Radiotelemetry of Pacific Lamprey *Lampetra tridentata* in the Lower Columbia River, 1996

by

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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 adult Pacific lamprey studies.

In 1996, we evaluated passage patterns of upstream-migrating, radio-tagged Pacific lamprey in the lower Columbia River. Objectives of this study were to 1) determine return time from the release site back upstream to Bonneville Dam, 2) determine passage routes and behavior, and 3) determine migration rates through reservoirs.

Adult Pacific lamprey were captured in the entrance fishway of the Fisheries Engineering Research Laboratory (FERL) at Bonneville Dam with a trap designed by the National Marine Fisheries Service. The trap was fished for 20 days between 7 June and 6 August from the hours of 11:00 p.m. to 7:00 a.m. for a total of 181.5 hours. A total of 562 Pacific lamprey were captured during this period. Catch per unit effort was 3.1 fish per hour.

Radio tags were surgically implanted into the body cavity of 100 Pacific lamprey. The first 85 tagged Pacific lamprey were released at two sites downstream from Bonneville Dam (Dodson, Oregon, and Skamania Landing, Washington). The remaining 15 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.

A total of 80 Pacific lamprey (94% of the downstream release) returned to the Bonneville Dam study area after release downstream. Eighteen (21% of the downstream release) of the fish returning to the study area were detected at the top of Bonneville Dam fish ladders, and eight of these 18 fish were detected at sites above the dam. Three Pacific lamprey that were not detected on the exit monitors at the top of the fish ladders were recorded on monitors upstream.

Eleven of the 15 fish released above Bonneville Dam were detected at The Dalles Dam. Of these 11 fish, 4 passed through the fish ladders and one moved downstream to the White Salmon River. Based on radio-tag data, the Little White Salmon and Deschutes Rivers were areas to which Pacific lamprey migrated in 1996.

CONTENTS

INTRODUCTION

Populations of Pacific lamprey (*Lampetra tridentata*), like those of other Northwest anadromous fish species, have significantly declined in abundance in recent years (Close 1995, Starke 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, but the development of radio transmitters for evaluation of fish behavior has provided 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 any study using radiotelemetry to determine the migrational behavior of adult Pacific lamprey.

The National Marine Fisheries Service (NMFS) and the Idaho Cooperative Fish and Wildlife Research Unit (UI) initiated a study to look at migrational passage behavior and passage patterns of Pacific lamprey approaching and passing Bonneville Dam in 1996. Our objectives were to determine return time of tagged lamprey from release sites back upstream to Bonneville Dam, passage routes and behavior at Bonneville Dam, and migration rates through reservoirs.

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 transport bucket. The fish were then placed in a 1.8- by 0.9- by 0.6-m holding tank prior to selection for tagging.

All study fish were anesthetized using tricaine methanesulfonate, MS-222, examined for injuries and sexual maturity (if possible), measured, and weighed. After examination and tagging, fish were placed in a recovery tank with aerated fresh water and allowed to regain equilibrium.

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).

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

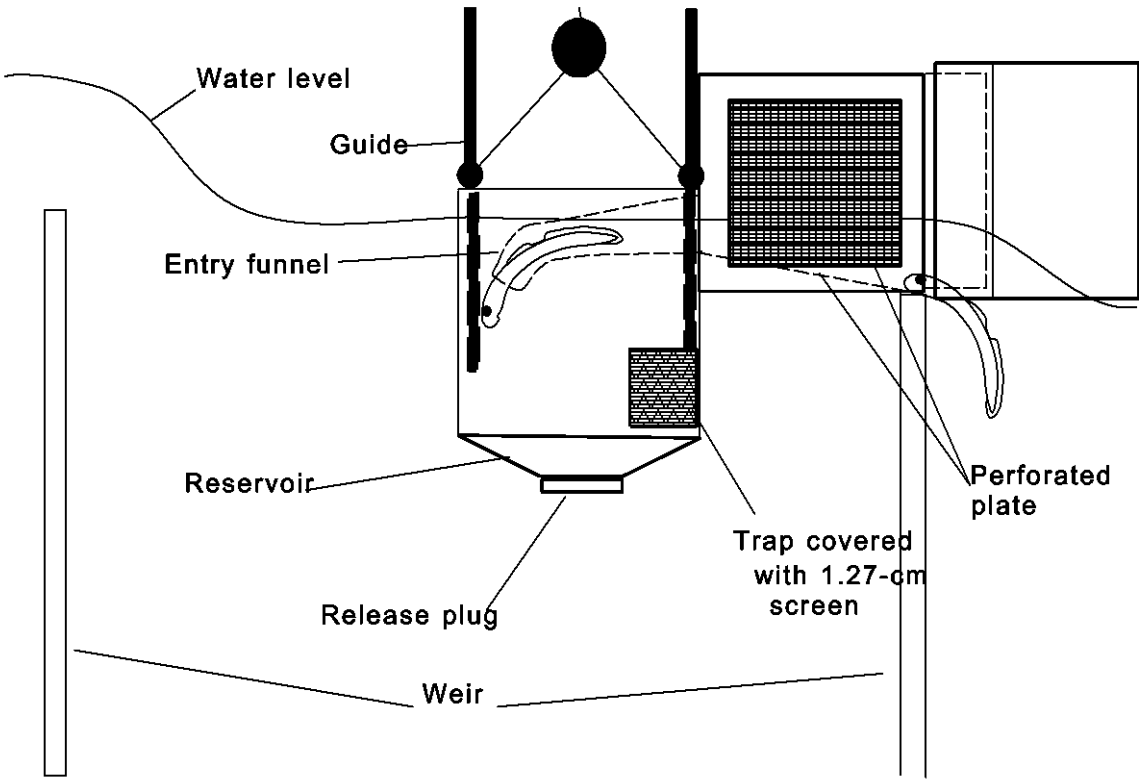

Figure 1. Side view of lamprey trap used at Bonneville Dam, 1996.

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 antenna 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.

Antenna and Receiver Locations

A total of 93 antennas were installed at Bonneville Dam. 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 3 m in water. Underwater antennas were placed at all 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 numbers and locations.

Antennas were connected to 26 receivers manufactured by Lotek Engineering. Each receiver was programmable and could detect radio transmitters for up to 150 individual codes on 25 different frequencies. Two types of receivers were utilized. The first, an SRX-400, scanned through each frequency at 6-second intervals, and stored up to 128 KB of data in seven or eight data banks. These receivers were used at single-antenna sites, such as downstream sites below the dam. The second receiver, the SRX-500 Digital Spectrum Processor (DSP), was used in tandem with the SRX-400. This 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 a 6-second scan interval.

RESULTS AND DISCUSSION

In 1996, the trap was fished for 20 days from 7 June to 6 August, and captured 562 Pacific lamprey. We fished the trap between the hours of 11:00 p.m. and 07:00 a.m. for a total of 181.5 hours during the study. This resulted in a catch per unit effort of 3.1 fish per hour.

A total of 100 Pacific lamprey were selected from those captured and were surgically implanted with radio transmitters. There were 85 radio-tagged Pacific lamprey released downstream from Bonneville Dam. Of those, 5 fish were not detected after release at either the downstream monitoring sites or the dam, and 10 were recorded only on the downstream monitors.

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 60 to 77 cm. Radio-tagged Pacific lamprey that did not return to Bonneville Dam were spread across the length range (Fig. 2), a distribution indicating 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 tagging-date period, which started 7 June and ended 16 July (Fig. 3). This distribution indicated that the lack of movement upstream was not caused by incorrect or different tagging procedures early in the season as compared to later. There were also no differences in return rates to Bonneville Dam based on release location (chi-square = 0.998, $P = 0.3177$, Table 1). This is an indication that the release sites were not affecting the migration behavior of radio-tagged lamprey.

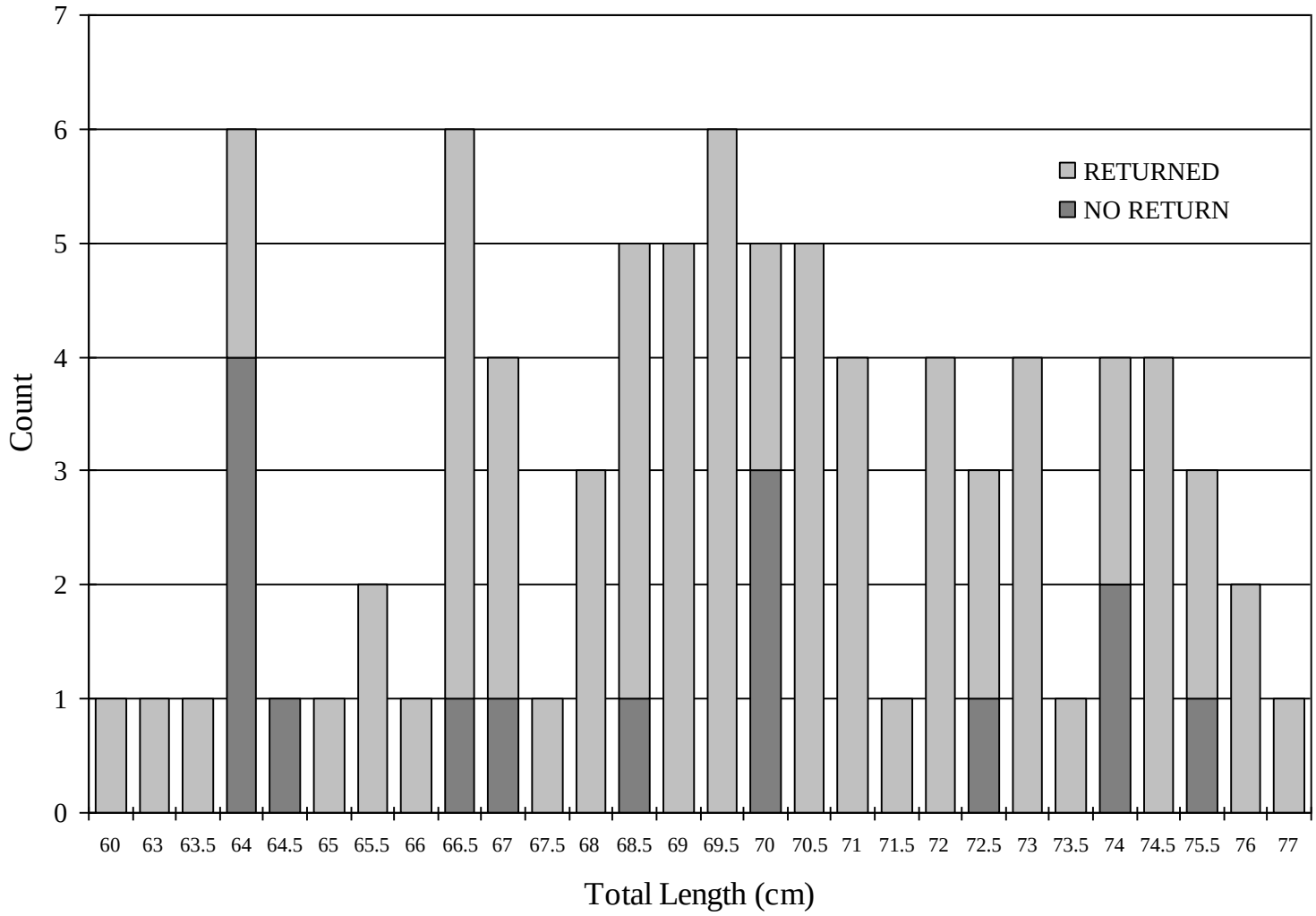

Figure 2. Number of radio-tagged Pacific lamprey returning to Bonneville Dam based on total length.

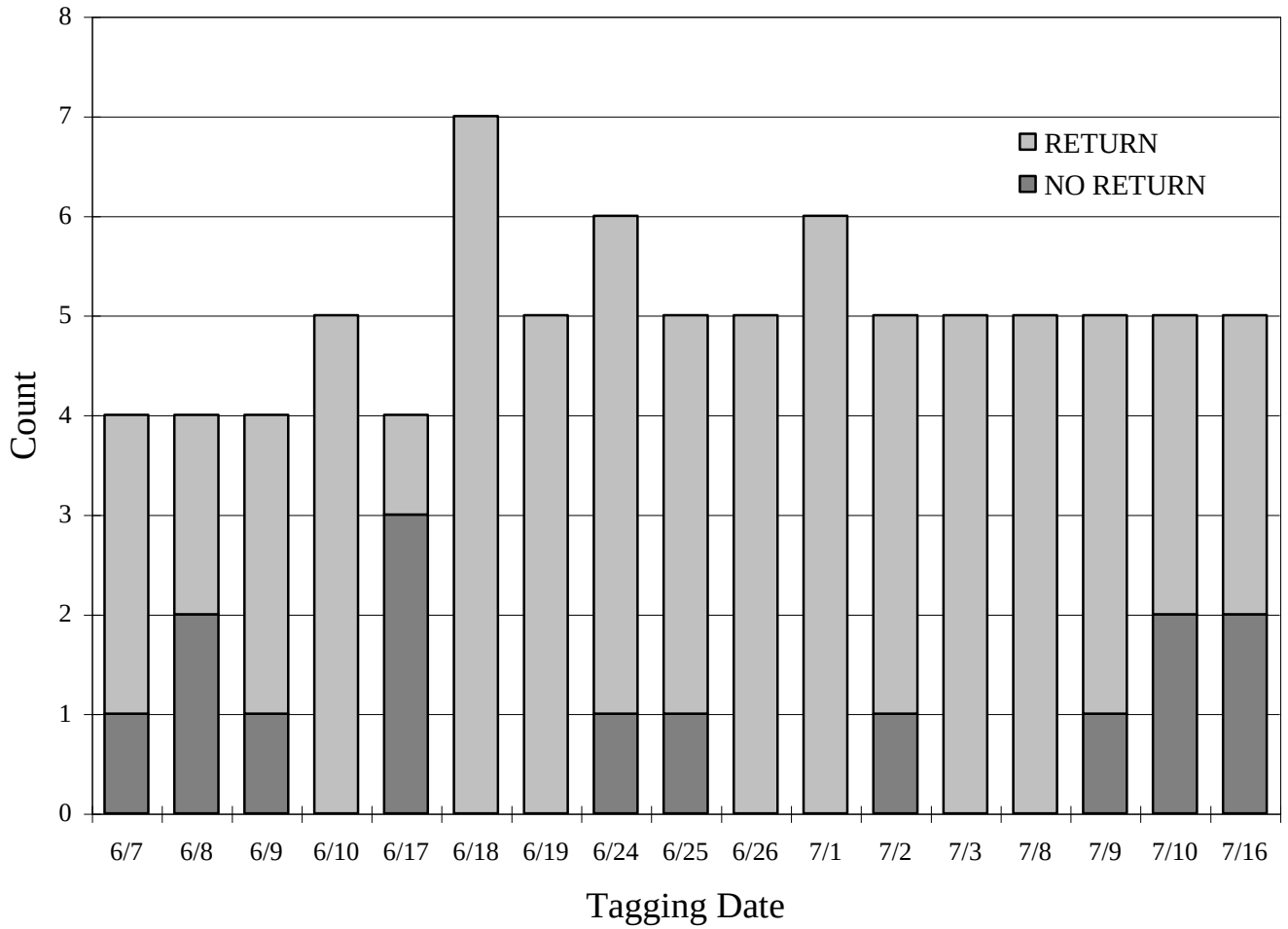

Figure 3. Number of radio-tagged Pacific lamprey returning to Bonneville Dam based on tagging date, 1996.

Table 1. Detections by release site of radio-tagged Pacific lamprey released downstream from Bonneville Dam.

	Dodson	Skamania
Detected at Bonneville Dam	36	34
Not detected	6	9

The sex of lamprey was undetermined for a large portion of fish that were released downstream, and no males were identifiable during the tagging procedure. Pacific lamprey whose sex was undetermined were grouped together. Females were grouped together based on the presence of eggs in the body cavity (Table 2). The chi-square value comparing fish that did not return to Bonneville Dam to those that did was 1.11 ($P = 0.2918$). This indicates that there was no difference in migration behavior based on sexual maturity of the fish.

Table 2. Detections by sex of radio-tagged Pacific lamprey released downstream from Bonneville Dam.

	Unidentifiable	Female
Detected at Bonneville Dam	43	27
Not detected	9	6

The travel time from release to first arrival at the downstream monitor was available for 10 of the 15 fish that did not return to Bonneville Dam. The median travel time for these fish was 11.8 days. Median travel time for fish that did return to Bonneville Dam was 4.1 days (records available for 64 of 70 lamprey). The lack of records on five tags released downstream from Bonneville Dam suggested some tagging-related mortality in these fish. However, loss to predation or undetected downstream movement cannot be ruled out. The travel time of 11.8 days for the 10 fish that were recorded on the downstream monitors suggests that mortality of fish that only returned to the study area was not directly related to tagging. Predation or undetected downstream movement very likely occurred with those fish.

The total number of fish detected on monitors at Bonneville Dam was 70 (82.4% of the total release). These fish were place in four groups, based on the upstream distance they traveled, as follows:

Group 1, Pacific lamprey that migrated to Bonneville Dam (18, 21.2% of the total release);

Group 2, Pacific lamprey that migrated into the collection channel (20, 23.5%);

Group 3, Pacific lamprey that migrated into the fish ladders (14, 16.5%); and

Group 4, Pacific lamprey that migrated past the dam (18, 21.2%).

Pacific lamprey in Group 1 took between 0.03 to 10.43 days to reach Bonneville Dam (median 0.44 days) from last detection on a downstream monitor to first detection at Bonneville Dam (Fig. 4a). Fish in Group 2 had a median travel time from the downstream site of 0.89 days (range 0.03 to 24.07 days). Fish in Group 3 had a median travel time of 0.14 days (range 0.06 to 8.64 days). Fish in Group 4 had a median migration time of 0.08 days (range 0.03 to 5.60 days). \

Median travel time for Group 2 fish was 0.10 days (range < 0.01 to 14.43 days) from first detection at the dam to first detection in the collection channel (Fig. 4b). Median travel time for Group 3 fish was also 0.10 days from first detection at the dam to entrance into the collection channel (range < 0.01 to 6.11 days). Median travel time from first record at the dam to first record inside the collection channel for Group 4 was 1.2 days (range < 0.01 to 14.22 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.

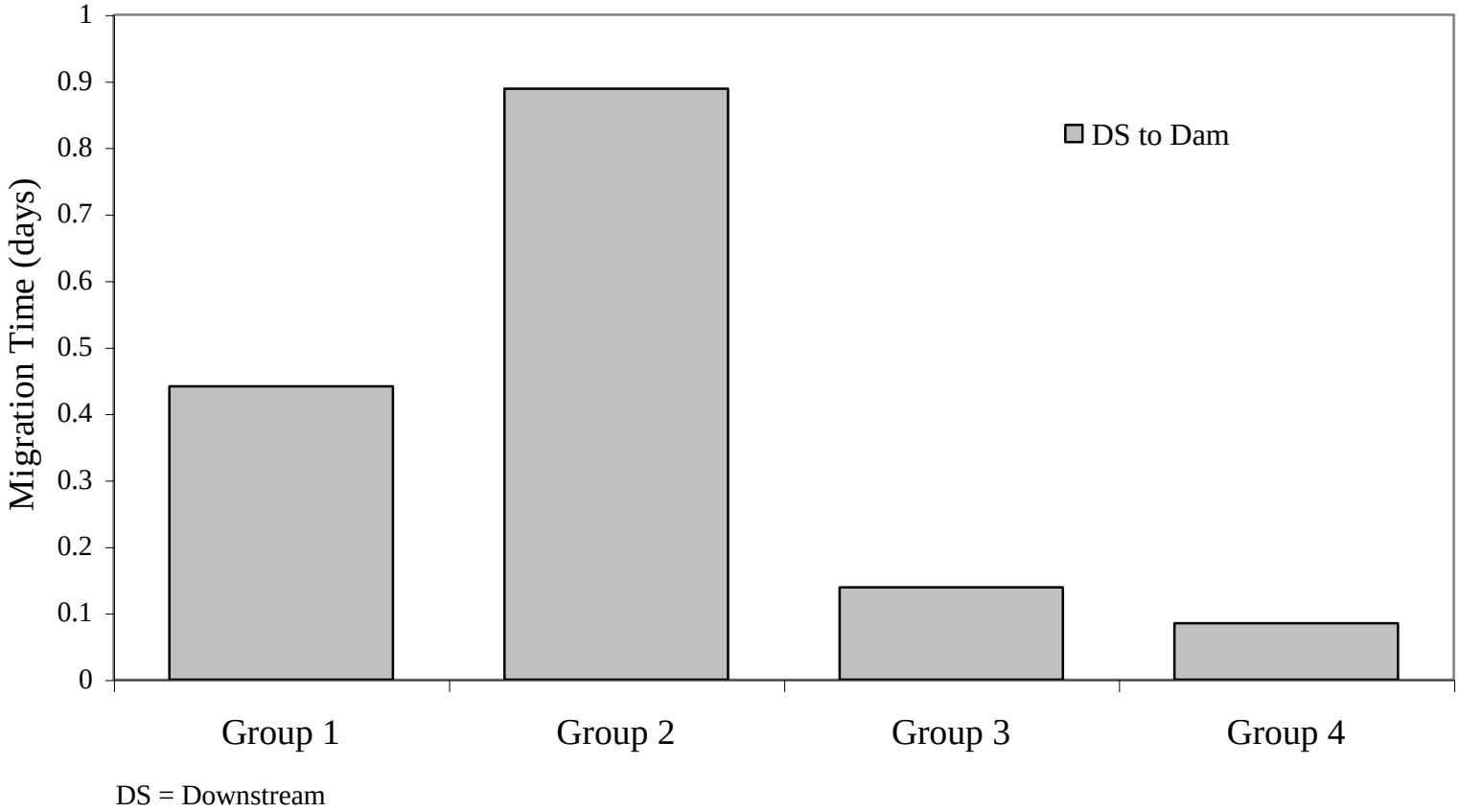

Figure 4a. Median migration times for radio-tagged Pacific lamprey from downstream monitoring sites to first detection at Bonneville Dam, 1996. Group 1 fish were only detected outside the collection channels; Group 2 fish migrated as far as the collection channel; Group 3 fish migrated into the fish ladder; Group 4 fish migrated upstream from Bonneville Dam.

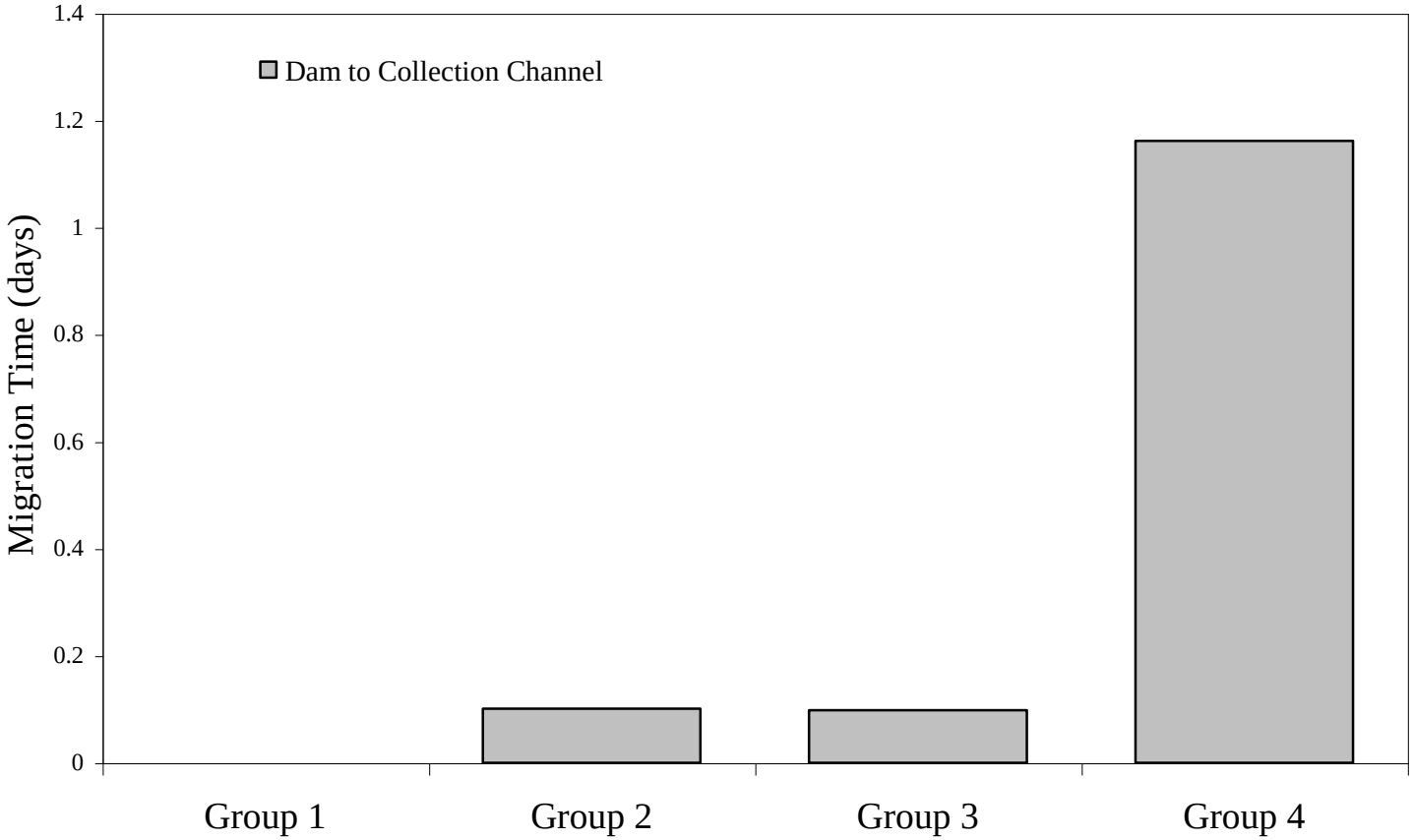

Figure 4b. Median migration times for radio-tagged Pacific lamprey from first detection at the dam to first detection inside the collection channel at Bonneville Dam, 1996. Group 1 fish were only detected outside the collection channels; Group 2 fish migrated as far as the collection channel; Group 3 fish migrated into the fish ladder; Group 4 fish migrated upstream from Bonneville Dam.

Pacific lamprey in Group 1 spent a median time of 3.17 days (range <0.01 to 82.11 days) at Bonneville Dam (Fig. 4c). Group 2 fish spent from 0.07 to 123.50 days at Bonneville Dam (median 8.27 days), Group 3 fish spent a median time of 9.62 days at the dam (range 0.21 to 99.88 days), and Group 4 fish spent from 0.39 to 23.13 days (median 4.46 days).

Pacific lamprey activity outside (or near) 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. Detections of fish outside the collection channel are shown in Figure 5 for entrances at Powerhouse I and the spillway. Pacific lamprey that passed Bonneville Dam were active across the powerhouse outside of the collection channel, with the greater amount of activity at the north end of the powerhouse (monitor 8BO, antennas 1 and 3) at the large entrances to the collection channel. Only one fish detected in the spillway eventually passed the dam at either the Bradford Island or Washington shore fish ladders.

Lamprey activity outside the collection channel at Powerhouse II is shown in Figure 6. Fish were detected across the powerhouse collection channel entrances. The greater amount of activity by lamprey outside the collection channel was at the south end of the Powerhouse II large entrances to the collection channel (monitor DBO, antennas 1, 4, and 5). The limited activity of radio-tagged lamprey from the passage group in the spillway channel (Fig. 5 BBO-1, CBO-1, CBO-2; Fig. 7 BBO-1, CBO-1) and the overall low collection-channel exits are notable. This suggests an obstacle for lamprey at the spillway entrances.

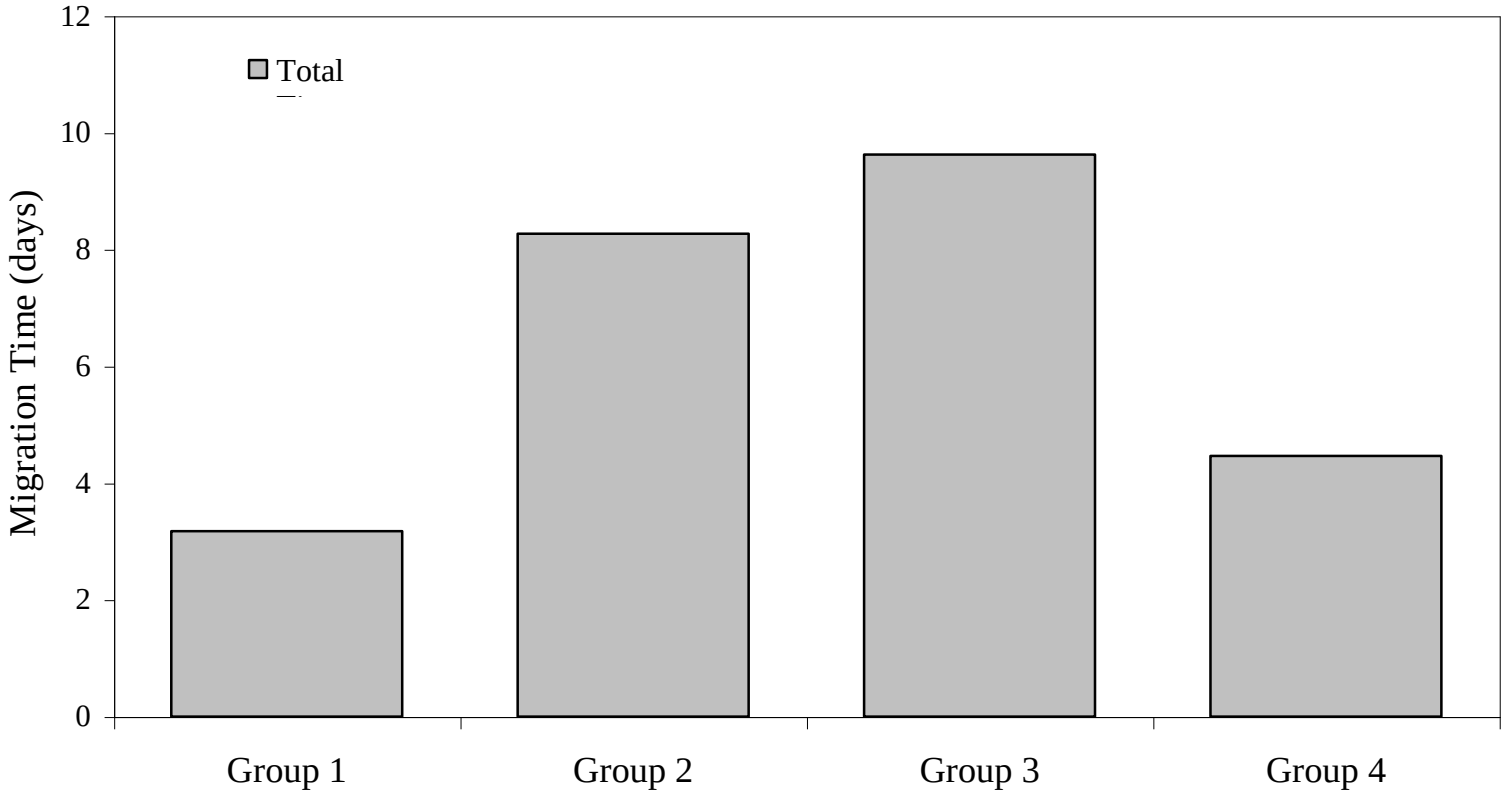

Figure 4c. Median time spent by radio-tagged Pacific lamprey at Bonneville Dam, 1996. Group 1 fish were only detected outside the collection channels; Group 2 fish migrated as far as the collection channel; Group 3 fish migrated into the fish ladder; Group 4 are fish migrated upstream from Bonneville Dam.

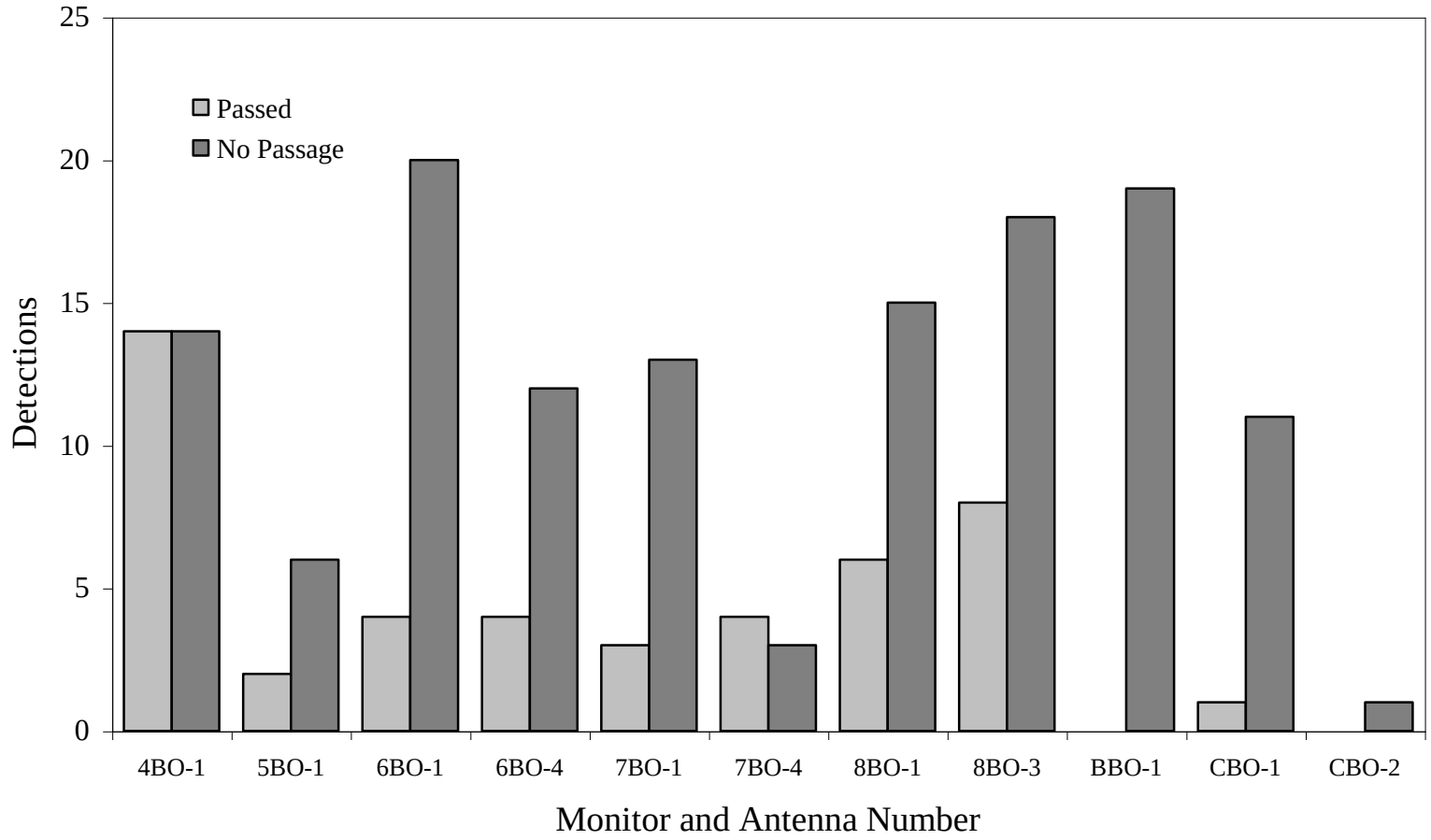

Figure 5. Number of first detections at receiver sites outside of the collection channel at Powerhouse I and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

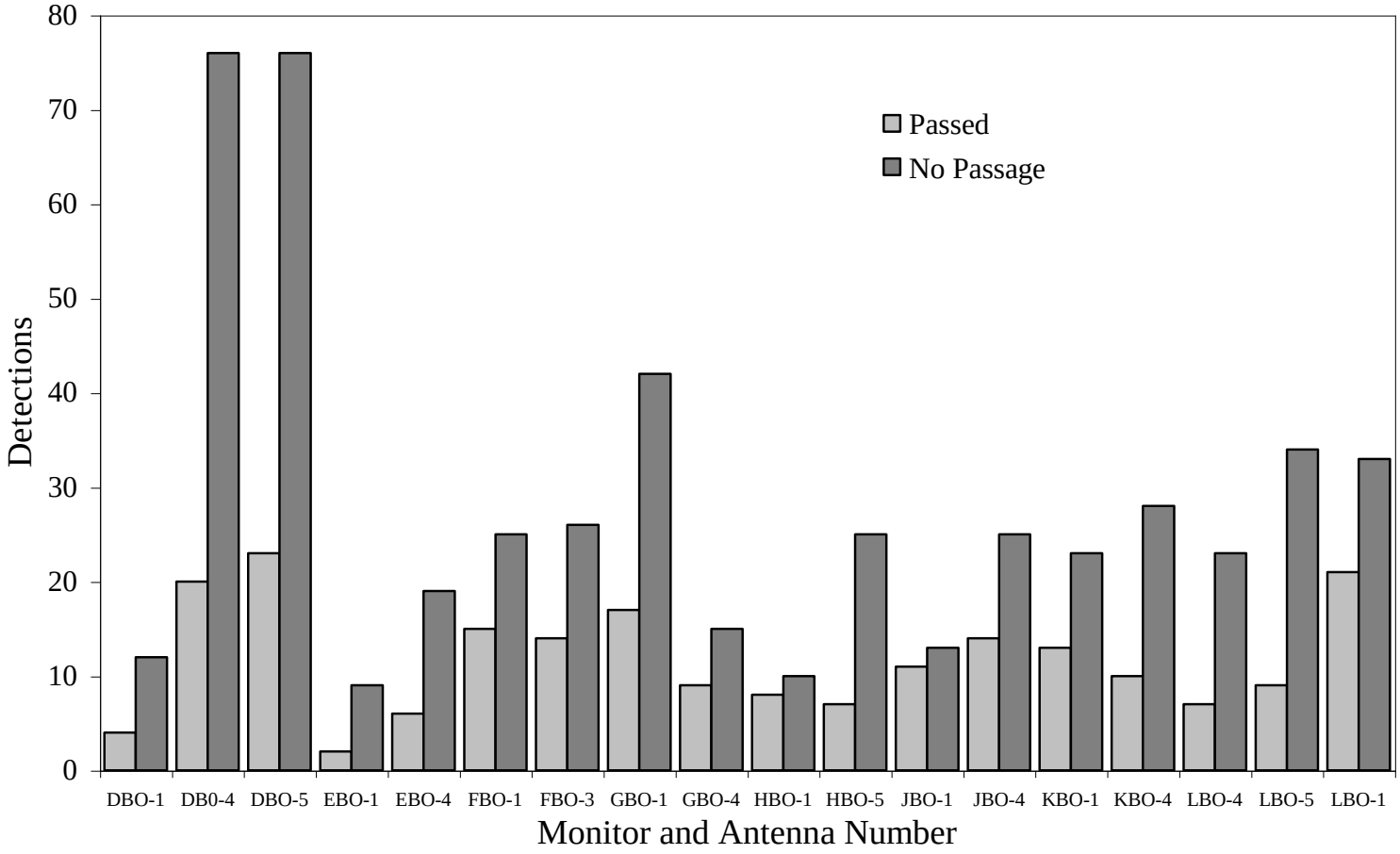

Figure 6. Number of first detections at receiver sites outside of the collection channel at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

Entrance activity of radio-tagged Pacific lamprey is shown in Figure 7 for Powerhouse I and Figure 8 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 had passed the dam was detected entering the collection channel at either of the spillway entrances. Fish that had passed the dam entered the collection channel either at the north or south end of Powerhouse II. Behavior at the collection channel of lamprey that did not pass the dam was similar to that of fish that passed the dam.

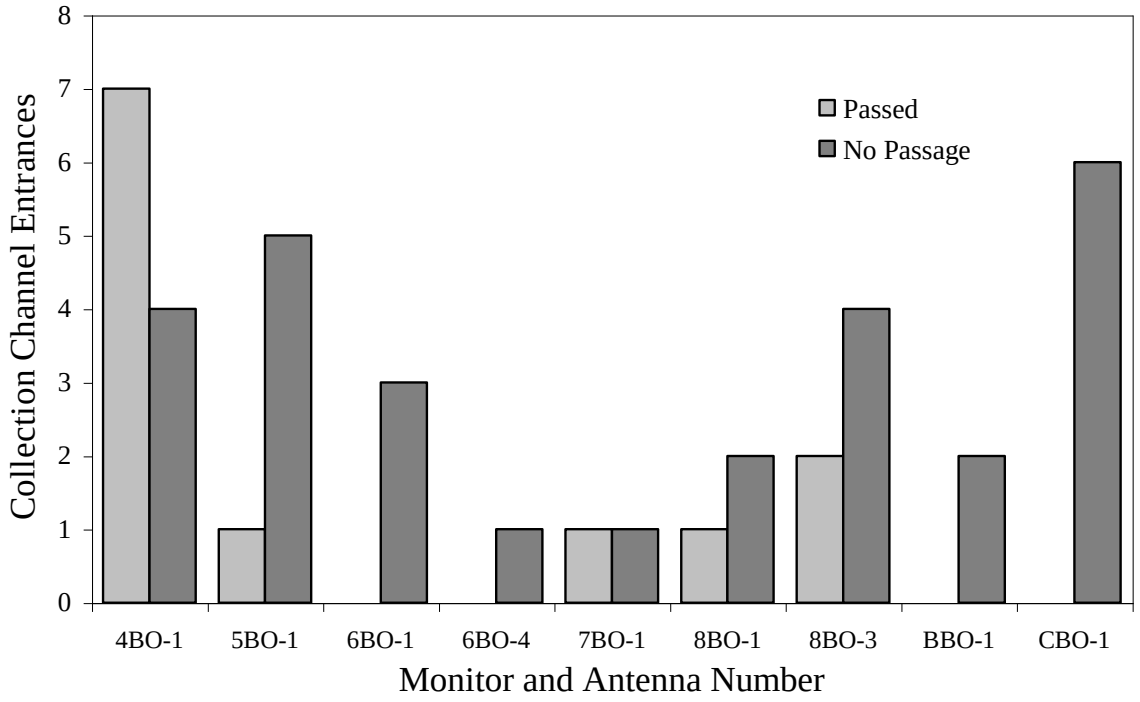

Figure 7. Number of collection channel entrances at Powerhouse I and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

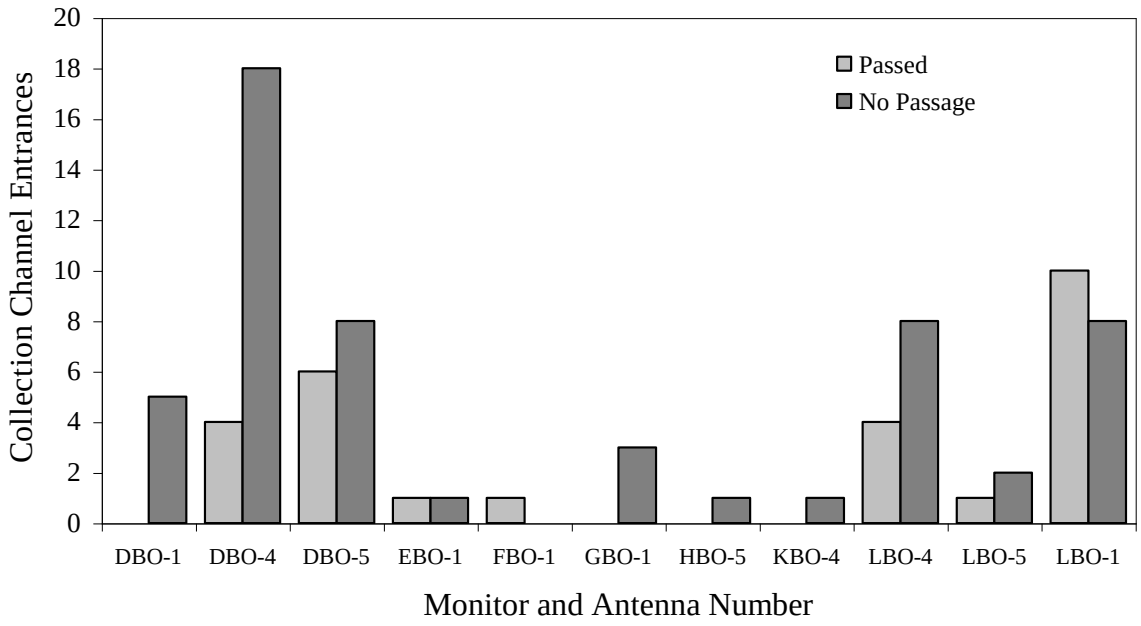

Figure 8. Number of collection channel entrances at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

Radio-tagged lamprey dropped out of the collection channel 21 times (passage tags 4, non-passage tags 17) at Powerhouse I and 11 times at the spillway entrances (Fig. 9). Lamprey dropped out of the collection channel 57 times (passage tags 17, non-passage tags 40) at Powerhouse II (Fig. 10). Activity of lamprey inside the collection channels at Powerhouses I and II are shown in Figures 11 and 12, respectively.

Pacific lamprey moved quickly within the collection channels (both upstream and downstream). 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 movement was relatively common for Pacific lamprey in Groups 1, 2, and 3.

Fish in Groups 1, 2, and 3 were last detected at several sites at Bonneville Dam. Twenty-one Pacific lamprey were last detected at spillway entrances, 12 at sites associated with the Powerhouse I collection channel, 15 at sites associated with the Powerhouse II collection channel, and 14 in the fish ladders. Of the tags recorded in the fish ladders, 10 were last detected in the Washington shore ladder and 4 in the Bradford Island ladder. Six of the 10 detected in the Washington shore ladder had progressed up the ladder to the counting station. Four of these six backed down the Upstream Migrant Transportation (UMT) channel, one backed down the main fish ladder, and one was last detected below the counting station. The other Washington shore fish ladder Pacific lamprey stopped downstream of the adult trap weir. The Bradford Island ladder fish were last detected downstream from the counting station (n = 2) and in the >A= branch, downstream from the junction pool with the >B= branch (n = 2).

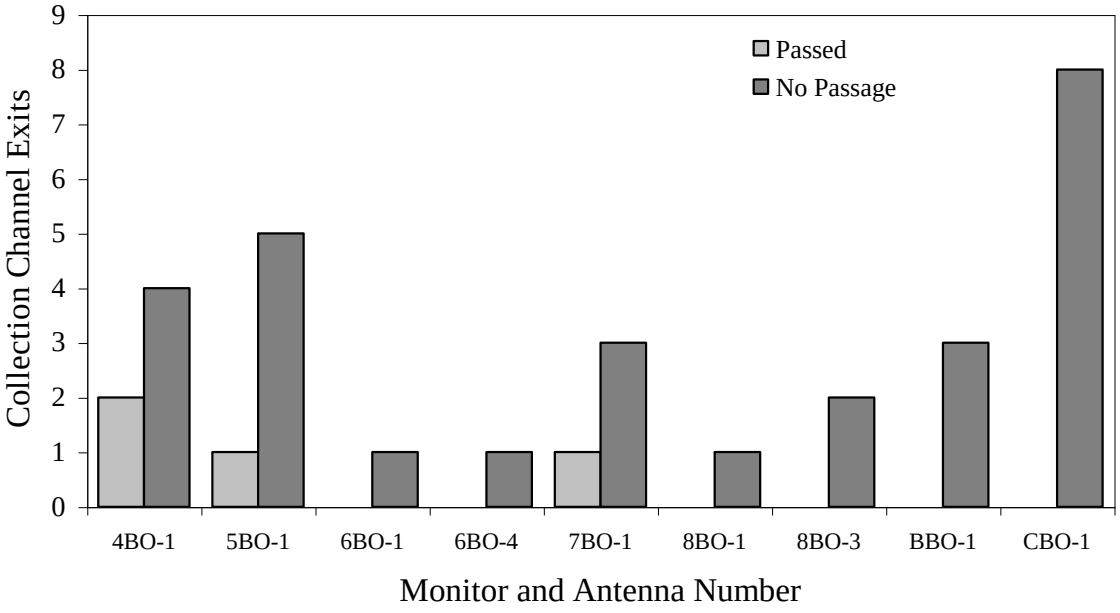

Figure 9. Number of collection channel exits at Powerhouse I and spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

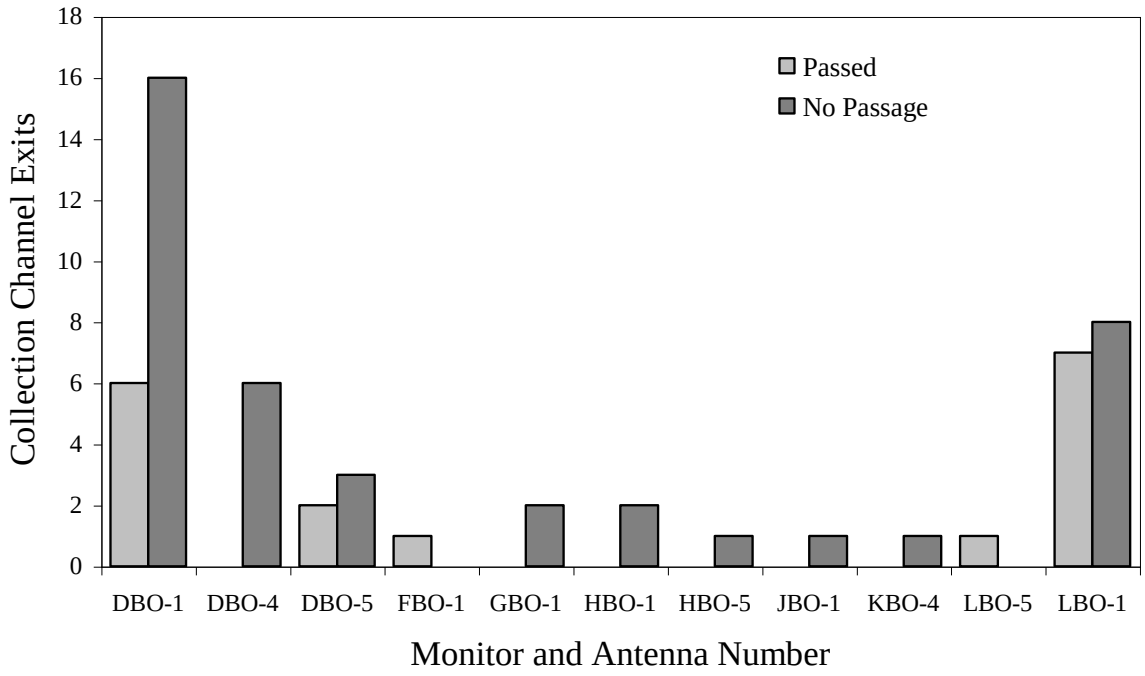

Figure 10. Number of collection channel exits at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

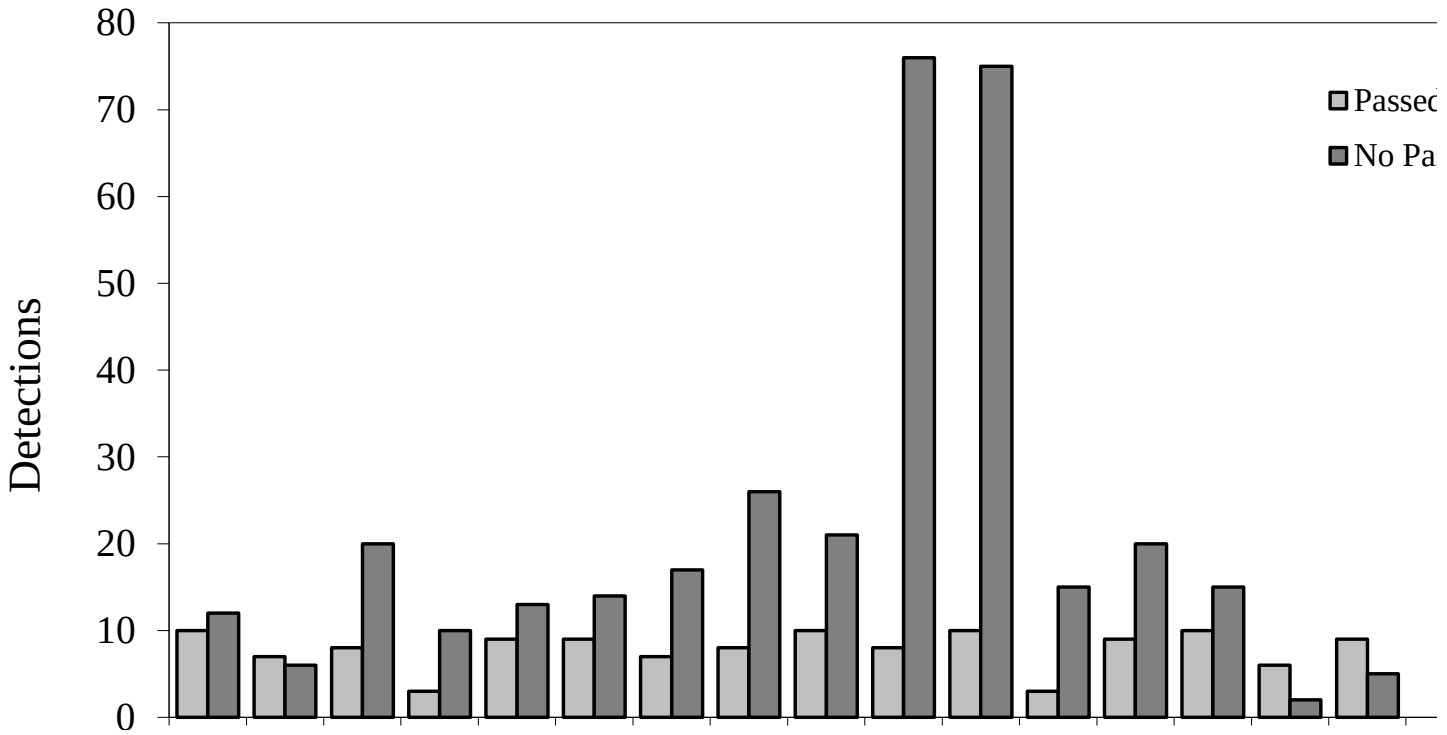

Figure 11. Number of first detections at receiver sites inside the collection channel at Powerhouse I and the spillway for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

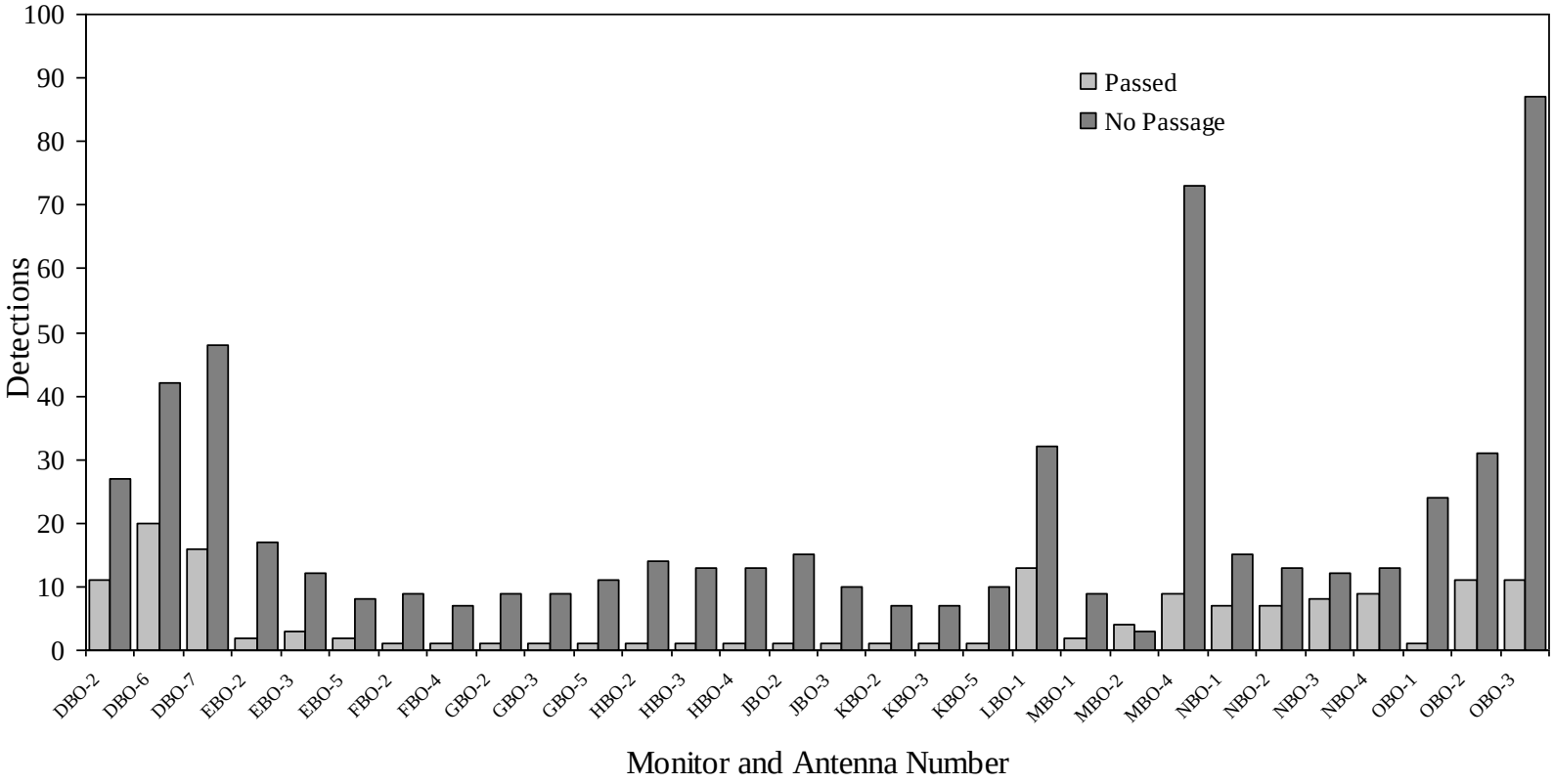

Figure 12. Number of first detections at receiver sites inside the collection channel at Powerhouse II for radio-tagged Pacific lamprey that passed and did not pass Bonneville Dam, 1996. Monitor and antenna locations are identified in Appendix A.

Eleven radio-tagged Pacific lamprey released downstream from Bonneville Dam were recorded on an upstream monitor. Eight of these fish were last detected on ladder-exit antennas at Bonneville Dam, three were last detected in the fish ladders, and six were recorded at The Dalles Dam. One of the six Pacific lamprey detected at The Dalles Dam reached John Day Dam, migrated upstream past McNary Dam, and was last recorded at Ice Harbor Dam on the Snake River. Five Pacific lamprey were recorded on monitors in Bonneville Reservoir tributaries: four of these were recorded in the Wind River and one was recorded in the Little White Salmon River.

Eleven radio-tagged Pacific lamprey that were released upstream from Bonneville Dam were detected at sites above the dam. Ten of these fish were recorded on monitors at The Dalles Dam; one dropped back and was detected in the White Salmon River. A total of four Pacific lamprey were recorded on monitors above The Dalles Dam: two fish migrated upstream and were detected at John Day Dam, and the other two were detected in the Deschutes River.

Our findings on radio-tagged lamprey that migrated past Bonneville Dam suggest that there are areas within the fish ladders that allow passage of lamprey without detection at the top of the ladder. Fish that did eventually pass Bonneville Dam did not utilize the collection channel entrances at either end of the spillway. Large accumulations of Pacific lamprey outside the spillway entrances were visually observed by National Marine Fisheries Service, University of Idaho, and U.S. Army Corps of Engineers employees. These entrances appear to present a barrier for upstream passage of Pacific lamprey.

Low passage rates of radio-tagged Pacific lamprey (21.3% of the downstream release) at first glance may suggest that there is a problem in the tagging technique. However, Bergstedt and Seelye (1995) found that sea lamprey did not appear to home as strongly as anadromous salmonids. They tagged 555 sea lamprey with coded-wire tags and recaptured returning adults 2 years later. Of the sea lamprey caught in the stream where fish were tagged, none had coded-wire tags. If this behavior is similar in Pacific lamprey, the lack of passage in radio-tagged Pacific lamprey may not result from a tag effect, but may relate to other sensory cues that attract lamprey to spawning streams.

ACKNOWLEDGMENTS

Special thanks go to Lyle Gilbreath, National Marine Fisheries Service, for his assistance in modifying the lamprey trap. For their help with tagging, release, and tracking lamprey we thank Dennis Quaempts and Sarah Patrick of the University of Idaho Cooperative Fish and Wildlife Research Unit.

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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)
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

Appendix Table A. Continued.

Monitor Number	Monitor location	River Km	Antenna number	Antenna location
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
	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
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 junction 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

Appendix Table A. Continued.

Monitor Number	Monitor location	River Km	Antenna number	Antenna location
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