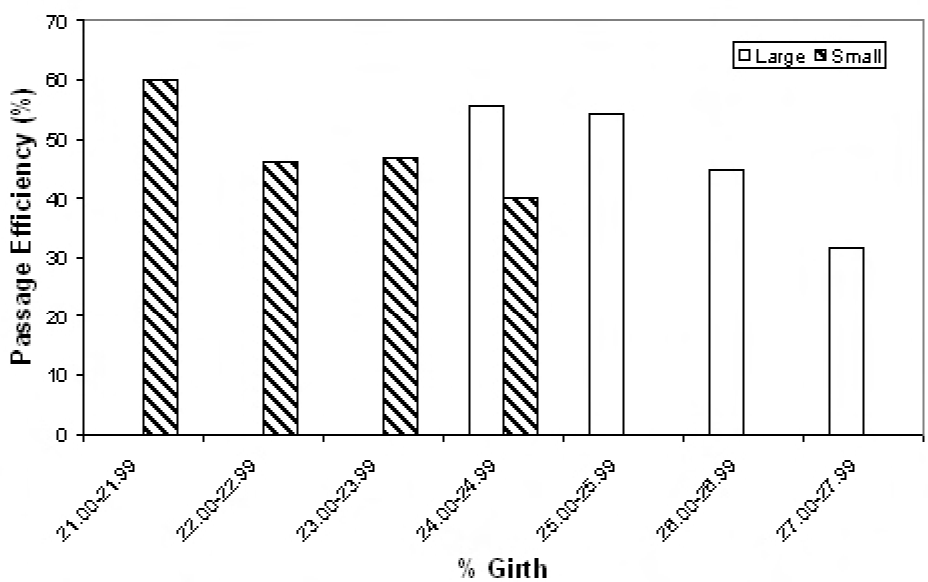

Figure 28. Passage efficiency (percent of lamprey that successfully passed over Bonneville Dam of those that approached the dam) of lamprey bearing small (hatched bars) or large (open bars) radio tags of increasing percentages of lamprey girth.

Median passage time at Bonneville Dam (i.e., the time from first detection at the base of the dam to last detection at the fishway exit) was 9.02 d (range = 0.26−46.22 d, SD = 11.34 d). We found no indication that either the percent body weight (Fig. 29) or the percent girth (Fig. 30) of the transmitters had any effect on the length of time lamprey required to pass through the fishways.

Of the 92 radio-tagged lamprey that passed over Bonneville Dam in 2002, only one was subsequently detected below the dam (i.e., it fell back over the dam). After initially passing over Bonneville Dam, this fish migrated to The Dalles Dam but did not approach any of the fishway entrances there. It then fell back downstream, over Bonneville Dam, and did not attempt to approach Bonneville Dam again.

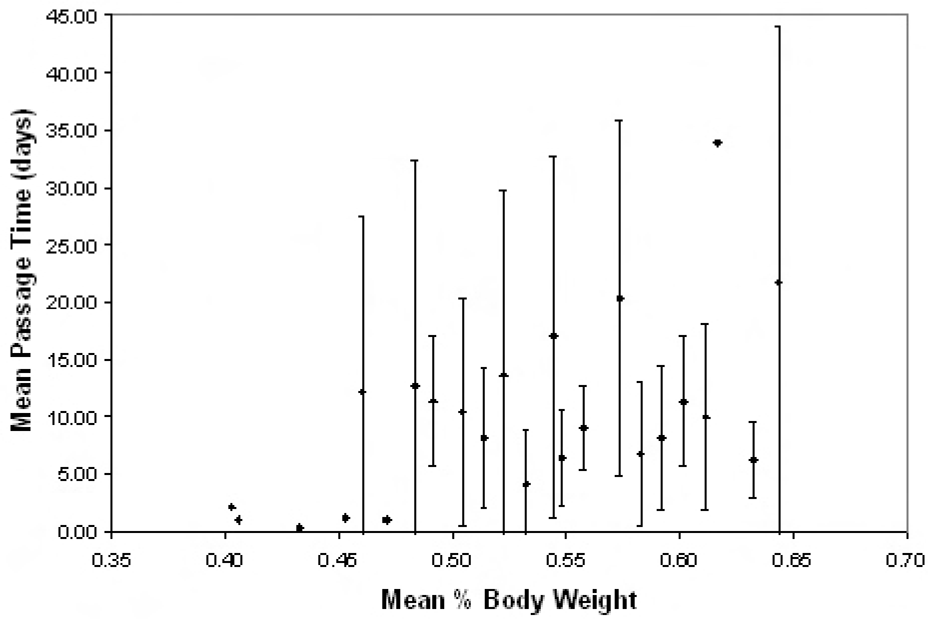

Figure 29. Mean time (error bars are standard deviation) from first approach to exit at the top of a Bonneville Dam fishway for lamprey bearing radio tags of increasing percent of their body weight.

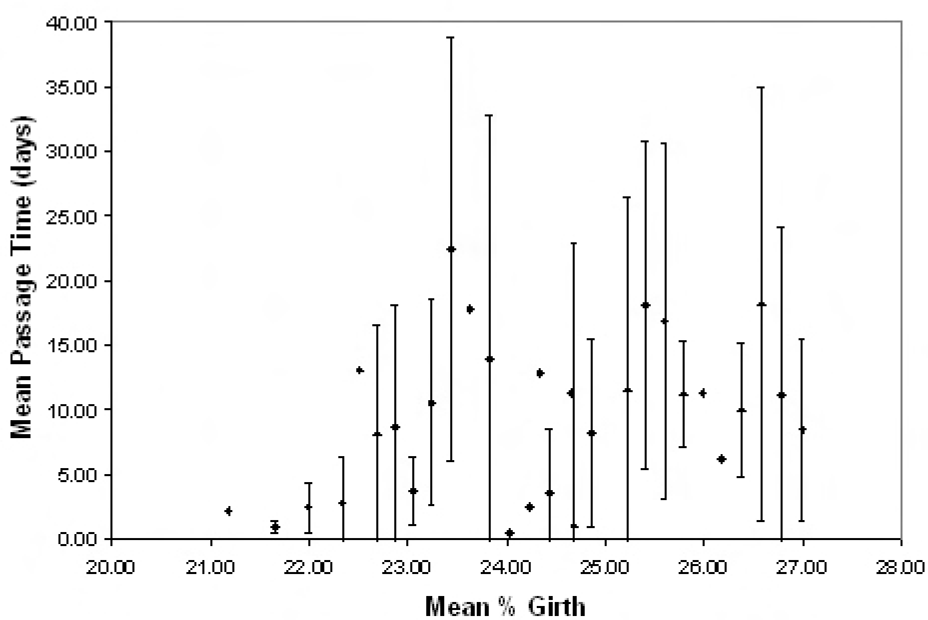

Figure 30. Mean time (error bars are standard deviation) from first approach to exit at the top of a Bonneville Dam fishway for lamprey bearing radio tags of increasing percent of girth.

The Dalles Dam

Of the 92 radio-tagged lamprey that passed over Bonneville Dam in 2002, we detected 73 in the vicinity of The Dalles Dam tailrace, and 70 of these were detected near fishway entrances at the dam. As in previous years, more lamprey approached the east fishway (n = 59) than the north fishway (n = 32) in 2002, but all of the lamprey that attempted to enter the north fishway were successful (Fig. 31). In contrast, entrance efficiency was low at the east fishway entrances (< 50% at each entrance) and represented a notable drop from levels recorded in 2000 and 2001 (Fig. 31).

Although entrance efficiency was 100% at the north fishway, fewer fish passed over the dam via this route (n = 18) than via the east fishway system (n = 28). This was likely due in part to a substantially lower passage success through the north fishway ladder (72%) when compared to previous years (>90%) (Table 3). As in other years, the transition areas in both fishways also had poor passage success relative to other parts of the fishways (Table 3).

Of the 70 radio-tagged lamprey that approached The Dalles Dam fishways, 46 passed over the dam, for an overall passage efficiency of 66%. Median passage time was 4.0 d (range = 0.60−35.65 d, SD = 6.43 d). Only one of the 46 lamprey that passed over The Dalles Dam was subsequently detected below the dam (i.e., fell back downstream). This fish made a second attempt to enter the fishways but was not successful.

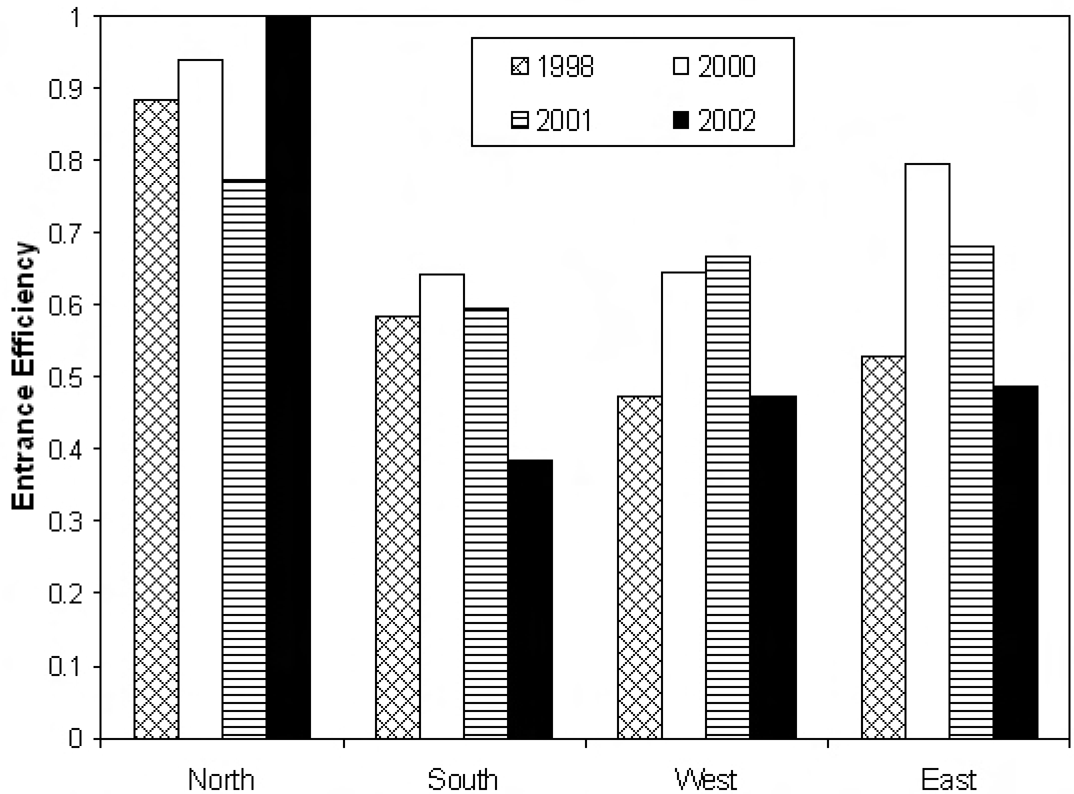

Figure 31. Entrance efficiency (the percent of lamprey that successfully entered of those that approached) for fishway entrances at The Dalles Dam in 1998 and 2000-02: the North Fishway entrance on the Washington shore (North), the East Fishway entrance at the south end of the spillway (South), the East Fishway entrance at the west end of the powerhouse (West), and the East Fishway entrance at the east end of the powerhouse (East).

Table 3. The number of radio-tagged lamprey that passed through each area within each fishway at The Dalles Dam in 1997, 1998, 2000, 2001, and 2002. Passage efficiency (number of lamprey that passed through the area/number that approached ×100) is in parentheses.

Area	1997	1998	2000	2001	2002
			East fishway		
Entrance	41 (85%)	22 (73%)	52 (87%)	71 (89%)	46 (78%)
Collection	34 (83%)	21 (95%)	47 (90%)	67 (94%)	43 (93%)
Transition	27 (79%)	12 (57%)	41 (87%)	52 (78%)	29 (67%)
Ladder	24 (89%)	12 (100%)	38 (93%)	50 (96%)	28 (96%)
Count station	24 (100%)	12 (100%)	37 (97%)	48 (96%)	28 (100%)
			North fishway		
Entrance	18 (67%)	15 (94%)	44 (94%)	34 (77%)	32 (100%)
Collection	14 (78%)	15 (100%)	42 (95%)	34 (100%)	32 (100%)
Transition	11 (79%)	13 (87%)	36 (86%)	24 (71%)	25 (78%)
Ladder	11 (100%)	12 (92%)	33 (92%)	22 (92%)	18 (72%)
Count station	11 (100%)	12 (100%)	33 (100%)	22 (100%)	18 (100%)

John Day Dam

Of the 46 radio-tagged lamprey that passed over The Dalles Dam in 2002, we detected 34 (74%) at the fishway entrances at John Day Dam. As in previous years, more lamprey approached the south fishway (n = 30) than the north fishway (n = 18). However, in contrast to most other years, lamprey exhibited greater entrance efficiency at the north fishway entrance than at the south fishway entrances (Table 4).

Overall passage efficiency at John Day Dam was 50% (17 of 34), with 11 fish passing via the south fishway and 5 passing via the north fishway. One fish passed through both fishways, using a different ladder after having fallen back downstream. As in previous years, lamprey had difficulty passing through the ladder section of the north fishway (Table 4). In the south fishway, lamprey attrition occurred throughout the collection channel, transition, and ladder areas (Table 4). Median passage time was 4.2 d (range = 0.48–5.00, SD = 4.68).

As in previous years, a relatively high percentage (35%) of the 17 fish that passed over John Day Dam fell back downstream over the dam. One of these 6 fish re-entered the fishway and fell back a second time, then re-entered but did not successfully pass on the third attempt. Only one fish re-entered and successfully passed over the dam a second time. Two of the remaining fallback fish did not re-approach the dam, and the remaining two fish entered the fishways a second time but did not successfully pass over the dam. Consequently, the effective passage efficiency at John Day Dam in 2002 was only 35%.

Table 4. The number of radio-tagged lamprey that passed through each area within each fishway at John Day Dam in 1997, 1998, 2000, 2001, and 2002. Passage efficiency (number of lamprey that passed through the area/number that approached × 100) is in parentheses.

Area	1997	1998	2000	2001	2002
			South fishway		
Entrance	20 (87%)	6 (60%)	48 (73%)	44 (96%)	26 (87%)
Collection	13 (65%)	6 (100%)	39 (81%)	41 (93%)	19 (73%)
Transition	13 (100%)	6 (100%)	30 (77%)	34 (83%)	15 (79%)
Count station	12 (92%)	6 (100%)	21 (70%)	34 (100%)	15 (100%)
Ladder	9 (75%)	4 (67%)	21 (100%)	23 (68%)	12 (80%)
			North fishway		
Entrance	3 (75%)	3 (75%)	18 (67%)	8 (73%)	17 (94%)
Collection	1 (33%)	3 (100%)	18 (100%)	8 (100%)	17 (100%)
Transition	0	2 (67%)	17 (94%)	6 (75%)	15 (88%)
Ladder	0	2 (100%)	7 (41%)	3 (50%)	6 (40%)
Count station	0	0	7 (100%)	3 (100%)	6 (100%)

Overall Passage Patterns

The passage efficiency at each dam was similar to 2001 results, with highest passage efficiency at The Dalles Dam (Fig. 32). As in 2001, we noted a slight decline in passage efficiency at The Dalles Dam and John Day Dam relative to 2000. However, Bonneville Dam passage efficiency in 2002 was slightly higher than in previous years (Fig. 32).

Median passage time at Bonneville Dam was 50% higher in 2002 than in 2001 (Fig. 33). This represented the greatest increase in passage time recorded to date at this dam. Similarly, we recorded passage times at The Dalles and John Day Dams in 2002 that were over twice as long as in previous years (Fig. 33).

Of the 12 fish that passed over the John Day Dam and into Lake Umatilla, 5 were detected in the tailrace of McNary Dam. Three of these lamprey never approached a fishway entrance and were not detected upstream from McNary Dam. The remaining two fish both successfully passed over the dam, one via the south fishway and one via the north fishway (Fig. 4). One of these fish was then detected passing over Priest Rapids Dam, Wanapum Dam, Rock Island Dam, and Rocky Reach Dam.

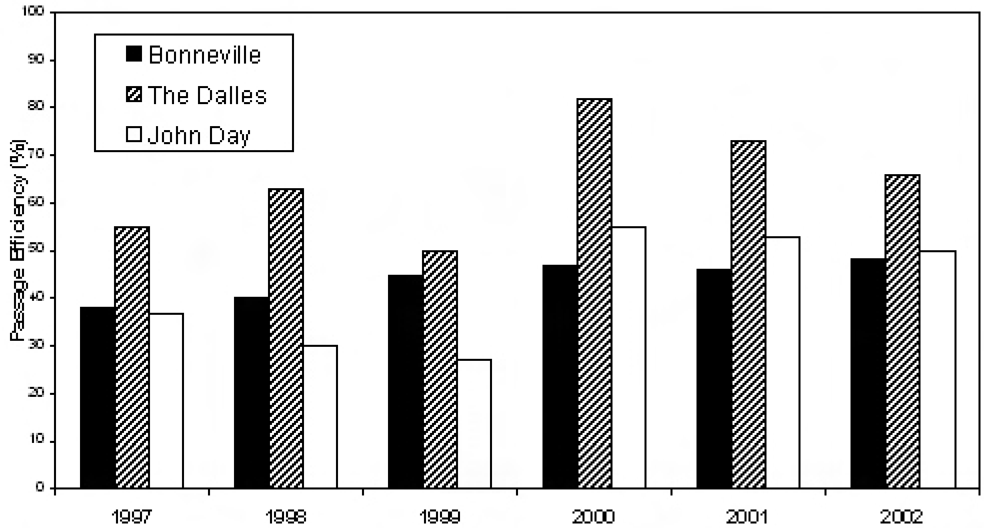

Figure 32. Overall passage efficiency (percent of lamprey that passed over each dam of those that approached each dam) for Bonneville, The Dalles, and John Day Dams in 1997-2002.

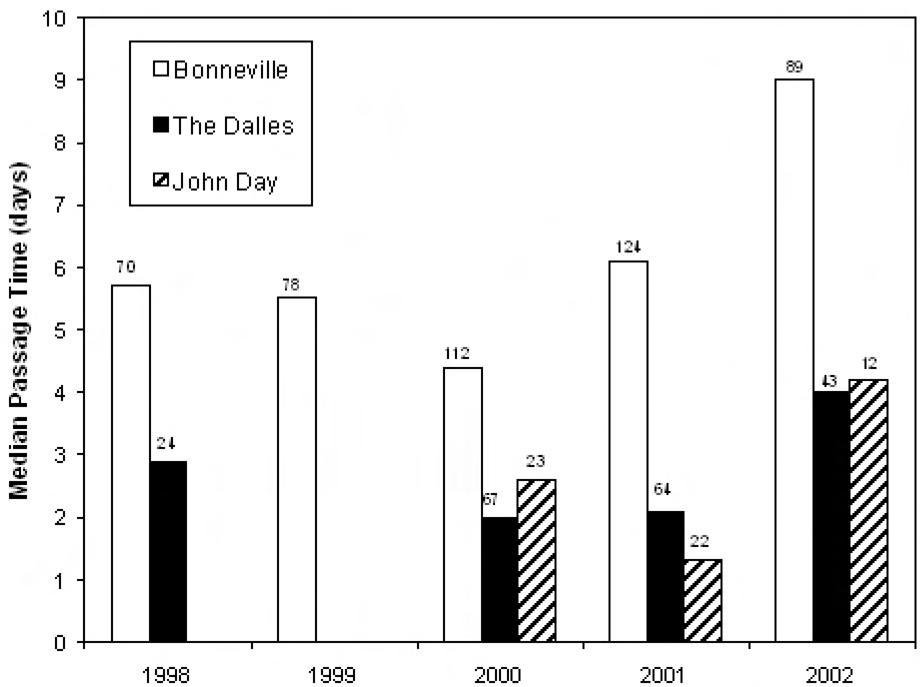

Figure 33. Median passage time (days from first detection outside a fishway entrance to last detection at the fishway exit) for fish that passed Bonneville, The Dalles, and John Day Dams in 1998-2002. Only fish with known times of first approach at an entrance and last exit into the forebay were included in this analysis.

Tributary Use and Seasonal Distribution

Receiving stations at the mouths of all major tributaries between Bonneville Dam and McNary Dam monitored lamprey entrances into each tributary. In 2002, we detected lamprey in the Deschutes and John Day Rivers. We found only two lamprey in the Deschutes River (which enters the Columbia River 20 km upstream from The Dalles Dam), and both of these fish were detected at Sherar's Falls (396 km from the mouth of the Columbia River, 68 km from the mouth of the Deschutes River). In addition, we detected one lamprey entering the John Day River (which joins the Columbia River 3 km upstream from John Day Dam).

From November 2002 to September 2003 (the 2003 tracking year), 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 45 (22%) of the lamprey tagged in 2002. The mean time at large (number of days between the last detection in the 2002 tracking year (May-October 2002) and the last detection after 31 October) was 166 d with a minimum of 19 d and a maximum of 290 d (Table 5).

The majority of fish that we detected in 2003 were within 2 km of their last location in 2002 (Table 5). The few fish that moved longer distances all moved downstream, except for fish 9-137. This individual was detected below Bonneville Dam in September 2002 and at the mouth of the Little White Salmon River in early April 2003. This fish was not detected on at Bonneville Dam in the time between these detections.

Of the 109 lamprey that were unable to successfully pass over Bonneville Dam, 46 (42%) were last detected either in the fishways or near fishway entrances. These fish were not subsequently detected downstream from the dam. The other 63 fish were either detected at tailrace receivers (located at rkm 232.3, near the release sites, Fig. 1) or during mobile tracking sessions.

In the summer of 2002, we conducted weekly surveys using a portable receiver from a vessel in the area downstream from Bonneville Dam to document the fates of lamprey that did not successfully pass over the dam. In addition, we conducted monthly surveys in this area from a vehicle during the winter and into the summer of 2003. Of the 36 lamprey that were detected during vessel surveys, 17 were detected more than once. A Global Positioning System (GPS) position was recorded each time a lamprey was located (Fig. 34). The lamprey we detected were distributed up to 30 km downstream from Bonneville Dam.

Table 5. The last date and location in the 2002 tracking year, the last date and location in the 2003 tracking year, time at large (days from last 2002 detection to last 2003 detection) and the distance (km) between 2002 and 2003 positions for each radio-tagged lamprey. All detections in both years were from channel 9.

	2002		2003		Time	Distance
Code	Date	Site	Date	Site	at large (d)	(km)
1	10/31/02	305	12/17/02	305	47	0
2	09/25/02	228	04/09/03	228	196	0
3	09/09/02	235	04/09/03	235	212	0
4	06/23/02	235	04/09/03	233	290	-2
22	09/24/02	DES388	04/08/03	DES388	196	0
26	09/22/02	232	03/12/03	235	171	3
29	08/18/02	235	11/04/02	207	78	-28
30	09/17/02	216	11/04/02	216	48	0
44	09/09/02	235	04/09/03	235	212	0
46	07/21/02	235	03/12/03	235	234	0
58	08/11/02	345	04/08/03	318	240	-27
66	09/09/02	235	03/12/03	235	184	0
68	09/24/02	329	04/08/03	330	196	1
73	10/31/02	347	11/19/02	347	19	0
74	08/06/02	347	04/08/03	347	245	0
75	08/26/02	235	01/16/03	229	143	-6
76	09/21/02	232	37738	232	220	0
83	09/09/02	234	02/13/03	235	157	1
86	09/17/02	230	03/12/03	228	176	-2
88	09/09/02	235	04/09/03	235	212	0
91	09/03/02	235	37781	235	281	0
99	09/08/02	347	37773	347	267	0
101	09/25/02	225	11/04/02	225	40	0
107	09/09/02	235	02/13/03	235	157	0
109	09/09/02	234	02/13/03	234	157	0

Table 5. Continued.

Code	2002 Date	2002 Site	2003 Date	2003 Site	Time at large (d)	Distance (km)
110	09/25/02	235	03/12/03	235	168	0
112	06/20/02	235	03/12/03	233	265	-2
115	07/27/02	235	12/11/02	235	137	0
137	09/10/02	228	04/09/03	271	211	43
139	07/26/02	467	02/13/03	426	202	-41
144	08/03/02	235	02/13/03	235	194	0
146	09/25/02	196	11/04/02	196	40	0
149	09/25/02	228	02/13/03	231	141	3
170	09/25/02	217	11/04/02	217	40	0
172	09/14/02	235	11/21/02	235	68	0
176	09/13/02	334	02/12/03	333	152	-1
181	07/21/02	232	11/04/02	217	105	-15
183	10/31/02	347	37711	347	152	0
184	09/09/02	235	03/12/03	235	184	0
187	09/09/02	234	04/09/03	234	212	0
188	09/17/02	214	03/12/03	213	176	-1
191	07/18/02	235	03/12/03	234	237	-2
192	09/09/02	234	03/12/03	235	184	1
204	09/09/02	235	04/09/03	235	212	0
212	10/31/02	347	11/19/02	347	19	0

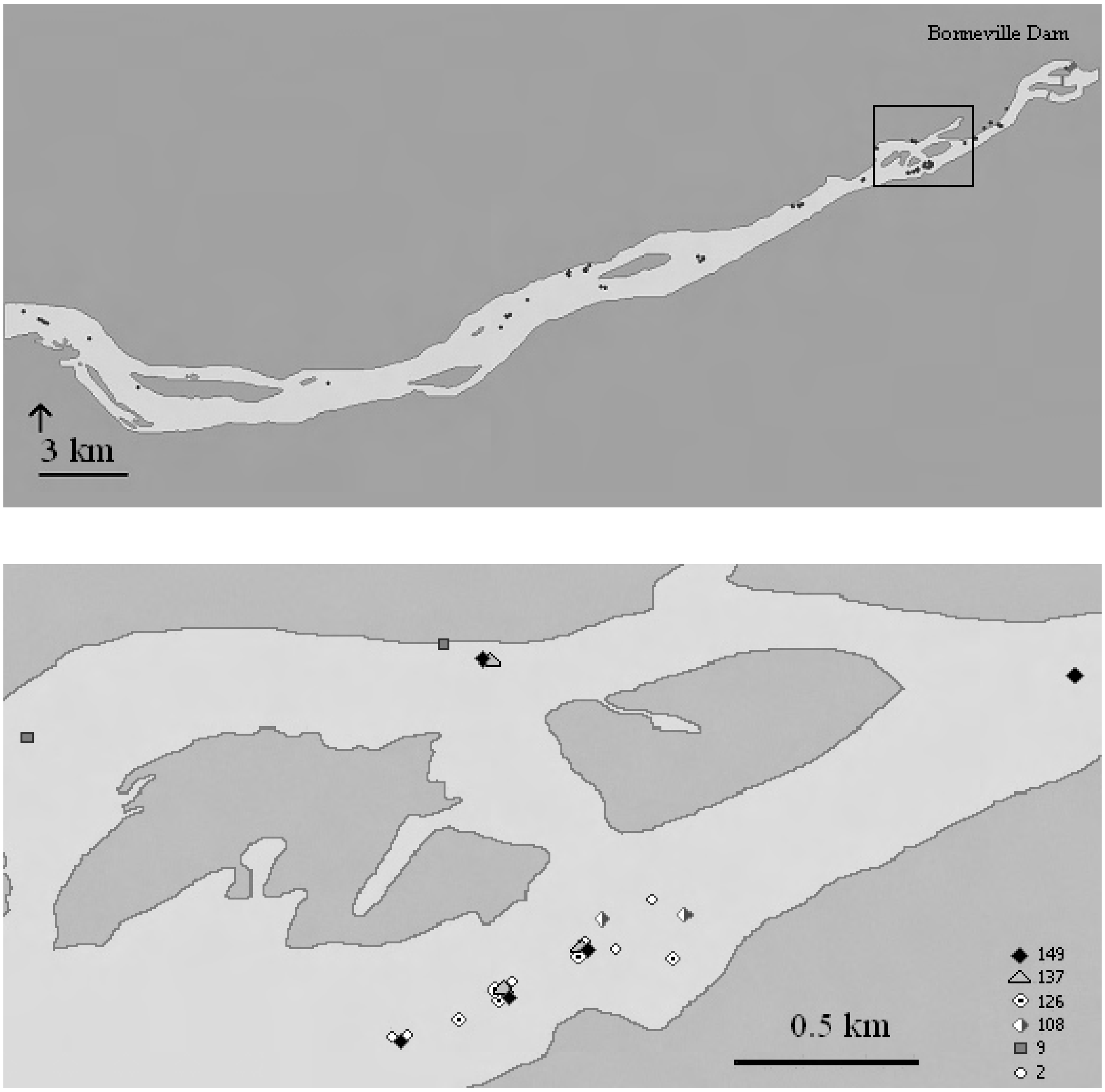

Figure 34. All positions of radio-tagged lamprey (black dots) obtained during tracking from a vessel in summer of 2002 (top panel) and an expanded view of individual lamprey positions in a 5-km area below Bonneville Dam (bottom panel).

Multiple detections of the same individual indicated that most lamprey did not move far between detections (Fig. 34). Some individuals were detected over 1 km from their previous location; however, others moved less than 0.5 km between detections. Due to error associated with determining lamprey positions with the portable receiver (±0.5 km), it is possible that these individuals were not moving and could have been dead. Interestingly, one lamprey was detected in the mouth of the Washougal River at the end of the summer, but this fish was not subsequently detected in either vessel or vehicle surveys. We surveyed the Willamette River from both vehicles and vessels during the course of this study, but no lamprey were detected.

Bypass Evaluation

Bypass structures were evaluated from 10 July to 19 September 2002. We caught a total of 346 lamprey during these experiments. Mean daily CPUE was highest for the closed tube without attraction flow (0.77 lamprey/hour, Fig. 35) and lowest for the open ramp oriented upstream (Fig. 35).

In each week of testing, marked lamprey were introduced directly into the MWC for a total of 272 marked fish during the closed-tube trials and 246 during the open-ramp trials. Only two of these marked fish were recovered in the bypass trap, both during the closed-tube trials. Consequently, estimates of collector efficiency based on the mark-recapture experiment were not possible.

Based on radiotelemetry, 35% of lamprey that passed the Bradford Island counting station would have been counted (the remainder passed during the night when counts were not made). Of fish that passed the counting station, 4% entered the MWC. During closed-tube trials, we estimated that 1,312 lamprey were in the MWC (based on adjusted Bradford Island count data). We caught a total of 182 lamprey using the closed-tube collector (13.9% of those in MWC). Based on the Bradford Island count data, we estimated that there were 892 lamprey in the MWC during the tests using the open ramp and that 164 (18.4%) of these were caught.

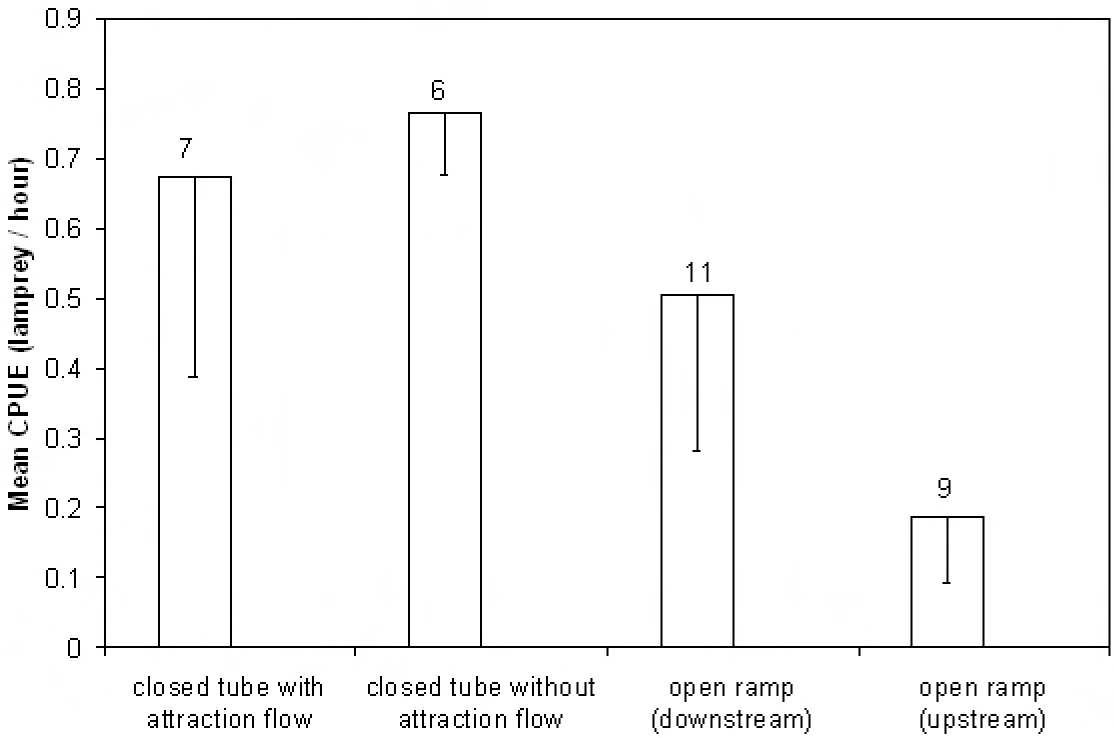

Figure 35. Mean catch per unit effort (CPUE) of lamprey collected at the trap box for each bypass treatment (closed tube bypass with and without attraction flow and open ramp bypass oriented both downstream and upstream). Error bars indicate standard deviation and the numbers above each bar are the number of replicates for that treatment.

DISCUSSION

The number of lamprey counted at Bonneville Dam in 2002 was over four times higher than the number counted in 2001 (Fig. 36). This increase was reflected in our increased CPUE at the Washington-shore trap. In addition, more lamprey were likely available to the trap because more lamprey used the PH2 fishway system in 2002 than either the fishways at PH1 or the spillway.

At Bonneville Dam in 2002, priority for power generation was at PH2. As in 2001 (when PH2 also had priority), more lamprey were initially attracted to the Washington-shore fishway entrances and more fish passed the dam via this fishway. However, as in previous years of study, passage efficiency was lower at PH2 fishways than at PH1. Consequently, it appears that PH2 priority operation may function to reduce overall passage efficiency at Bonneville Dam by attracting lamprey into fishways where they are less successful.

Interestingly, the percentage of lamprey that initially approached Bonneville Dam spillway entrances in 2002 did not differ much from 2001, even though there was more spill in 2002 than in 2001 (DART 1995). Moreover, the entrance success of lamprey at individual spillway entrances in 2002 was the same or higher than in previous years. We speculate that the attraction flow created by spill and the effects of spill on conditions near spillway entrances do not dictate lamprey behavior when approaching and attempting to enter fishways at the spillway. Data from 2002 provide further support for the observation that lamprey entrance efficiency was improved when the spillway bulkheads were rounded in 2000-01 (Moser et al. 2002a, 2003).

In 2002, the orifice gates at PH1 were open for the entire tracking season, whereas they were closed intermittently in 2000 and 2001. We noted that passage efficiency through the PH1 collection channel was lower in 2002 than in previous years. This may have resulted because lamprey were able to exit the collection channel more easily in 2002 via the open orifice gates. While we were unable to document negative impacts of orifice gate closure in 2000 and 2001, the 2002 results indicate that orifice gate closure could have a positive effect on lamprey passage.

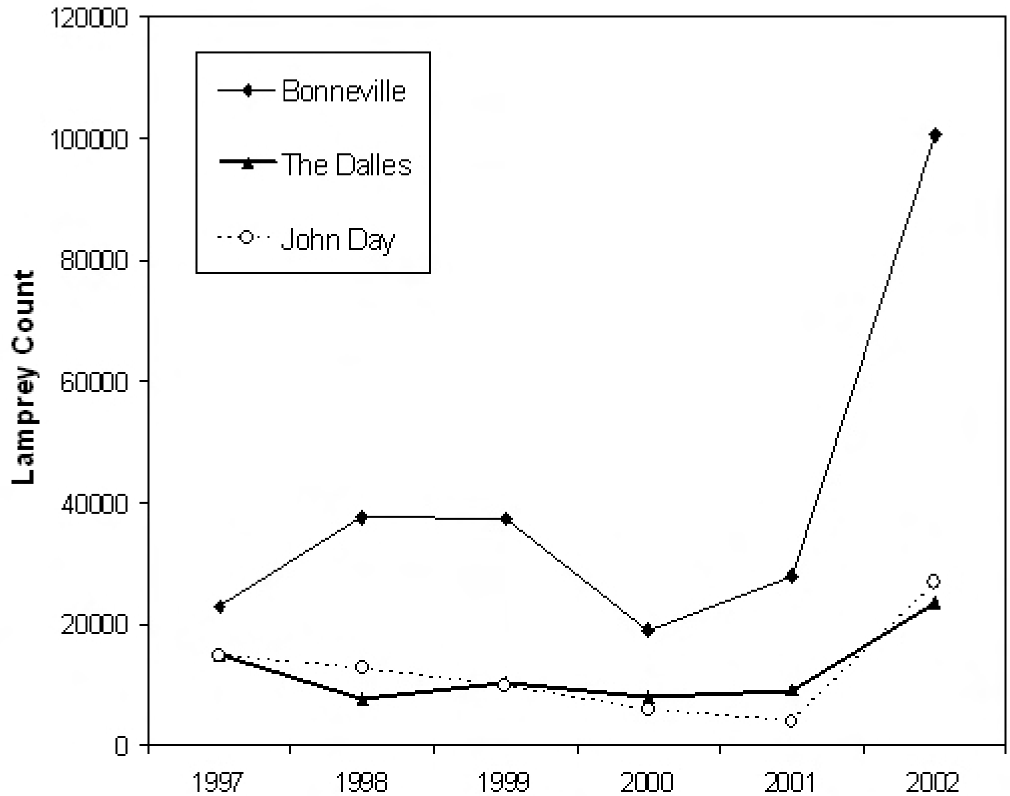

Figure 36. The number of lamprey counted at Bonneville Dam, The Dalles Dam, and John Day Dam count stations in 1997-2002 (USACE 1997, 1998, 1999, 2000, 2001, 2002).

We continued to test the addition of attachment plates at the PH2 transition area in 2002. The results from this work were equivocal. In 2001, plates were added over grating in the floor between the downstream-most weirs in the PH2 fishway. This resulted in a modest improvement in lamprey passage through this area in 2001 (Moser et al. 2003). However, in 2002 lamprey passage through this area returned to pre-attachment plate levels.

Video observations also indicated that lamprey did not use the attachment plates in their current configuration (R. Stansell, U.S. Army Corps of Engineers, personal communication). It is possible that lamprey did not find the plates because they tend to move along the walls of the PH2 transition area, rather than in a line down the center of the orifice openings (the location of the attachment plates). Any further examination of the use of attachment plates should include testing of attachment plates that allow lamprey to attach near the walls of the fishway, in addition to providing attachment surfaces in and directly upstream from orifice openings.

In 2002 we examined lamprey behavior through the top of the ladders at Bonneville Dam in great detail. Lamprey tended to fall back at the upstream-most serpentine weirs at both the Washington-shore and Bradford Island fishways. While there was no evidence that lamprey were more likely to fall back at straight slot than at angled slot weirs, we did find that lamprey took longer to negotiate the angled slots than the straight slots. In addition, lamprey that did not successfully exit the fishways exhibited longer holding times in the serpentine weir area than those that passed successfully. This was particularly obvious at both the angled and straight weirs that were farthest downstream.

Of the 201 lamprey that we released below Bonneville Dam, 109 did not pass over the dam. Of these, 42% were last detected either at a fishway entrance or in the Bonneville Dam fishways. The fate of these fish is unknown. The remaining fish were last detected as they passed tailrace receivers or during mobile tracking surveys. Lamprey that were detected multiple times did not move appreciably between detections; however, it is impossible to know whether these fish were alive. One of these fish was detected above Bonneville Dam in 2003. We had no other evidence that the radio-tagged lamprey attempted to pass over the dam in their second summer.

As in previous years, we found that radio-tagged lamprey entered the MWC and held there for extended periods. In 2002, we designed and tested two prototype bypass collectors at the Bradford Island MWC: a closed tube collector and an open ramp collector. In preliminary testing, we found that providing attraction flow at the closed tube did not improve its efficacy. We also learned that a downstream orientation of the open ramp collector resulted in higher lamprey use than an upstream orientation.

The bypass collectors that we tested showed great promise, with as many as 50 lamprey collected per night of operation. Moreover, we estimated that as many as 18% of the lamprey in the MWC could be trapped using collectors of this type. Further testing and refinement are needed to improve the performance of these devices. In addition, improvements to the tag recapture methods are needed to provide better measures of collector efficiency. Many marked fish released in the MWC were later observed at the Bradford Island count window, indicating that they were are not staying in the study area, thereby reducing the probability of recapture. Improvements to methods for releasing the fish into the MWC may result in better retention of fish in the study area.

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