Migration Patterns of Pacific Lamprey *Lampetra tridentata* in the Lower Columbia River, 1997

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EXECUTIVE SUMMARY

The Pacific lamprey (*Lampetra tridentata*) population, like that of other northwest anadromous fish species, has significantly declined in recent years. Study of adult migration patterns past dams and reservoirs in the Columbia River Basin may provide some insight into factors that have affected or limited Pacific lamprey survival. Radiotelemetry has been used to determine migrational behavior for many anadromous fish species; however, we are unaware of its use in Pacific lamprey studies.

In 1997, we evaluated passage patterns of upstream-migrating radio-tagged Pacific lamprey in the lower Columbia River. Objectives of this study were to determine 1) return time from the release sites back to Bonneville Dam, 2) passage routes and behavior at the dam, and 3) migration rates through reservoirs.

Adult Pacific lamprey were captured in the entrance fishway of the Fisheries Engineering Research Laboratory (FERL) at Bonneville Dam utilizing a trap designed by the National Marine Fisheries Service. A total of 834 adult Pacific lamprey were captured, and catch per unit effort was 1.9 fish per hour.

Radio tags were surgically implanted into the body cavity of 197 Pacific lamprey. A total of 147 tagged lamprey were released at two downstream locations: Dodson, Oregon, and Skamania Landing, Washington. The remaining 50 fish were released above Bonneville Dam at either Cascade Locks, Oregon, or Stevenson, Washington. Mobile tracking of Pacific lamprey downstream from Bonneville Dam was done by boat, motor vehicle, and foot.

Results indicated that 138 of the 147 tagged lamprey released downstream from Bonneville Dam were detected at the dam and at tailrace sites one mile below the dam. Of those lamprey, 47 were detected at the top of fish ladders at Bonneville Dam. There were 33 lamprey released below Bonneville Dam that were detected upstream at The Dalles Dam. Of the 50 lamprey that were released above the dam, 38 were detected at The Dalles Dam.

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INTRODUCTION

Populations of Pacific lamprey (*Lampetra tridentata*), like those of other northwest anadromous fish species, have significantly declined in abundance in recent years (Close et al. 1995). Study of adult migration patterns past dams and reservoirs in the Columbia River Basin may provide some insight into factors that have affected or limited Pacific lamprey survival. Mark and recapture studies cannot provide complete descriptions of the movement of free-ranging fish; thus the development of radio transmitters for evaluation of fish behavior provides the possibility for continuous monitoring without recapture (Hart and Summerfelt 1975). Radiotelemetry has been used to determine migrational behavior for many anadromous fish species; however, we are not aware of studies using radiotelemetry to determine the migrational behavior of adult Pacific lamprey.

In 1996, The National Marine Fisheries Service (NMFS), the Idaho Cooperative Fish and Wildlife Research Unit (UI), and the U.S. Army Corps of Engineers (COE) initiated a study of passage behavior and passage patterns of Pacific lamprey approaching and passing Bonneville Dam. Work in 1997 was a continuation of those studies. We determined return time of tagged lamprey from release sites to Bonneville Dam, passage routes at Bonneville Dam, and migration rates through reservoirs.

The Pacific lamprey's distribution ranges from the Aleutian Islands to Baha California and Hokkaido, Japan. In the Columbia and Snake River Basins, the Pacific lamprey was once present in all waters where salmon and steelhead could be found (Simpson and Wallace 1978). Currently the distribution of Pacific lamprey is limited to the waters below Chief Joseph Dam on the Columbia River and below Hells Canyon Dam on the Snake River (Close et al. 1995). Both of these dams lack adult fishways for passage. Kan (1975) suggests that access to available habitat rather than distance from the ocean is the critical factor in the distribution of lamprey. In this study, we looked at ways in which dams may be affecting Pacific lamprey access to spawning habitat.

METHODS AND MATERIALS

Trapping and Tagging

Pacific lamprey were collected from the fishway entrance at the Fisheries Engineering Research Laboratory (FERL) at Bonneville Dam. We utilized a trap in the third plunge pool just above the third weir crest of the entrance fishway (Fig. 1). The original design of the trap was modified to avoid blockage of the fishway during adult salmonid trapping operations. After the trap had been fished overnight, Pacific lamprey were removed and put into a 75.7-L transport bucket (25 L of water). Fish were then placed in a 1.8- by 0.9- by 0.6-m holding tank prior to selection for tagging.

A total of 834 Pacific lamprey were caught, and 197 of these were randomly selected for tagging. All fish selected for tagging were anesthetized using tricaine methanesulfonate (MS-222), examined for injuries and sexual maturity (if possible), measured, and weighed. Adult Pacific lamprey were anesthetized with a 0.06-g/L anesthetic solution. The anesthetic tank was 0.4 by 0.4 by 1.0 m, with 45 L of anesthetic solution. Surgical procedures were similar to those used in 1996 (Vella et al. In prep.). After examination and tagging, fish were placed in a recovery tank with aerated fresh water and allowed to regain equilibrium.

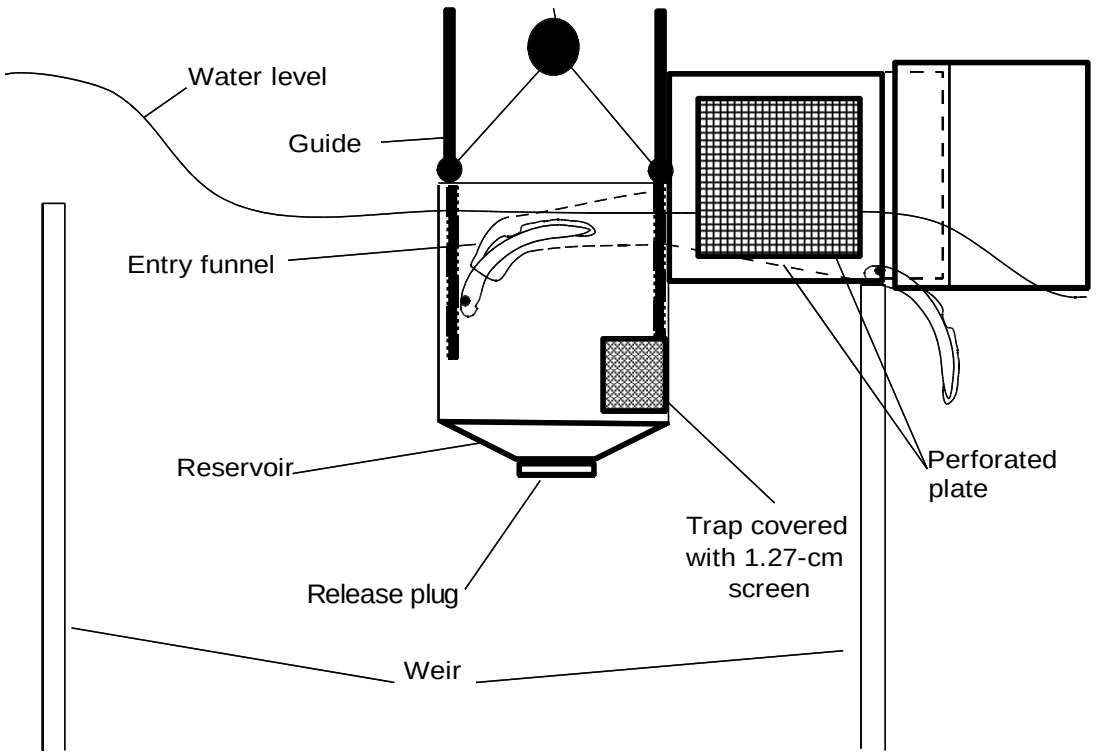

Figure 1. Side view of lamprey trap used at Bonneville Dam, 1996 and 1997.

Radio Transmitters

Tags were manufactured by Lotek Engineering Inc.[1] of Newmarket, Ontario, Canada. The tags were sealed in an epoxy capsule, 4.3-cm long by 0.9-cm diameter; each tag weighed 7.0 g in air and had a 20-cm-long external antenna attached to one end. The water weight of the tag did not exceed 1-1.25% of the fish dry weight, as recommended by Winter et al. (1978).

Surgical Implant

Surgical techniques were similar to those described by Hart and Summerfelt (1975), Reinert and Cundall (1982), Ross (1982), and Mellas and Haynes (1985). Surgical procedures were similar to those used for evaluation of tagging techniques in 1995 (Bjornn et al. 1996). Surgical tools and transmitters were sanitized in a solution of benzalkonium chloride. The tag was implanted into the body cavity through a 4- to 5-cm incision in the mid-ventral body wall. A cannula was used to thread the antenna of the radio-tag subcutaneously to an exit site anterior to the cloaca. Individual stitches with a 19-mm, FS-1 quarter-round cutting needle and absorbable polydioxanone monofilament suture were used to close the incision. Baciguent and Betadine were applied to the suture area and antennae exit to prevent infection.

Release Sites

Lamprey were released at four sites: two below Bonneville Dam and two above the dam. The two release sites below Bonneville Dam were on the north shore at Skamania Landing, Washington (River Kilometer (RKm) 225.7), and on the south shore at Dodson, Oregon (RKm 225.6). Release sites above the dam were at Stevenson, Washington (RKm 242.2), on the north shore and Cascade Locks, Oregon (RKm 239.1), on the south shore.

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[1] Reference to trade names does not imply endorsement by NMFS.

Antenna and Receiver Locations

A total of 93 antennas were installed at Bonneville Dam (Fig. 2). Nine-element air antennas were placed at two downstream fixed sites, one on the south shore at Tanner Creek (RKm 232.3) and one on the north shore at Hamilton Island boat launch (RKm 231.2). Three other air antennas were placed at Bonneville Dam, one at the entrance to the new navigation lock and two on the north and south sides of the forebay above the spillway. Air antennas were utilized to cover a distance of up to 0.4 kilometers on level ground but were limited in detecting tags below 9.1 m in water. Underwater antennas were placed at all the large openings to and inside the fishways and collection channels of both Powerhouse I and Powerhouse II, at the spillway entrances, and at the exits to the fish ladders. Underwater antennas detected radio-transmitted fish within a range of approximately 9 m in all directions. Appendix A contains a detailed list of antenna locations.

These antennas were connected to 26 receivers manufactured by Lotek Engineering. Each receiver was programmable and could detect radio transmitters on 25 different frequencies and up to 150 individual codes. Two types of receivers were utilized. First, the SRX-400, which scanned each frequency at 6-second intervals and stored up to 128 KB of data in 7 or 8 data banks (these receivers were used at single-antenna sites, such as downstream sites below the dam). The second receiver was the SRX-500 Digital Spectrum Processor (DSP), which was used in tandem with the SRX-400 and which allowed for multiple detections at a fixed site. The DSP was also used with the ASP-8 multiple-antenna switching unit, which allowed for monitoring up to eight different antennas simultaneously. Thus, a combination of the ASP-8, SRX-500, and SRX-400 at a fixed site with multiple antennas was able to monitor up to eight different antennas and 25 separate frequencies simultaneously. In comparison, the SRX-400, with one antenna scanning 25 separate channels, would take 2.5 minutes to scan all channels given its 6-second scan interval.

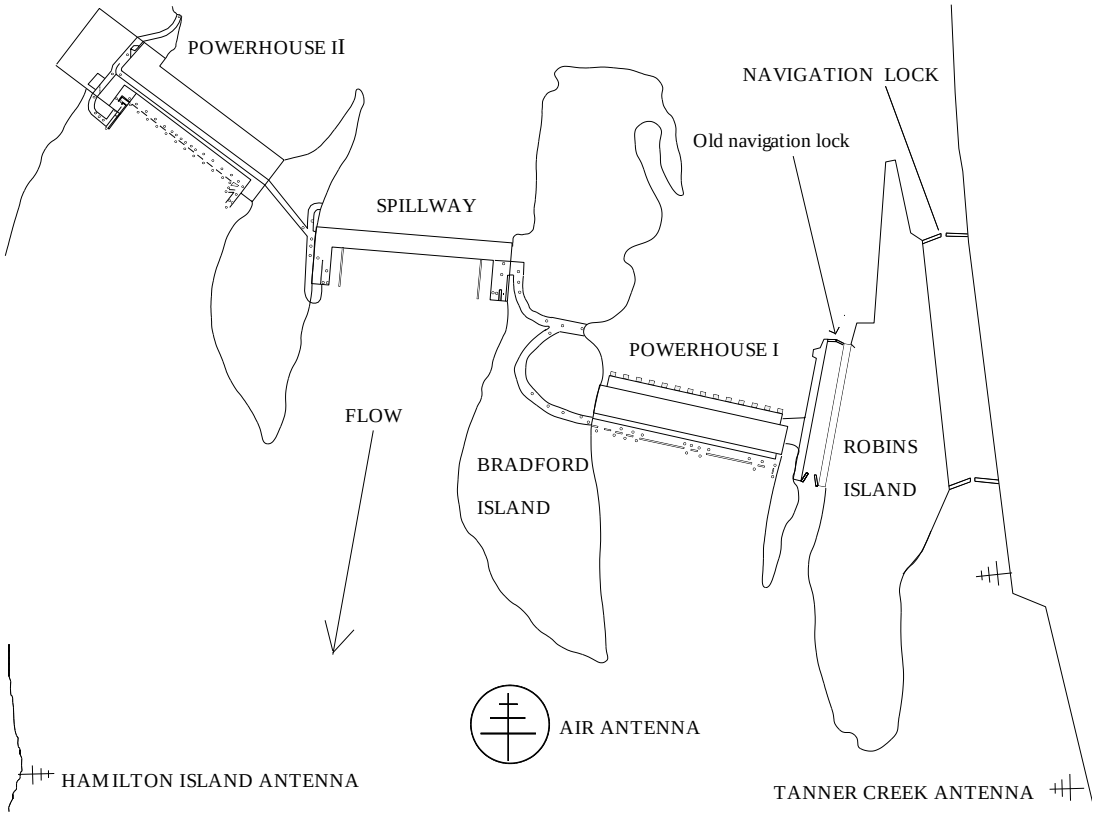

Figure 2. Bonneville Dam study area.

RESULTS AND DISCUSSION

In 1997, we captured 834 adult Pacific lamprey with our trap in the entrance fishway to the FERL at Bonneville Dam. We fished the trap between 2100 and 0800 hours for 44 days, from 19 May to 29 July, for a total of 428.9 hours during the study. These hours of operation were chosen because these were the times during which trapping effort for adult Pacific lamprey was most productive. The catch per unit effort for trapping was 1.9 fish per hour.

A total of 197 adult Pacific lamprey were randomly selected from those captured and were surgically implanted with radio transmitters. All adult Pacific lamprey selected to be tagged had a total body weight of at least 450 g. There were 147 radio-tagged Pacific lamprey released downstream from Bonneville Dam. Of fish released downstream from the dam, 47 (32.0%) were detected at the top of the Bonneville Dam fish ladders, compared to only 16 (18.8%) that passed the dam in 1996 (Vella et al. In prep.)(Table 1).

Table 1. Detections of radio-tagged Pacific lamprey at Bonneville Dam ladder exits.

Year	Total Released	Total Passed (% release)	Left	Right
1996	85	16 (18.8)	8	8
1997	147	47 (32.0)	23	24

Fish length, release date, sex, release location, and travel time to the downstream monitors were analyzed for insights regarding the lack of upstream movement by Pacific lamprey. Lengths of fish ranged from 61 to 79.5 cm. Radio-tagged Pacific lamprey that did not return to Bonneville Dam were spread across the length range of detected fish (Fig. 3). This indicated that tagging effects were not specific for a particular size of fish. Pacific lamprey released downstream that did not return to Bonneville Dam were also spread across the entire range of tagging dates, which began 20 May and ended 30 July (Fig. 4). This indicated that the lack of movement upstream was not caused by incorrect tagging procedures early in the season as compared to later.

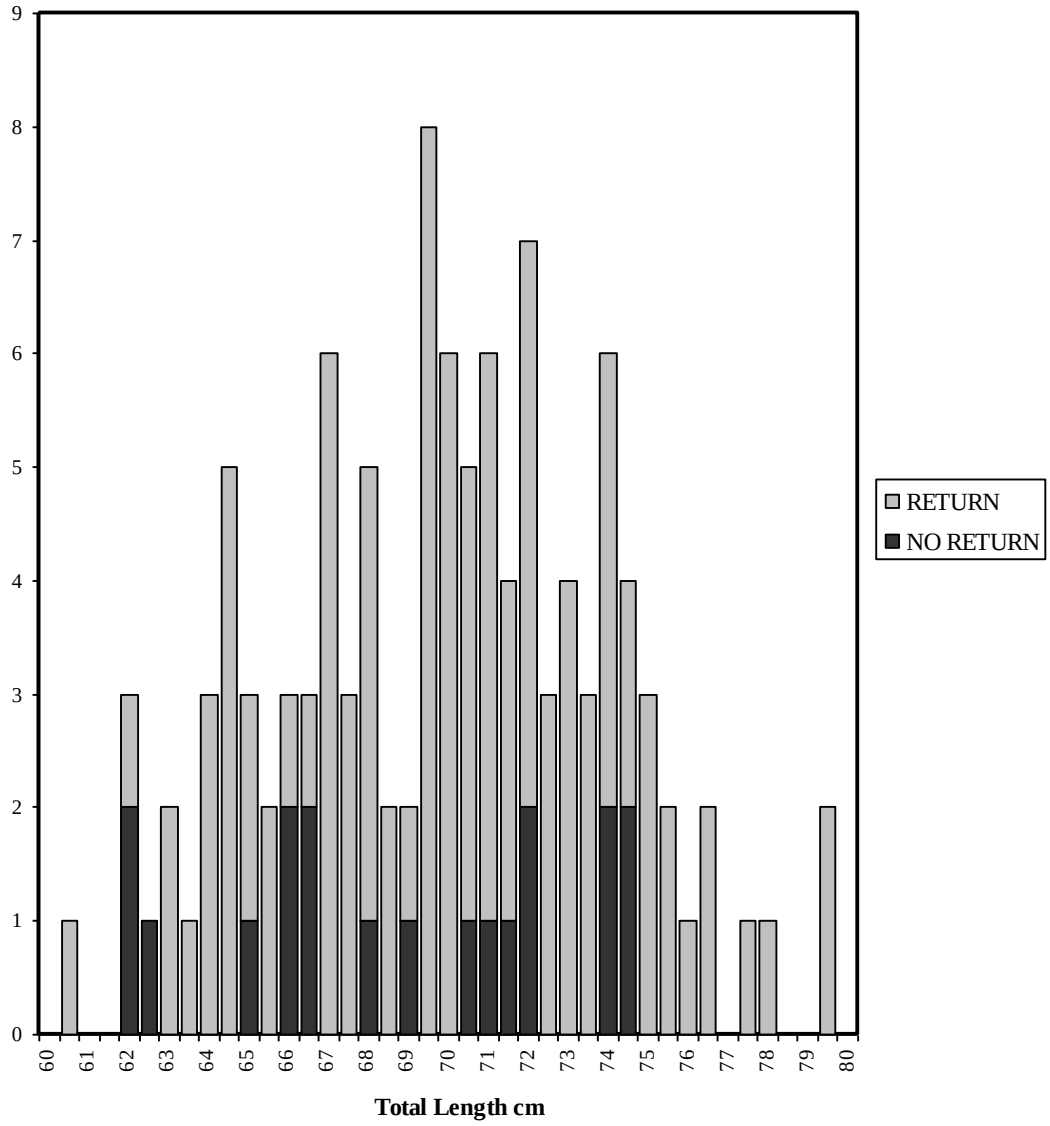

Figure 3. Number of radio-tagged Pacific lamprey returning to Bonneville Dam based on total length.

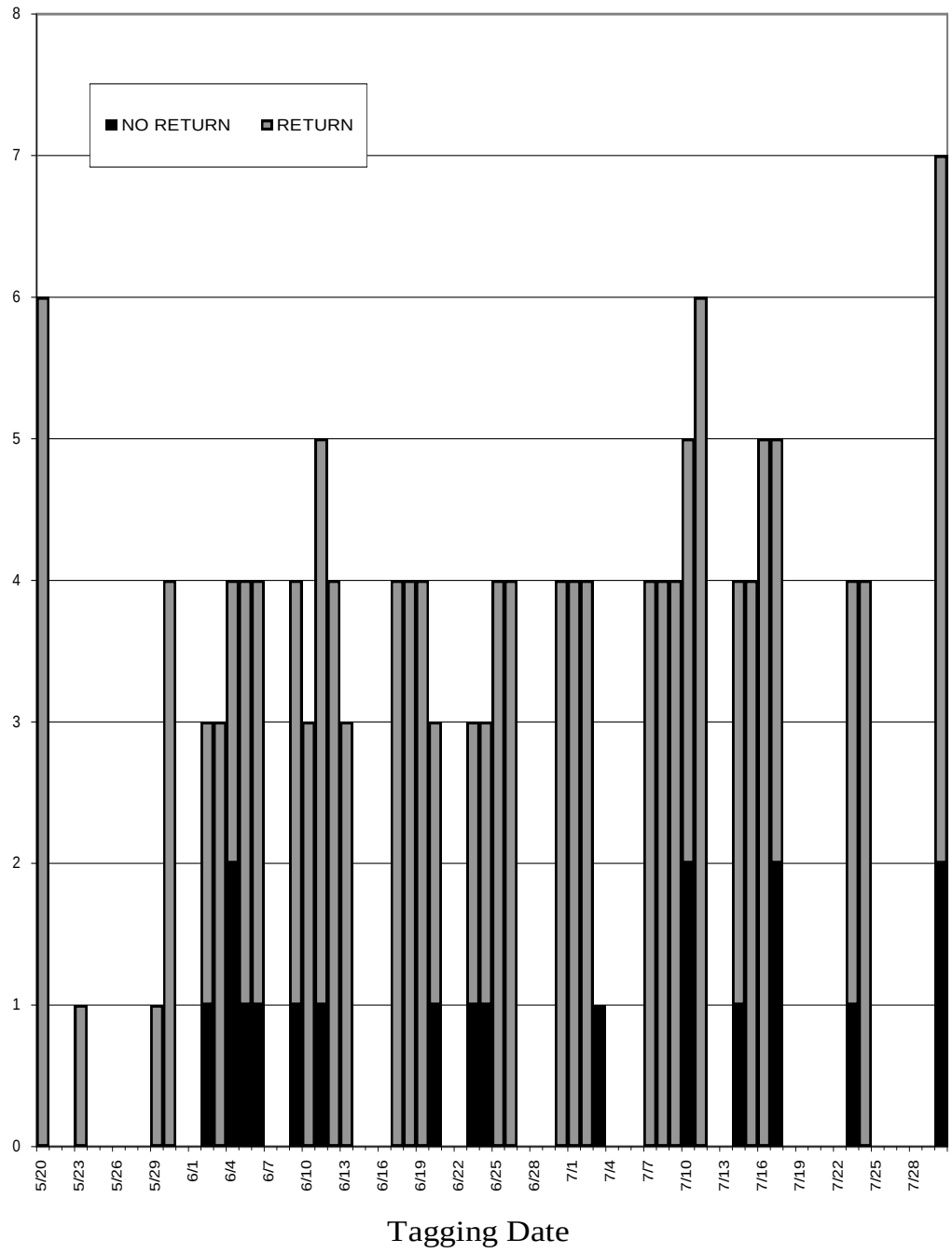

Figure 4. Number of radio-tagged Pacific lamprey returning to Bonneville Dam based on tagging date, 1996.

There was no difference in return rates to Bonneville Dam based on release location (chi-square = 0.498, *P* = 0.480, Table 2). This indicated that the release sites were not affecting the migration behavior of radio-tagged lamprey.

Table 2. Fate of radio-tagged Pacific lamprey released downstream from Bonneville Dam based on release site.

Fate	Dodson	Skamania
Returned to Bonneville Dam	65	63
No Return	8	11

The sexing of lamprey was undetermined for a large portion of fish that were released downstream. No males were identifiable during the tagging procedure. Pacific lamprey whose sex was undetermined were grouped together, and females were grouped together based on the presence of eggs in the body cavity (Table 3). The chi-square value comparing fish that did not return to Bonneville Dam to those that did was 1.016 (P = 0.314). This indicated that there was no difference in migration behavior based on sexual maturity of the fish.

Table 3. Fate of radio-tagged Pacific lamprey released downstream from Bonneville Dam based on sex.

Fate	Unidentifiable	Female
Returned to Bonneville Dam	65	63
No Return	12	7

The travel time from release to first arrival at the downstream monitor was available for 9 of the 20 fish that did not return to Bonneville Dam. The median travel time for these fish was 17.0 days, while median travel time for fish that did return to Bonneville Dam was 5.6 days (records available for 118 of 127 lamprey). The lack of records on 11 of the tags released downstream from Bonneville Dam could suggest predation, downstream movement, or tagging-related mortality in these fish.

Lamprey arrivals at Bonneville Dam in relation to flow are shown in Figure 5. The first arrival of radio-tagged Pacific lamprey at Bonneville was 1 June, just before the flows were at their highest levels. The majority of fish returned to Bonneville Dam between 28 June and 31 July, during the period after high flows, with the largest number (8) returning to the dam on 29 June. Flows between 1 June and 23 August, the period when radio-tagged lamprey were returning, ranged from 5.6 to 15.8 Kcms with a median flow of 8.49 Kcms.

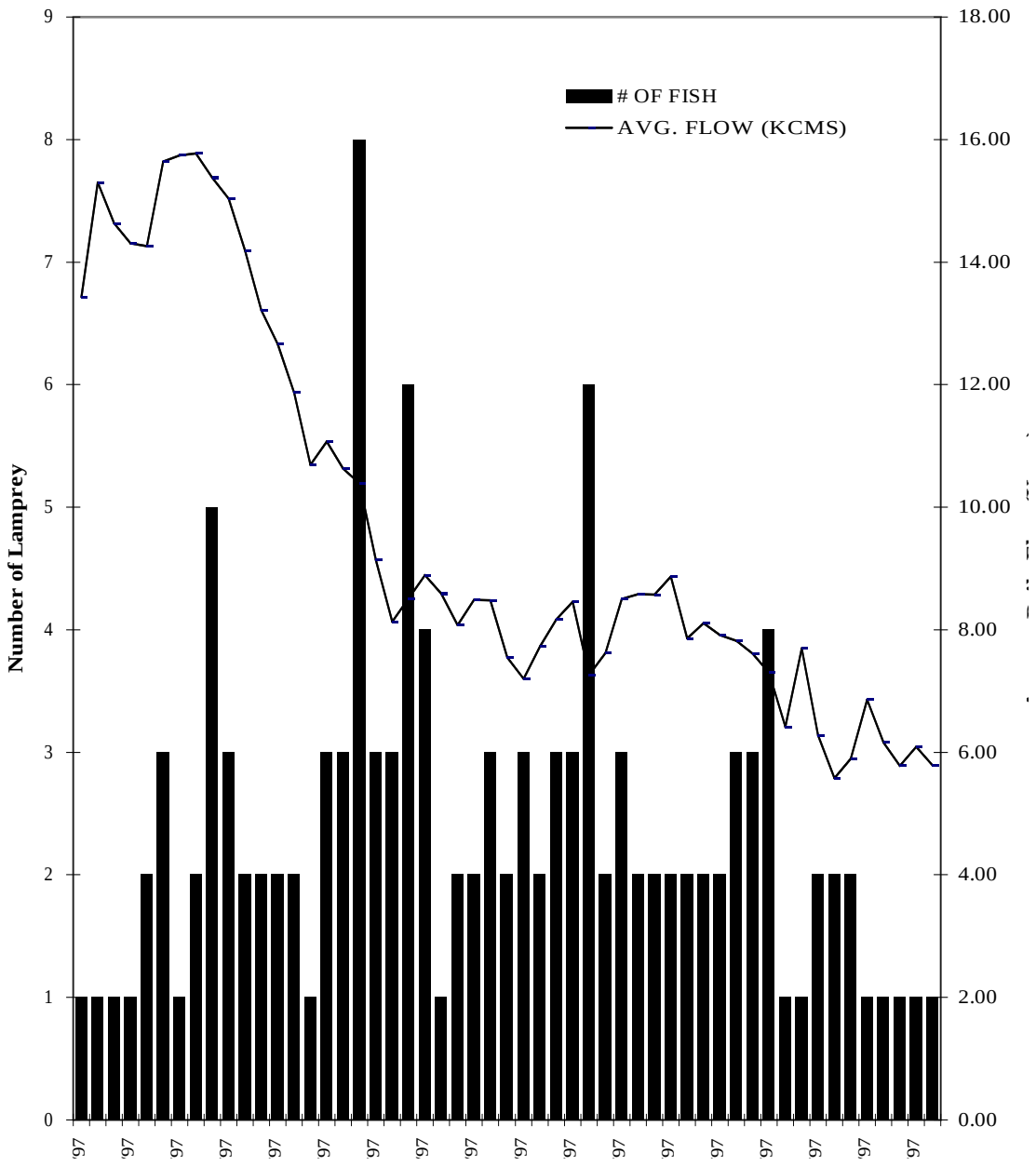

Figure 5. Number of radio-tagged Pacific lamprey returning to Bonneville Dam compared to the average daily flow on the day of arrival.

The total number of fish detected on monitors at Bonneville Dam was 127 (86.4% of the total release). These fish were placed in the following four groups, based on the upstream distance they traveled:

Group 1, Pacific lamprey that migrated to Bonneville Dam (30 detected at dam, 20.4% of the total release);

Group 2, Pacific lamprey that migrated into the collection channel (24 detected in channel, 16.3%);

Group 3, Pacific lamprey that migrated into the fish ladders (26 detected at ladder, 17.7%); and

Group 4, Pacific lamprey that migrated past the dam (47 detected upstream from the dam, 32.0%).

Pacific lamprey in Group 1 took between 0.04 and 12.2 days to reach Bonneville Dam from last detection on a downstream monitor to first detection at Bonneville Dam (median 2.1 days) (Fig. 6a). Fish in Group 2 had a median travel time from the downstream site of 0.13 days (range 0.04 to 11.7 days). Fish in Group 3 had a median travel time of 0.9 days (range 0.04 to 11.1 days). Fish in Group 4 had a median travel time of 0.08 days (range 0.03 to 11.6 days).

The median travel time for Group 2 fish was 0.10 days (range < 0.01 to 12.03 days) from first detection at the dam to first detection in the collection channel (Fig. 6b). Group 3 fish also had a median travel time of 0.10 days passing into the collection channel (range < 0.01 to 11.9 days) after first detection at the dam. Median travel time from first detection record at the dam to first detection record inside the collection channel for Group 4 was 0.3 days (range < 0.01 to 36.0 days). Based on the time that radio-tagged lamprey spent at Bonneville Dam, we do not believe that tag size or tagging technique affected the number of fish that were recorded passing the dam. It is likely that passage conditions at the dam delayed or prevented some Pacific lamprey from migrating farther upstream.

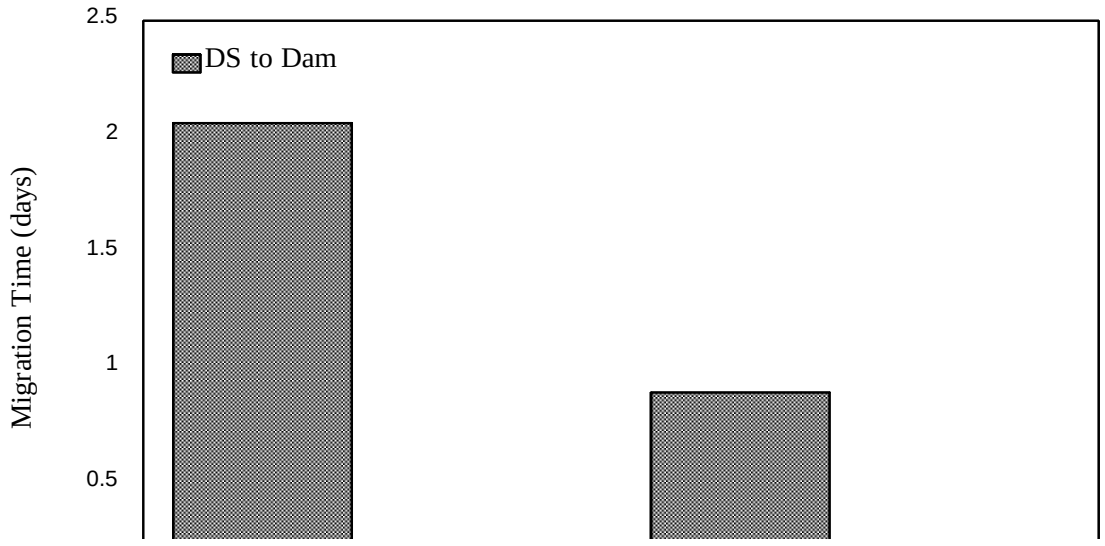

Figure 6a. Median migration times for radio-tagged Pacific lamprey from downstream monitoring sites to first detection at Bonneville Dam, 1997. Group 1 fish were only detected outside the collection channel, Group 2 fish migrated as far as the collection channel, Group 3 fish migrated into the fish ladder, and Group 4 fish migrated upstream from Bonneville Dam. Migration times shown are from last detection at the downstream site (DS) to first detection at the dam.

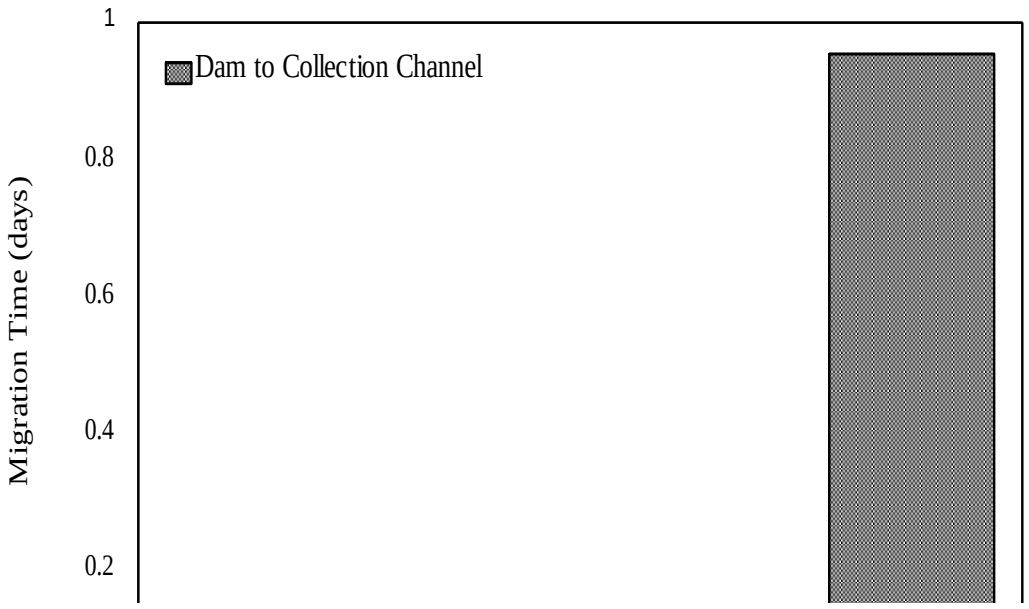

Figure 6b. Median migration times for radio-tagged Pacific lamprey from downstream monitoring sites to passage into the collection channels at Bonneville Dam, 1997. Group 1 fish were only detected outside the collection channels, Group 2 fish migrated as far as the collection channel, Group 3 fish migrated into the fish ladder, and Group 4 fish migrated upstream from Bonneville Dam. Migration times shown are from last detection on an antenna outside the collection channel to first detection inside the collection channel.

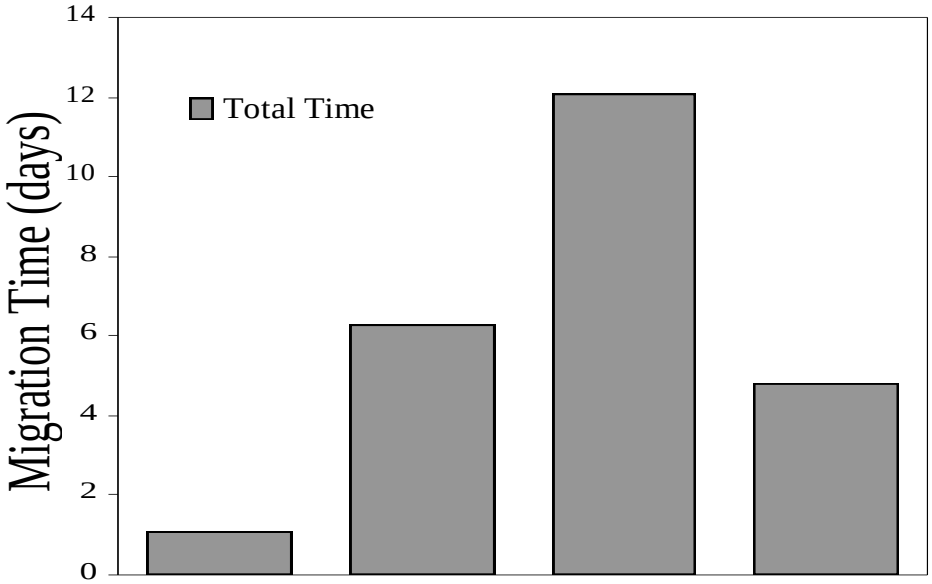

Figure 6c. Total median migration time spent at Bonneville Dam by radio-tagged Pacific lamprey. 1997. Group 1 fish were only detected outside the collection channels, Group 2 fish migrated as far as the collection channel, Group 3 fish migrated into the fish ladder, and Group 4 fish migrated upstream from Bonneville Dam.

Pacific lamprey in Group 1 spent a median time of 1.03 days (range < 0.01 to 24.21 days) at Bonneville Dam (Fig. 6c). Group 2 fish spent from 0.01 to 28.93 days at Bonneville Dam (median 6.34 days). Group 3 fish spent a median time of 12.10 days at the dam (range 0.88 to 39.82 days). Group 4 fish spent from 0.31 to 37.23 days (median 4.83 days).

Pacific lamprey activity at and inside the adult collection channel was divided between fish that were recorded as having passed the dam and all other tags detected at Bonneville Dam. Activity of fish outside the collection channel is shown in Figure 7 for first detections at Powerhouse I, Powerhouse II, and the spillway. Pacific lamprey that passed Bonneville Dam showed activity across the powerhouses outside of the collection channel, with the greater amount of first detections at the middle of Powerhouse I (monitor 6BO). There were seven detections of fish in the spillway that eventually passed the dam at either the Bradford Island or Washington shore fish ladders in 1997. First approaches of radio-tagged Pacific lamprey at Powerhouse II were at the north- and south-shore entrances of the collection channel (monitors DBO and LBO).

Lamprey activity outside the collection channel at Powerhouse I is shown in Figure 8. Fish were detected across the powerhouse collection channel entrances. The activity by lamprey outside the collection channel at Powerhouse I and the spillway was fairly uniform, with the exception of the limited activity at the south end of Powerhouse I (antenna 41). Activity outside the collection channel at Powerhouse II is shown in Figure 9. Lamprey were active across the powerhouse, with the greater amount of activity occurring at the south entrances to the collection channel (antennas D1, D2, D4, and D5). In the spillway channel and at the south end of Powerhouse II, there was a notably greater amount of activity in radio-tagged lamprey that did not pass the dam than in those that passed (Fig. 8, antennas B1, B2, C1, and C2; Fig. 9, antennas D1, D4, and D5). This suggested a possible obstruction to lamprey passage at the spillway and south shore Powerhouse II entrances.

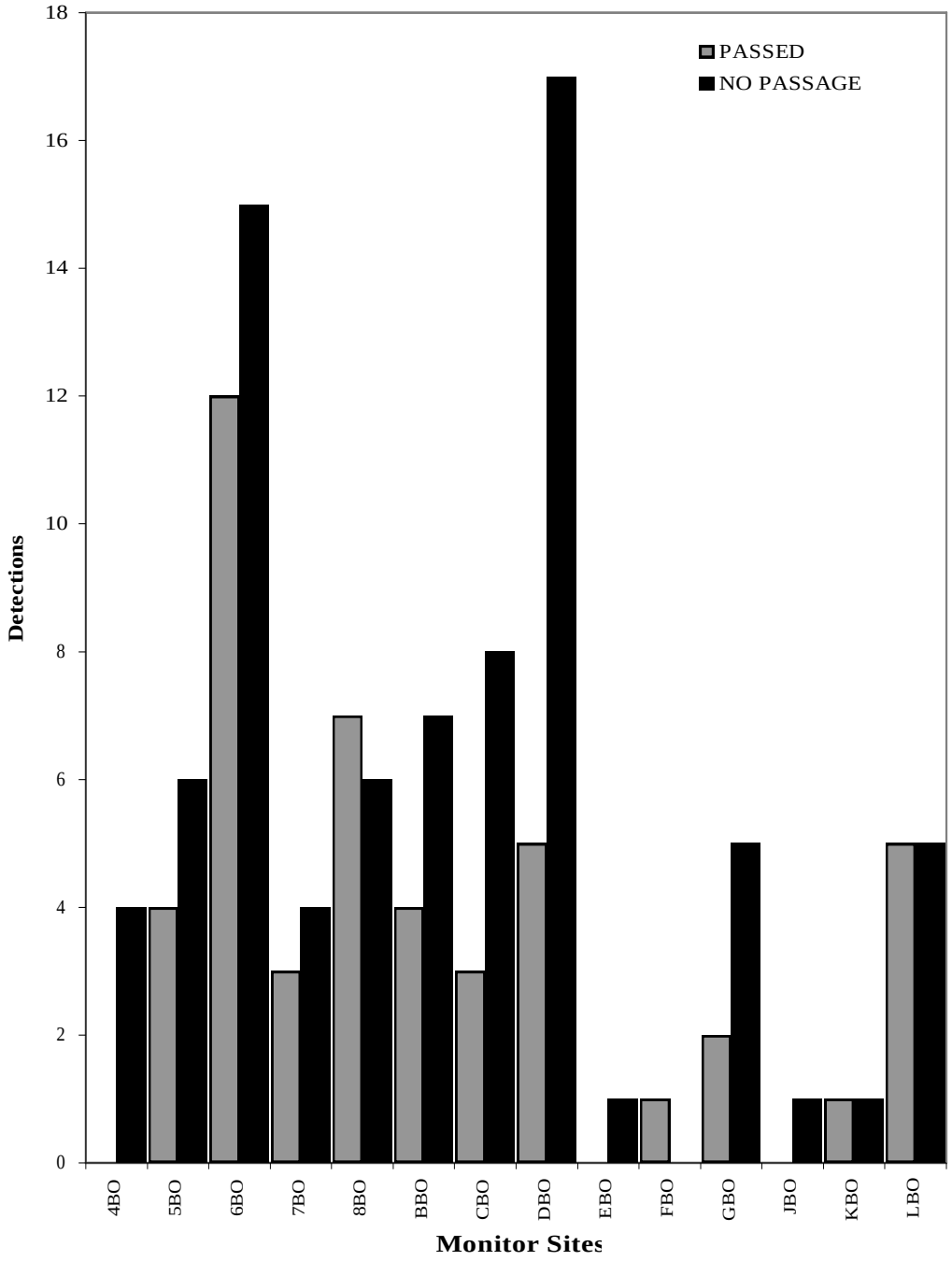

Figure 7. Number of first detections at monitor sites outside the collection channel at Powerhouse I, Powerhouse II, and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor locations are identified in Appendix A.

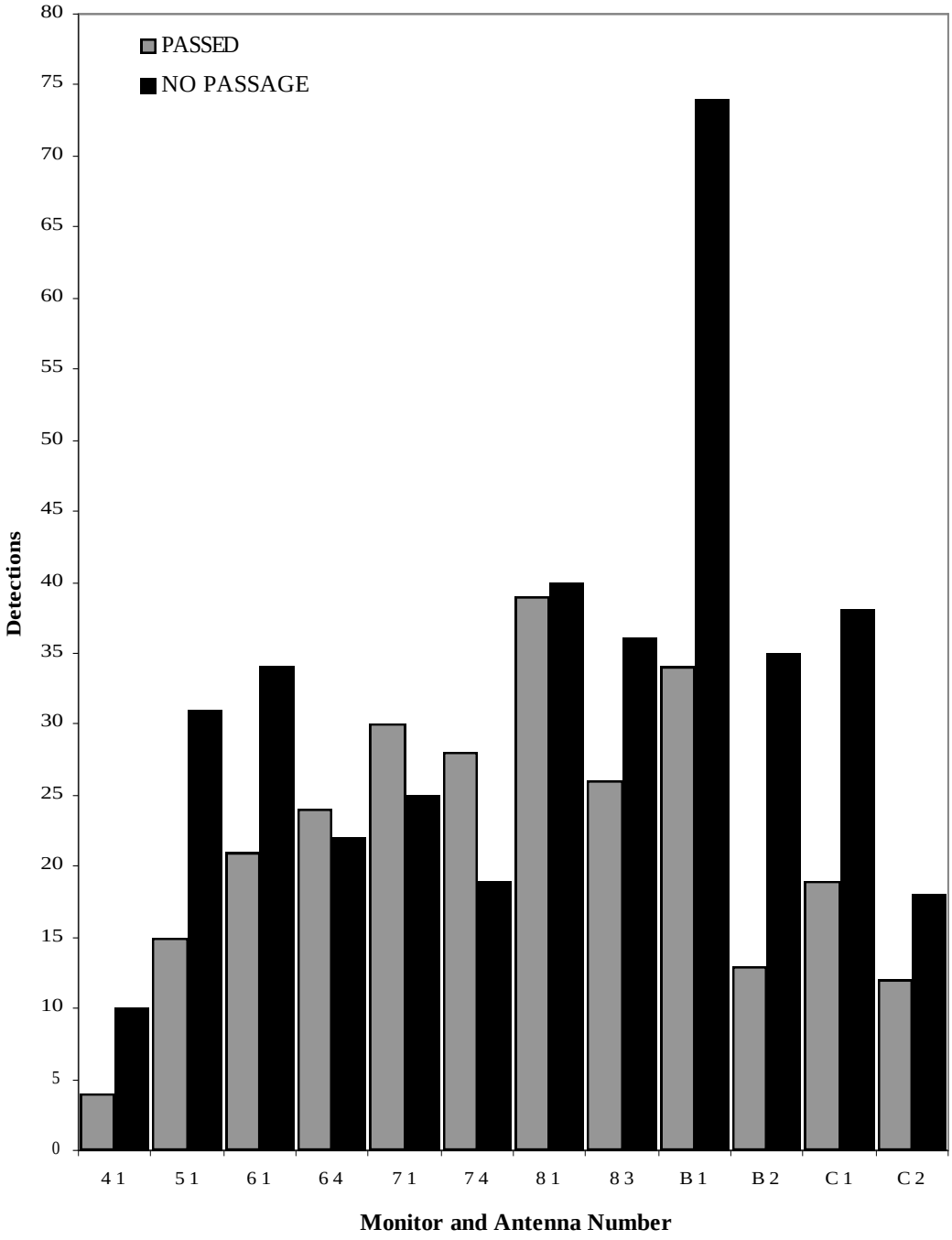

Figure 8. Total number of detections at monitor sites outside the collection channel at Powerhouse I and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor and antenna locations are identified in Appendix A.

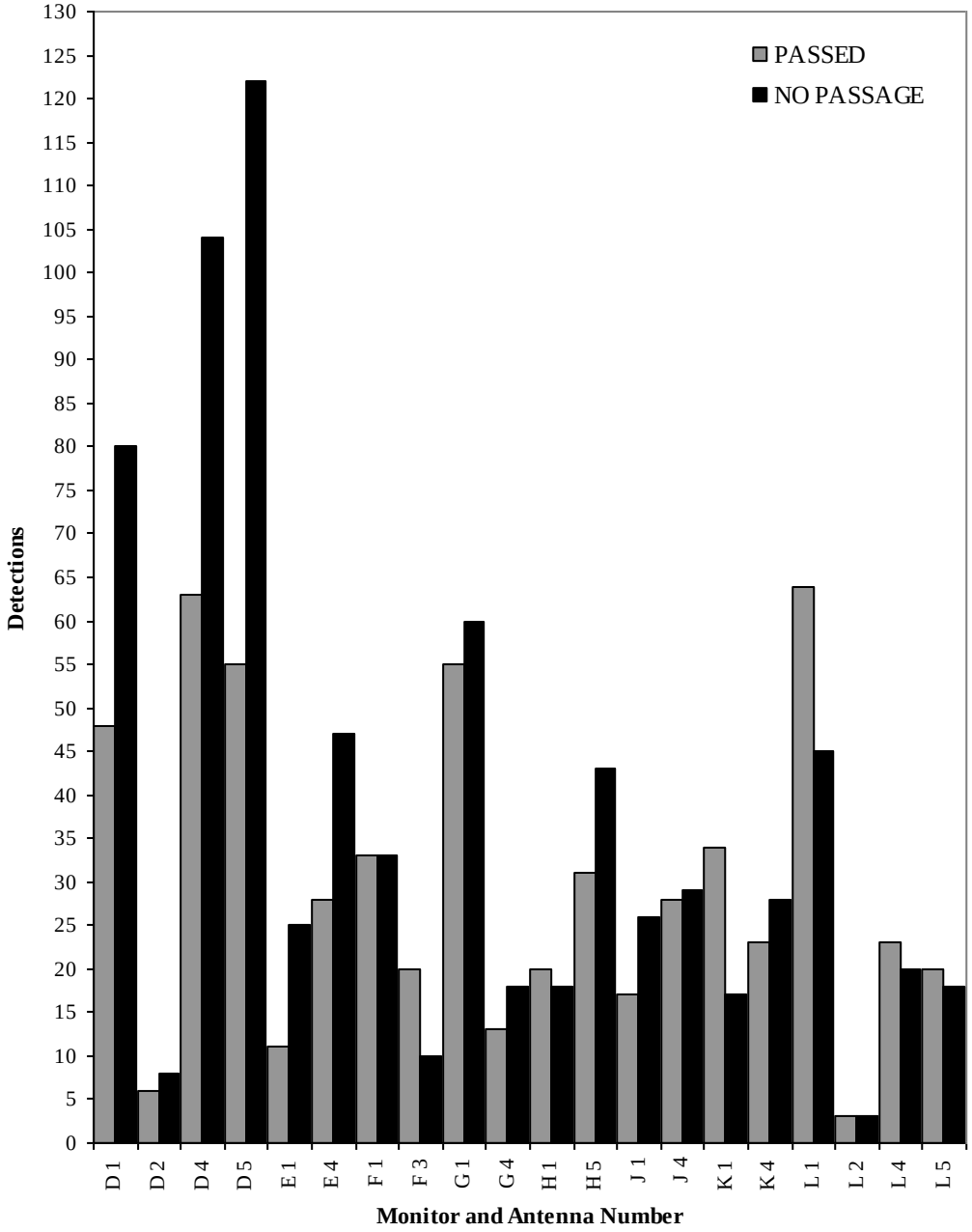

Figure 9. Total number of detections at monitor sites outside the collection channel at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor and antenna locations are identified in Appendix A.

Entrance activity of radio-tagged Pacific lamprey is shown in Figure 10 for Powerhouse I and Figure 11 for Powerhouse II. Fish that did not pass the dam were detected entering the collection channel at all sites across Powerhouse I; however, fish that did pass entered the collection channel at either the north or south end. No fish that passed the dam was detected entering the collection channel at the north spillway entrance. Fish that passed the dam entered the collection channel mainly at the north or south end of Powerhouse II (antennas D1, D4, D5, and L1), with limited entrance activity at the floating orifices in the middle of the channel. Lamprey that did not pass the dam showed activity at the collection-channel entrance similar to that of fish that passed the dam.

Radio-tagged lamprey dropped out of the collection channel at Powerhouse I 17 times (10 passage tags, 7 non-passage tags) and 17 times at the spillway entrances (Fig. 12). Lamprey dropped out of the collection channel at Powerhouse II 95 times (54 passage tags, 41 non-passage tags) (Fig. 13).

Pacific lamprey moved quickly within the collection channels (both upstream and downstream). The duration of movements from one end to the other in the collection channel ranged between 7 and 20 minutes. Group 4 fish had no downstream movement in the spillway entrance channels, while this was relatively common for Pacific lamprey in Groups 1, 2, and 3.

Last locations for fish that did not enter the collection channels at Bonneville Dam are shown in Figure 14. Nine lamprey that were released below Bonneville Dam were never detected in the study area. There were records for 40 radio-tagged lamprey detected in the study area but not in the collection channels. Nine of these lamprey were detected only at the downstream sites and not at the dam, 2 were detected at the navigation lock monitor, 11 at Powerhouse I, 11 in the spill channel, and 7 at Powerhouse II.

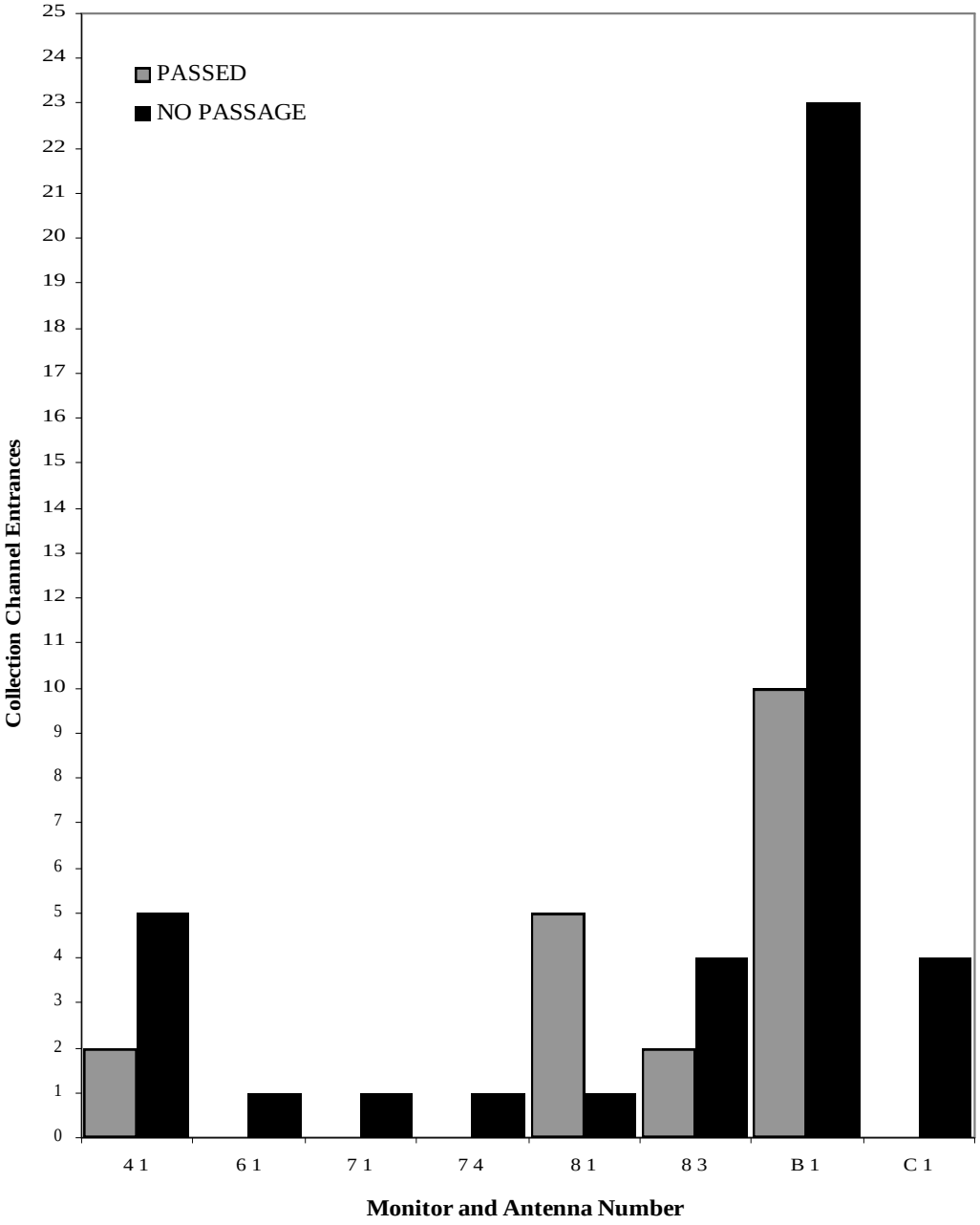

Figure 10. Number of collection channel entrances at Powerhouse I and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor and antenna locations are identified in Appendix A.

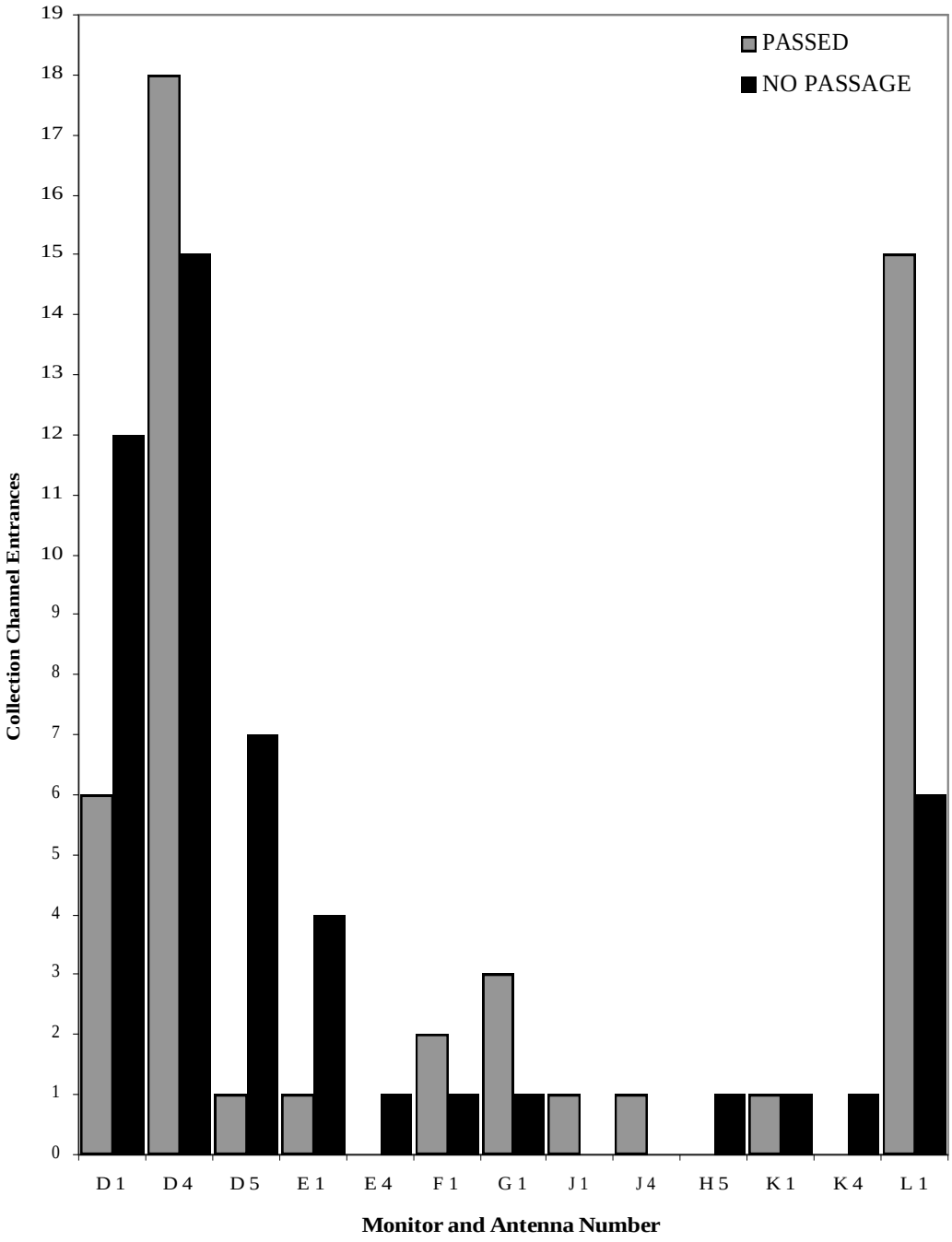

Figure 11. Number of collection channel entrances at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor and antenna locations are identified in Appendix A.

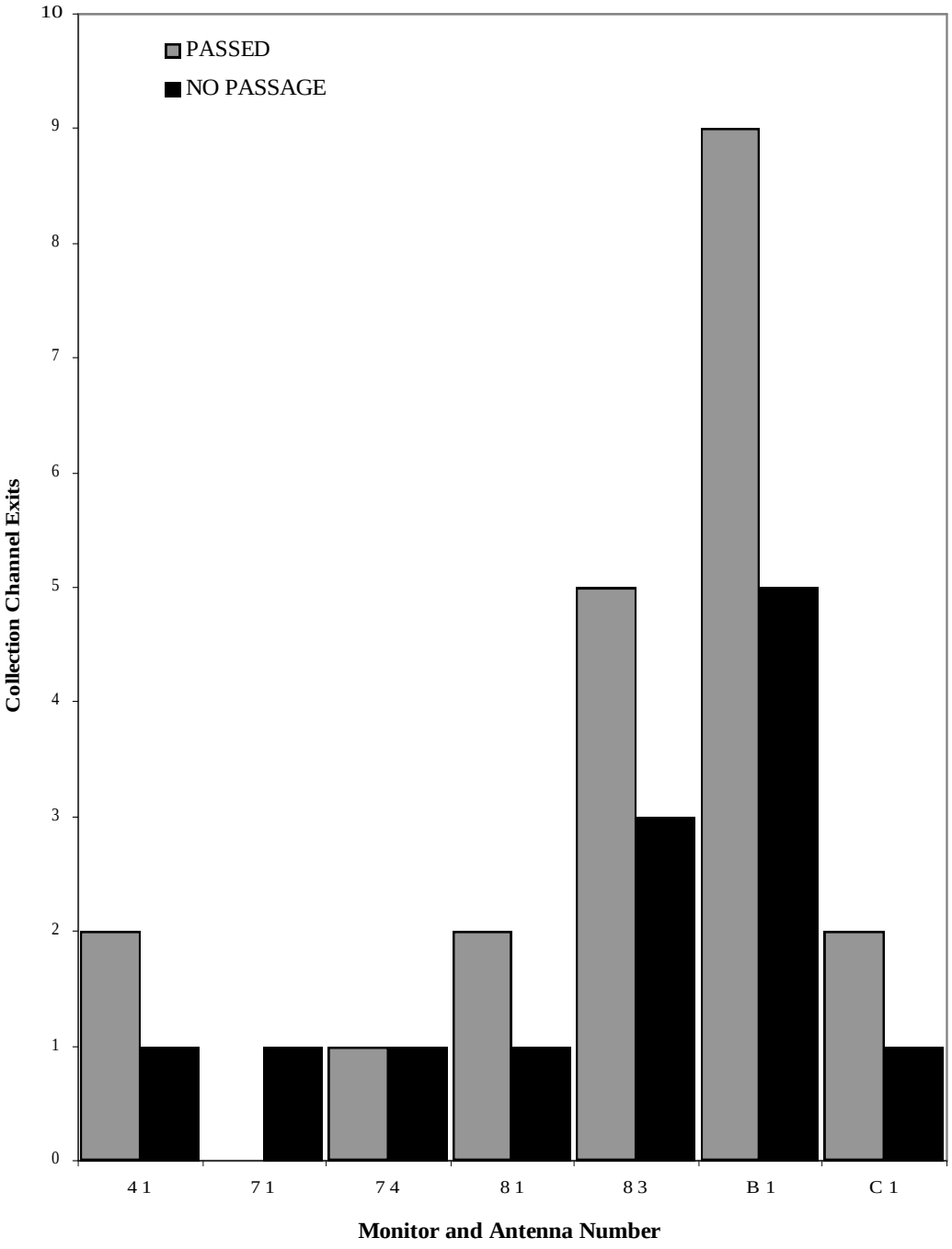

Figure 12. Number of collection channel exits at Powerhouse I and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor and antenna locations are identified in Appendix A.

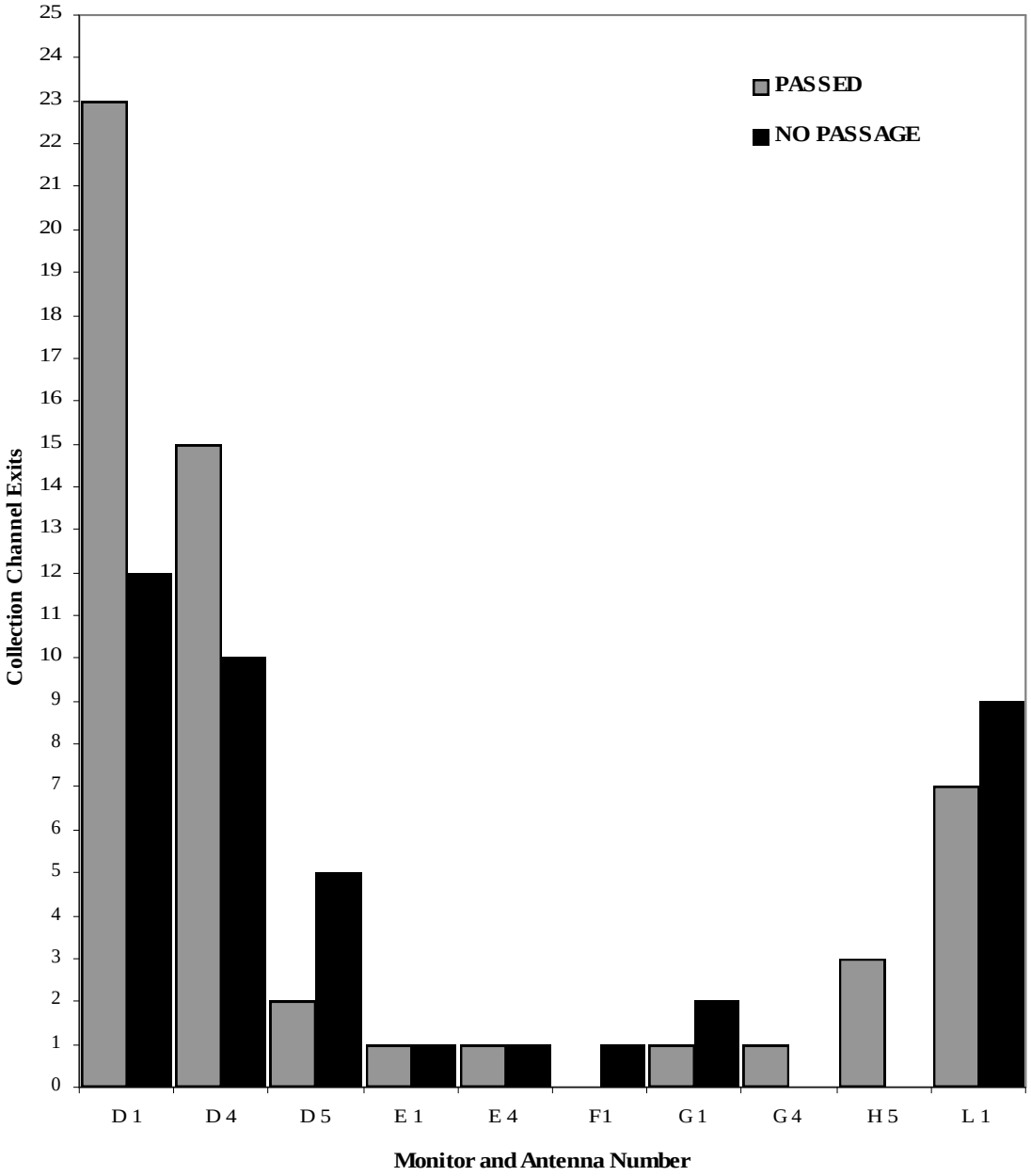

Figure 13. Number of collection channel exits at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1997. Monitor and antenna locations are identified in Appendix A.

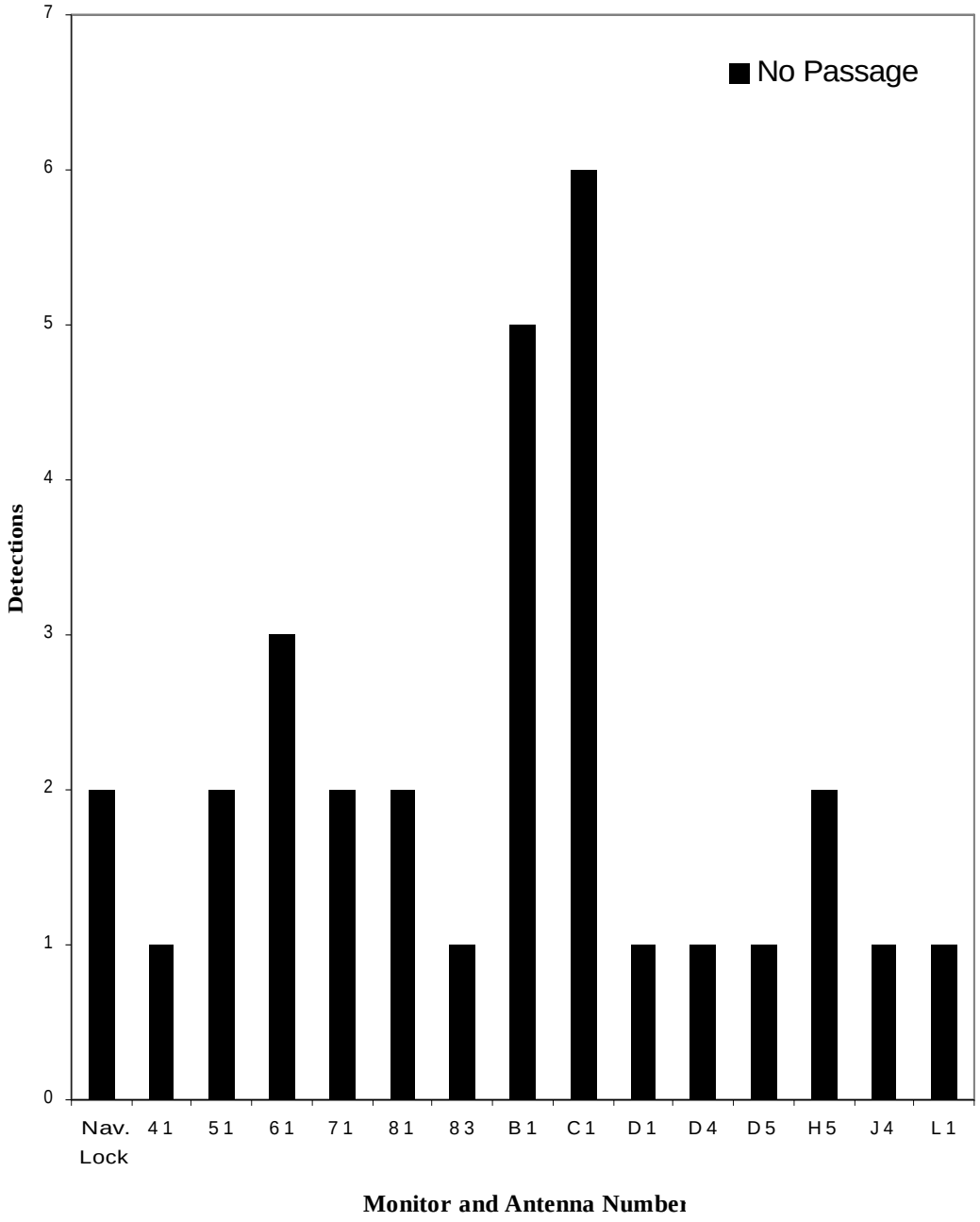

Figure 14. Last locations and number of radio-tagged Pacific lamprey that were detected outside fishway entrances and did not enter collection channels at Bonneville Dam 1997. Monitor and antenna locations are identified in Appendix A.

Fifty radio-tagged Pacific lamprey were recorded at sites inside the collection channels at Bonneville Dam, but did not pass the dam. One of these fish was last located on the navigation lock monitor, 11 were detected at Powerhouse I, 18 in the B-branch entrance at Bradford Island (Fig. 14), 6 in the UMT channel entrance, and 14 at Powerhouse II (Fig. 15).

The point at which fish were turning around in the fish ladders was analyzed. Of tagged fish that entered the Bradford Island fishway, two were recorded at the top of the ladder, but they did not exit into the forebay. Six tagged fish backed down the ladder and were recorded on monitor 9BO antenna 3. One of these six lamprey later passed the dam using the Washington shore ladder. All six lamprey backed down the ladder using the B-branch entrance in the spill channel. Movement from monitor 9BO antennas 1 and 2 was upstream for all tags. This may have been an indication that there is some hindrance to passage at the counting station for lamprey. None of the fish passing the Bradford Island fishway showed down-ladder movement upstream from the A/B- branch junction pool.

In the Washington shore fishway, the highest number of ladder back-downs was at monitor OBO antenna 3, where 6 backed down the ladder (Fig. 16). The higher number of ladder back-downs at this area may be an indication of a similar hindrance to passage at the counting station. However, these are low numbers, so the weight of the problem cannot be assessed from this data, and there are still a large number of fish not getting to the counting station. Of the 28 fish that entered the right-bank fishway and then backed out, greater than half (15) did not make it into the ladder section of the fishway (Fig. 17).

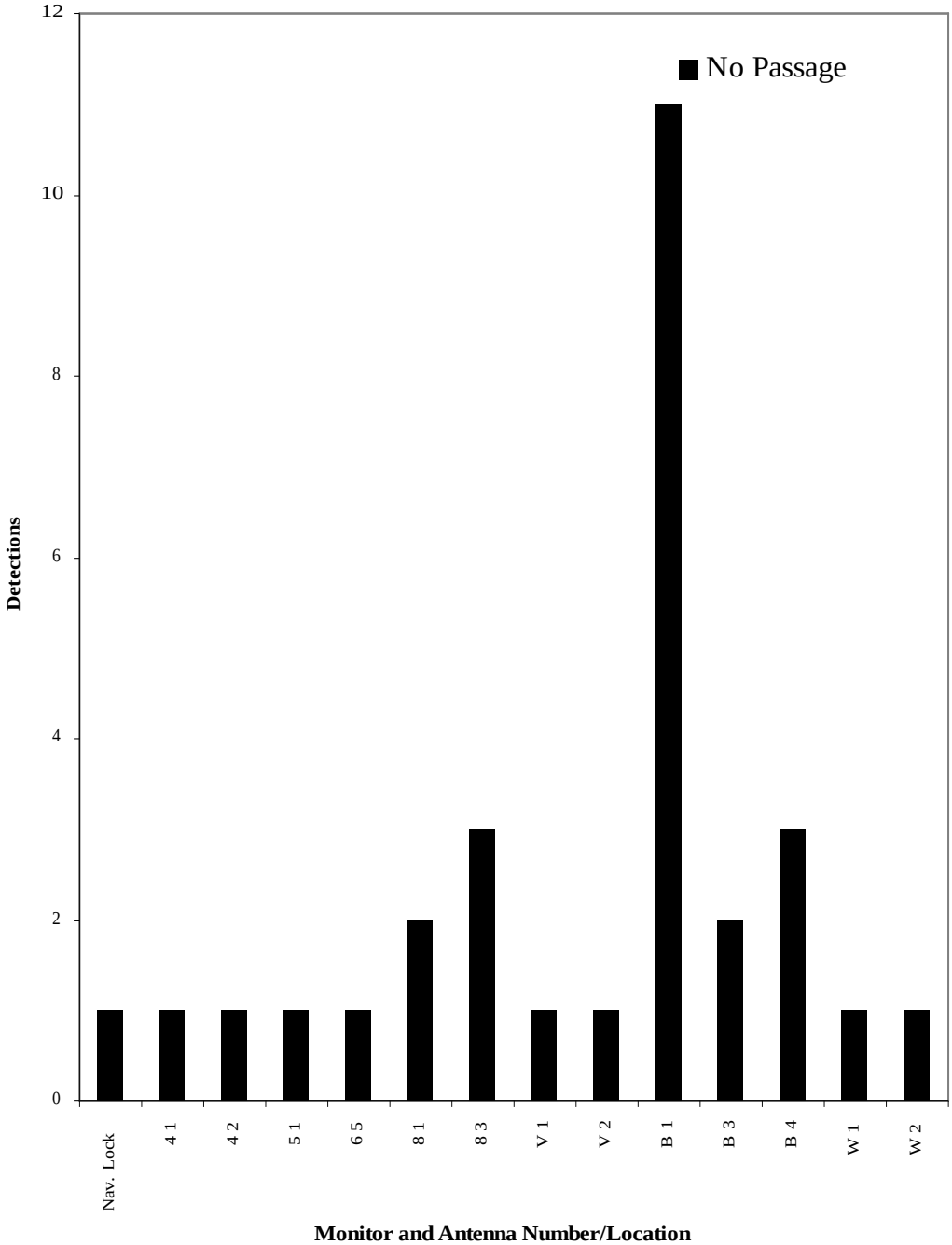

Figure 15. Last locations for radio-tagged Pacific lamprey that did not pass Bonneville Dam and were detected inside the collection channels, Powerhouse I and south spillway entrance (Bradford Island ladder). Monitor and antenna locations are identified in Appendix A.

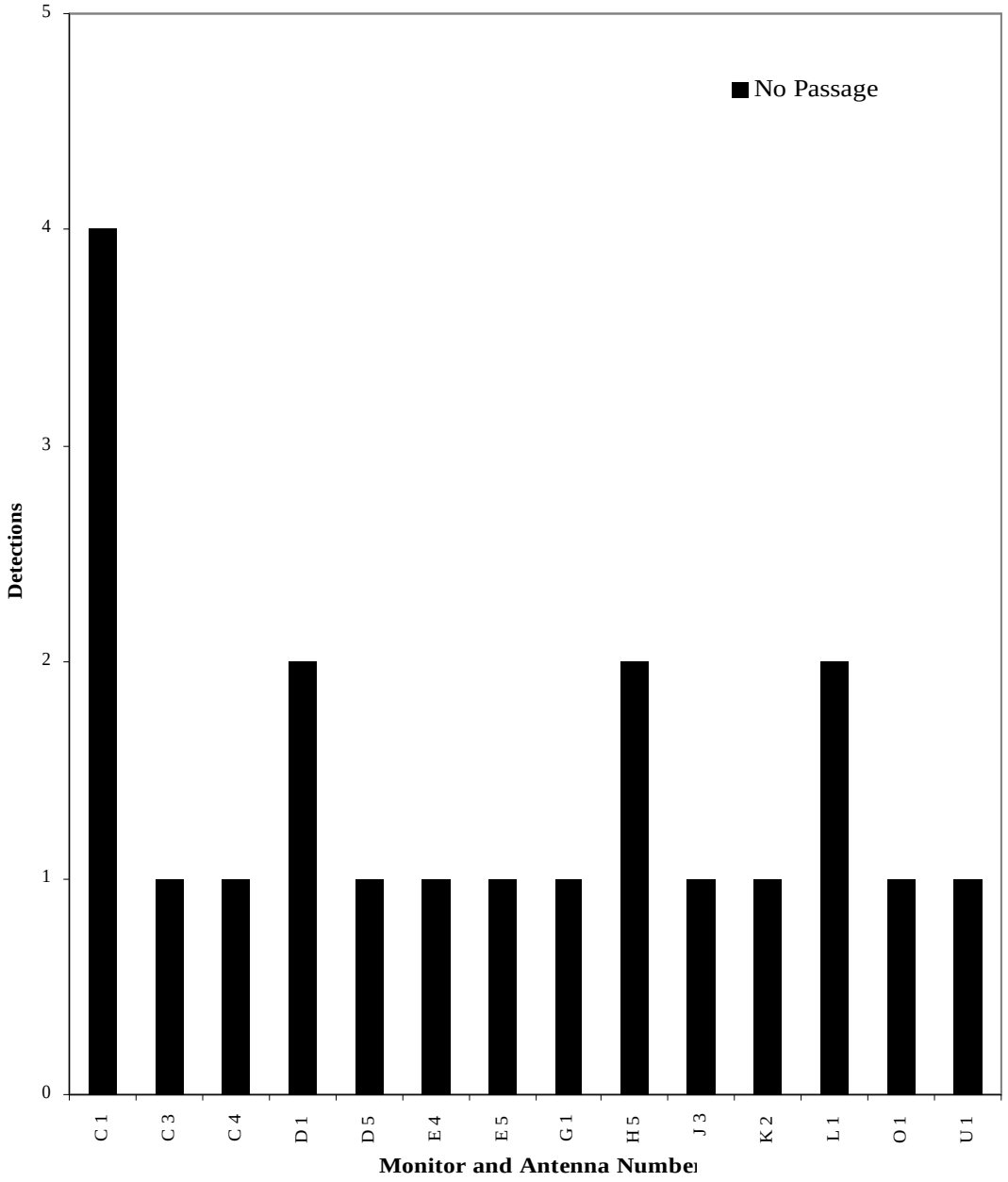

Figure 16. Last locations and number of radio-tagged Pacific lamprey that did not pass Bonneville Dam that were detected inside the collection channels, Powerhouse II and spillway north shore entrance (Cascade Island). Monitor and antenna locations are identified in Appendix A.

Data for radio-tagged lamprey that migrated upstream from the Bonneville Dam study area and were detected at upstream dams are shown in Table 4. These data compare lamprey released above Bonneville Dam (RKm 235.1) and subsequently detected at The Dalles (RKm 308.1), John Day (RKm 346.1), and McNary (RKm 466.6) Dams with those released below Bonneville Dam. To date a total of 138 (93.9%) of the 147 fish released downstream from Bonneville Dam have been detected in the Bonneville Dam study area. Of fish released downstream from Bonneville Dam, 47 (32.0%) were detected at the top of the Bonneville Dam fish ladders.

Table 4. Detections of radio-tagged Pacific lamprey released downstream and upstream from Bonneville Dam and number (percent) migrating to upstream Columbia River dams.

	Released downstream (n = 147)	Released upstream (n = 50)
At Bonneville Dam	138 (93.9%)	-
Top of Bonneville Dam ladders	47 (32.0%)	-
Bonneville to The Dalles Dam	29 (19.7%)	40 (80.0%)
Top of the Dalles Dam ladders	15 (10.2%)	18 (36.0%)
The Dalles Dam to John Day Dam	10 (6.8%)	15 (30.0%)
Top of John Day Dam ladder	3 (2.0%)	0
John Day to McNary Dam	2 (1.4%)	0
Top of McNary Dam ladders	0	0

A total of 29 (19.7%) radio-tagged lamprey released below Bonneville Dam were detected at The Dalles Dam. Fifteen of these were detected at the top of The Dalles Dam ladders. A total of 10 (6.8%) lamprey migrated from The Dalles Dam to John Day Dam, with 3 (2.0%) being detected at the top of the John Day Dam ladders. Two of these three fish were later detected in the McNary Dam study area.

Of the 50 lamprey released upstream from Bonneville Dam, 40 (80.0%) were detected at The Dalles Dam. Detections at the top of the ladders at The Dalles Dam indicated that 18 (36.0%) of those lamprey passed the dam. Fifteen radio-tagged lamprey were then detected in the John Day Dam study area.

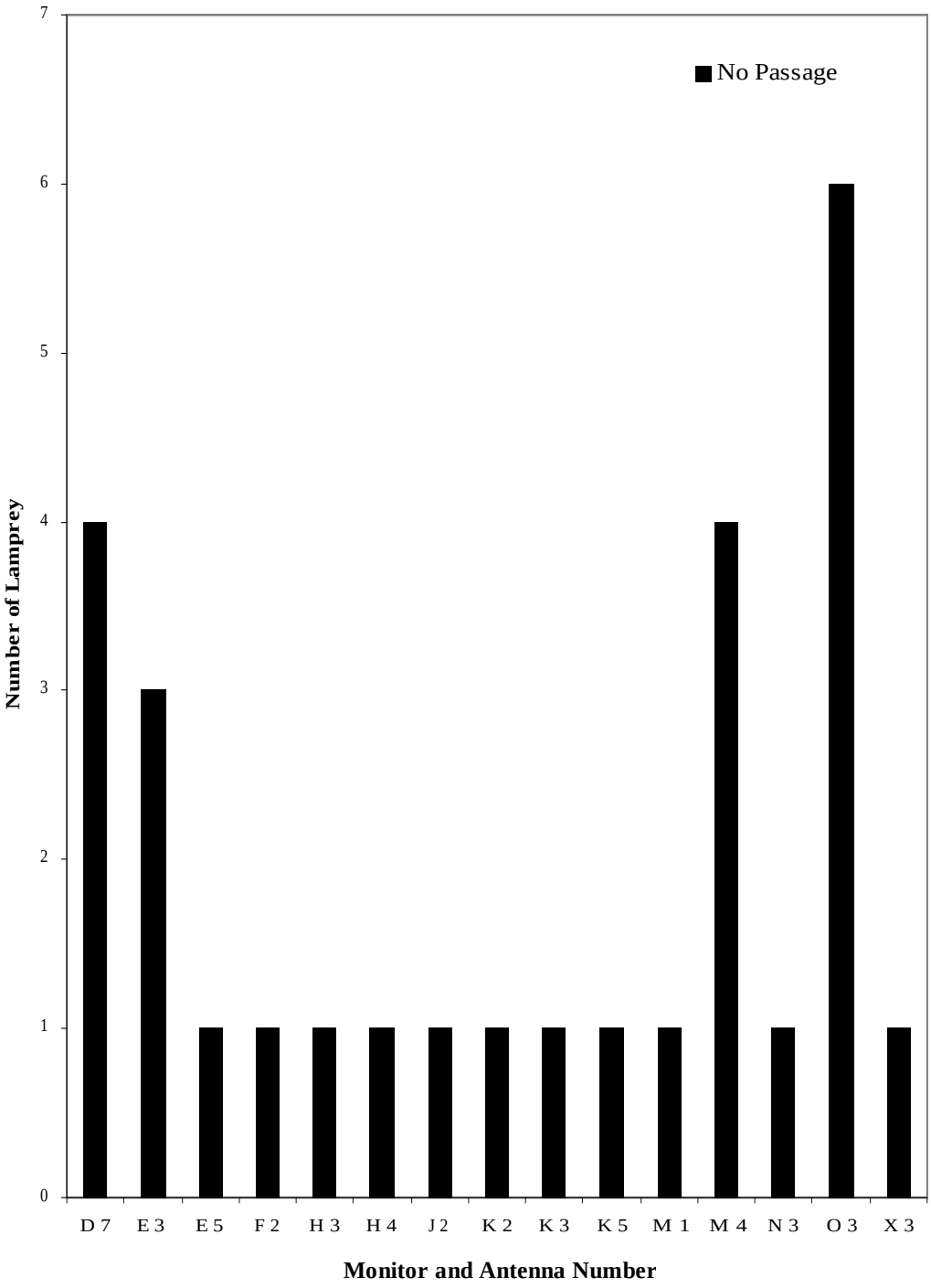

Figure 17. Highest point reached for Pacific lamprey entering the right bank fishway but not passing Bonneville Dam. Descriptions of receiver and antenna locations are found in Appendix A.

Of the 69 radio-tagged lamprey detected in The Dalles Dam study area, 61 had records of detection at the dam. Of fish detected at the top of the ladders at Bonneville Dam, 24 had records of detection in The Dalles Dam study area. Three fish released below Bonneville Dam and not detected at the top of the ladders at Bonneville had records of detection on the downstream monitors at The Dalles Dam. There were 37 records of detection on monitors below The Dalles Dam. Fifty lamprey were detected on monitors outside the collection channel and 53 were detected inside. Eleven fish detected on monitors inside the collection channel had no records of detection on monitors outside the collection channel. Of these 11 fish, 8 passed the dam utilizing the right-bank ladder. The remaining three fish did not pass the dam.

A total of 33 radio-tagged lamprey were detected at the top of the ladders at The Dalles Dam. Of these fish, 18 had been released above and 15 had been released below Bonneville Dam. There was a 2 to 1 ratio for all fish passing the right-bank ladder compared to those passing the left-bank ladder (Table 5). This was also true when fish were analyzed based on release sites, above or below the dam. However this was not true when a comparison was made based on the bank from which fish were released, left or right. Nine of the 11 fish that passed the dam at the right-bank ladder entered the fishway at monitor ETD. The 22 fish passing the dam at the left-bank ladder were spread across the collection channel entrances. Four entered the collection channel at monitor ATD, 8 entered at BTD, 5 entered at CTD, 4 entered at DTD, and 1 entered at ETD.

Table 5. Number of fish passing The Dalles Dam left-bank or right-bank ladders based on release site above or below Bonneville Dam. Skamania Landing and Dodson were the release sites located below the dam, and Cascade Locks and Stevenson were the release sites above the dam.

Release site	Left-bank ladder	Right-bank ladder
Cascade Locks	2	6
Dodson	1	6
Skamania Landing	4	4
Stevenson	4	6

There were records on 12 fish detected at the top of the ladders at Bonneville Dam and detected at the downstream monitors at The Dalles Dam. Median travel time from the top of the ladder at Bonneville Dam to the downstream site at The Dalles Dam was 2.8 days (range 1.3 to 20.1 days). Median time for fish released above Bonneville Dam to migrate to the downstream sites at The Dalles Dam was 4.8 days (range 0.3 to

17.8 days). Median time for fish to migrate from the downstream monitor sites to The Dalles Dam was 3.2 days (range 0.1 to 22.3 days).

Median time from detection at The Dalles Dam to first detection inside the collection channel was 0.1 days (range < 0.1 to 17 days). After entering the collection channel, the median time it took lamprey to migrate to the top of The Dalles Dam fish ladder was 1.8 days (range 0.3 to 15.1 days).

At Bonneville Dam, one radio-tagged fish was detected in the make-up water channel at the top of the Bradford Island ladder. This ladder section is blocked off by a picketed lead at the downstream end of the channel that was installed to guide larger fish such as salmon and steelhead past the counting window. Lamprey, however, are able to pass through the 2.3-cm-wide openings in the lead (Starke and Dalen 1995). In this area of the fishway, we observed lamprey attempting to pass the dam by climbing up the tainter gate at the upstream end of the channel. During the lamprey peak-migration period, five lamprey were observed passing over the gate while the forebay water was at an elevation that allowed water to flow down the gate. The lamprey were following the stream of water up the gate, over the other side, and presumably, into the forebay.

Observations at the spillway entrances have shown that this route of passage is not preferred by radio-tagged Pacific lamprey. A total of 82 tagged lamprey were detected in the spill channel, and only 3 of those fish passed the dam using the spillway entrance at Cascade Island. Of fish detected in the spillway, 12 eventually passed the dam by way of the A-branch of the Bradford Island ladder, and 14 passed by way of the Powerhouse II collection channel on the Washington shore. This behavior also occurred with fish detected in both the Powerhouse I and II collection channels, where fish were first detected in one of these channels and then chose another route of passage past the dam. Although the spillway channel is not a preferred passage route, entrance into the spillway channel does not appear to be detrimental to fish survival and eventual dam passage.

RECOMMENDATIONS

We recommend 1) prohibition of lamprey passage into the make-up water channel at the top of the Bonneville Dam fish ladders or development of a passage device in the channels that would allow lamprey to pass into the forebay, and 2) modification of the spillway channel entrance so lamprey can enter the fishway without accumulating outside the entrance during peak-migration periods. In addition, a flat surface rather than the current angle-iron surface on the outside of the spillway entrance could aid the passage of lamprey into the fishway.

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APPENDIX

Appendix Table A. Location and antenna configuration for fixed-site telemetry monitors at Bonneville Dam, Columbia River. Letters (BO) included with monitor number indicate Bonneville Dam study area.

Monitor Number	Monitor location	River Km	Antenna number	Antenna location
1BO	Tailrace south	234.0	1	Tanner Creek
2BO	Tailrace north	231.9	1	Hamilton Island
3BO	Navigation lock	235.1	1	Bottom of Navigation lock
4BO	PH1 SSE	235.1	1	South shore entrance outside
	PH1 SSE	235.1	2	South shore entrance inside
	PH1 SSE	235.1	3	South shore entrance pool
5BO	OG-9	235.1	1	Orifice gate 9, outside
	OG-9	235.1	2	Orifice gate 9, downstream
	OG-9	235.1	3	Orifice gate 9, upstream
6BO	OG-21, 34	235.1	1	Orifice gate 21, outside
	OG-21, 34	235.1	2	Orifice gate 21, downstream
	OG-21, 34	235.1	3	Orifice gate 21, upstream
	OG-21, 34	235.1	4	Orifice gate 34, outside
	OG-21, 34	235.1	5	Orifice gate 34, downstream
	OG-21, 34	235.1	6	Orifice gate 34, upstream
7BO	OG-58, 62	235.1	1	Orifice gate 58, outside
	OG-58, 62	235.1	2	Orifice gate 58, downstream
	OG-58, 62	235.1	3	Orifice gate 58, upstream
	OG-58, 62	235.1	4	Orifice gate 62, outside
8BO	EG-64, 65	235.1	1	SG-64, outside
	EG-64, 65	235.1	2	SG-64, downstream
	EG-64, 65	235.1	3	SG-65, outside
	EG-64, 65	235.1	4	SG-65, upstream (wall)
	EG-64, 65	235.1	5	SG-65, upstream (rope)
9BO	A/B branch junction pool	235.1	1	A-branch, top ladder (before junction pool)
	A/B branch junction pool	235.1	2	B-branch, top ladder (before junction pool)
	A/B branch junction pool	235.1	3	Upstream of A/B branch junction pool
ABO	Bradford Island	235.1	1	Bradford Island ladder exit
BBO	B-branch entrance	235.1	1	North entrance outside
	B-branch entrance	235.1	2	South entrance outside
	B-branch entrance	235.1	3	Entrance 1,2 inside (wall)
	B-branch entrance	235.1	4	Entrance 1,2 inside (ladder)
CBO	UMT entrance	235.1	1	North entrance outside
	UMT entrance	235.1	2	South entrance outside
	UMT entrance	235.1	3	Entrance 1,2 inside (wall)
	UMT entrance	235.1	4	Entrance 1,2 inside (ladder)

Appendix Table A. Continued.

Monitor Number	Monitor location	River Km	Antenna number	Antenna location
DBO	PH2, SSE	235.1	1	Downstream outside
	PH2, SSE	235.1	2	Downstream inside
	PH2, SSE	235.1	3	Downstream inside
	PH2, SSE	235.1	4	Upstream outside
	PH2, SSE	235.1	5	Upstream outside
	PH2, SSE	235.1	6	Upstream inside
	PH2, SSE	235.1	7	Upstream inside
EBO	PH2 OG-1, 2	235.1	1	Orifice gate 1, outside
	PH2 OG-1, 2	235.1	2	Orifice gate 1, downstream
	PH2 OG-1, 2	235.1	3	Orifice gate 1, upstream
	PH2 OG-1, 2	235.1	4	Orifice gate 2, outside
	PH2 OG-1, 2	235.1	5	Orifice gate 2, upstream
FBO	PH2 OG-3, 4	235.1	1	Orifice gate 3, outside
	PH2 OG-3, 4	235.1	2	Orifice gate 3, upstream
	PH2 OG-3, 4	235.1	3	Orifice gate 4, outside
	PH2 OG-3, 4	235.1	4	Orifice gate 4, upstream
GBO	PH2 OG-5, 6	235.1	1	Orifice gate 5, outside
	PH2 OG-5, 6	235.1	2	Orifice gate 5, upstream
	PH2 OG-5, 6	235.1	3	Orifice gate 6, downstream
	PH2 OG-5, 6	235.1	4	Orifice gate 6, outside
	PH2 OG-5, 6	235.1	5	Orifice gate 6, upstream
HBO	PH2 OG-7, 8	235.1	1	Orifice gate 7, outside
	PH2 OG-7, 8	235.1	2	Orifice gate 7, downstream
	PH2 OG-7, 8	235.1	3	Orifice gate 7, upstream
HBO	PH2 OG-7, 8	235.1	4	Orifice gate 8, downstream
	PH2 OG-7, 8	235.1	5	Orifice gate 8, outside
JBO	PH2 OG-9, 10	235.1	1	Orifice gate 9, outside
	PH2 OG-9, 10	235.1	2	Orifice gate 9, downstream
	PH2 OG-9, 10	235.1	3	Orifice gate 9, upstream
	PH2 OG-9, 10	235.1	4	Orifice gate 10, outside
KBO	PH2 OG-11, 12	235.1	1	Orifice gate 11, outside
	PH2 OG-11, 12	235.1	2	Orifice gate 11, downstream
	PH2 OG-11, 12	235.1	3	Orifice gate 11, upstream
	PH2 OG-11, 12	235.1	4	Orifice gate 12 outside
	PH2 OG-11, 12	235.1	5	Orifice gate 12, upstream
LBO	PH2 NSE 1,2	235.1	1	NSE downstream outside
	PH2 NSE 1,2	235.1	2	NSE downstream inside, 1
	PH2 NSE 1,2	235.1	3	NSE downstream inside, 2
	PH2 NSE 1,2	235.1	4	NSE upstream outside, 1
	PH2 NSE 1,2	235.1	5	NSE upstream outside, 2

Appendix Table A. Continued.

Monitor Number	Monitor location	River Km	Antenna number	Antenna location
MBO	NSE transition pool 1	235.1	1	Exit from collection channel
	NSE transition pool 1	235.1	2	Exit from NSE upstream, inside
	NSE transition pool 1	235.1	3	Upstream transition pool
	NSE transition pool 1	235.1	4	Upstream transition pool
	NSE transition pool 1	235.1	5	Downstream channel entrance into junct. pool
NBO	NSE transition pool 2	235.1	1	Upstream turnpool
	NSE transition pool 2	235.1	2	Mid section
	NSE transition pool 2	235.1	3	Downstream upper turnpool
	NSE transition pool 2	235.1	4	Downstream FERL weir
OBO	UMT/WA ladder junction	235.1	1	UMT channel exit to junction pool
	UMT/WA ladder junction	235.1	2	Washington ladder exit to junction pool
	UMT/WA ladder junction	235.1	3	Above junction pool
PBO	Washington ladder	235.1	1	Washington ladder exit
QBO	Navlock, top	235.1	1	North side
	Navlock, top	235.1	2	Middle
	Navlock, top	235.1	3	South side
RBO	Spillway	235.1	1	South, forebay
SBO	Spillway	235.1	1	North, forebay
TBO	Powerhouse I	235.1	1	Ice and trash sluiceway
UBO	Powerhouse II	235.1	1	Ice and trash sluiceway
VBO	A Branch transition pool	235.1	1	Between weirs 17 and 18 (19 ft. elevation)
	A Branch transition pool	235.1	2	Between weirs 25 and 26 (27 ft. elevation)
	A Branch transition pool	235.1	3	Between weirs 33 and 34 (35 ft. elevation)
WBO	B Branch transition pool	235.1	1	Between weirs 12 and 13 (13 ft. elevation)
	B Branch transition pool	235.1	2	Between weirs 20 and 21 (21 ft. elevation)
	B Branch transition pool	235.1	3	Between weirs 31 and 32 (32 ft. elevation)
XBO	UMT Entrance trans. pool	235.1	1	Between weirs 5 and 6 (10 ft. elevation)
	UMT Entrance trans. pool	235.1	2	Between weirs 11 and 12 (16 ft. elevation)
	UMT Entrance trans. pool	235.1	3	Between weirs 18 and 19 (23 ft. elevation)
	UMT Entrance trans. pool	235.1	4	Between weirs 30 and 31 (34 ft. elevation)