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RADIO TELEMETRY ASSESSMENTS OF MIGRATION PATTERNS AND FALLBACKS OF ADULT SALMON AND STEELHEAD IN THE FOREBAY OF BONNEVILLE DAM, 1997-1998

by

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Table of Contents

List of Figures iii
List of Tables iv
Abstract v
Introduction 1
Methods 4
  Tagging 4
  Radio Tracking 5
1997 Results 6
  Migration Routes 6
    Chinook salmon 9
    Sockeye salmon 12
    Steelhead 15
  Migration Times 18
    Chinook salmon 18
    Sockeye salmon 18
    Steelhead 18
  Fallback Rates 21
    Chinook salmon 21
    Sockeye salmon 22
    Steelhead 22
1998 Results 23
  Migration Routes 23
  Migration Times 25
  Fallback Rates 26
Discussion 26
References 29

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List of Figures

1. Map of the Columbia River basin with the location of Columbia and Snake River dams 2

2. River flow, spill, temperature, and secchi disk visibility at Bonneville Dam, 1997 and 1998 3

3. Map of Bonneville Dam study area 5

4. Location of radio-receiver antennas at Bonneville Dam in 1997 and 1998 . . 6

5. Location of the radio-receiver site at the Bridge of the Gods in 1997 and 1998 8

6. Movements of a chinook salmon following the Bradford Island shore into the spillway and falling back at Bonneville Dam, 1997 9

7. Movements of a chinook salmon from the Bradford Island shore crossing the spillway to the north shore in the forebay of Bonneville Dam, 1997 10

8. Movements of a chinook salmon along the Bradford Island shore crossing the channel to the Oregon shore in the forebay of Bonneville Dam, 1997 10

9. Movements of a chinook salmon crossing the face of powerhouse I to the Oregon shore in the forebay of Bonneville Dam, 1997 11

10. Composite map of chinook salmon movements in the forebay of Bonneville Dam, 1997 11

11. Movements of a sockeye salmon following the Bradford Island shore into the spillway and falling back at Bonneville Dam, 1997 12

12. Movements of a sockeye salmon from the Bradford Island shore crossing the spillway to the north shore in the forebay of Bonneville Dam, 1997 13

13. Movements of a sockeye salmon along the Bradford Island shore crossing the channel to the Oregon shore in the forebay of Bonneville Dam, 1997 13

14. Movements of a sockeye salmon crossing the face of powerhouse I to the Oregon shore in the forebay of Bonneville Dam, 1997 14

List of figures (continued)

15. Composite map of sockeye salmon movements in the forebay of Bonneville Dam, 1997 14

16. Movements of a steelhead following the Bradford Island shore into the spillway and falling back at Bonneville Dam, 1997 15

17. Movements of a steelhead from the Bradford Island shore crossing the spillway to the north shore in the forebay of Bonneville Dam, 1997 16

18. Movements of a steelhead along the Bradford Island shore crossing the channel to the Oregon shore in the forebay of Bonneville Dam, 1997 16

19. Movements of a steelhead crossing the face of powerhouse I to the Oregon shore in the forebay of Bonneville Dam, 1997 17

20. Composite map of steelhead movements in the forebay of Bonneville Dam, 1997 17

21. Composite map of chinook salmon movements in the forebay of Bonneville Dam, 1998 24

List of Tables

1. Migration routes of salmon and steelhead in the forebay of Bonneville Dam, 1997 7

2. Migration rates of chinook salmon in the forebay of Bonneville Dam, 1997 19

3. Migration rates of sockeye salmon and steelhead in the forebay of Bonneville Dam, 1997 20

4. Migration rates of steelhead in the forebay of Bonneville Dam, 1997 21

5. Migration routes of chinook salmon in the forebay of Bonneville Dam, 1998 24

6. Migration rates of chinook salmon in the forebay of Bonneville Dam, 1998 25

Abstract

Migration routes of adult spring and summer chinook *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka*, and steelhead *O. mykiss* were monitored in the forebay of Bonneville Dam in 1997 to obtain information that could be used to reduce fallback of adults at the dam. Adult spring and summer chinook salmon were also radio-tracked in 1998 as a continuation of the 1997 study. In 1996, we determined in the adult passage studies that significant numbers of chinook salmon fell back over Bonneville Dam, and that most of the fallbacks were fish that had passed the dam via the Bradford Island fishway. In 1997, 991 adult spring and summer chinook salmon, 577 sockeye salmon, and 975 steelhead were trapped at Bonneville Dam, outfitted with radio transmitters, and released downstream from the dam. In 1998, adult spring/summer (957 fish) and fall chinook salmon (1022 fish) were trapped, tagged and released downstream from Bonneville Dam, but only a sample of the spring/summer chinook salmon were tracked in the forebay. As the fish with transmitters reascended the dam and exited the Bradford Island fishway into the forebay, they were followed by boat to determine their route through the forebay of powerhouse I and on upstream. We were particularly interested in routes that led to fallbacks at the dam. Because of high flows in 1997, there was an extended period of forced spill that lasted into July. During the April-July period, 122 spring/summer chinook salmon,110 sockeye salmon, and 10 steelhead in 1997, and 129 adult spring/summer chinook in 1998 were tracked in the forebay of Bonneville Dam.

In 1997 and 1998, radio tracked adult salmon and steelhead moved along four migrations routes after leaving the Bradford Island fishway: 1) along the south shore of Bradford Island to the spillway (90 fish in 1997 with 43 fallbacks; 39 fish in 1998 with 20 fallbacks), 2) along the shore of Bradford Island then across the forebay of the spillway to the Washington shore (56 fish; 60 fish), 3) along Bradford Island to the upstream end then across to the Oregon shore (71 fish; 19 fish), and 4) across the powerhouse I forebay to the Oregon shore and then upstream (16 fish; 8 fish). Twenty-one percent (26 of 122 fish) of the chinook salmon and 14% (16 of 110) of the sockeye salmon tracked in 1997 fell back over Bonneville Dam. In 1998, 15% (20 of 129) of the chinook salmon tracked fell back at the dam.

Mean migration time for all species combined (n=126) from the Bradford Island fishway exit upstream to the receiver at the Bridge of the Gods in 1997 was 0.41 d, with a range of 0.03 to 8.01 d, and a median travel time of 0.08 d. Mean times for each species to pass the Bridge of the Gods were 0.42 d for steelhead (8 fish), 0.62 d for chinook salmon (59 fish), and 0.19 d for sockeye salmon (57 fish). Median travel times for all three species in 1997 were similar, ranging from 0.08 to 0.11 d. In 1998, mean migration time for spring and summer chinook (n=103) from the Bradford Island fishway exit to the receiver at the Bridge of the Gods was 0.19 d with a range of 0.03 to 4.80 d, and a median of 0.07 d.

Introduction

This study of adult salmon *Oncorhynchus* spp. and steelhead *O. mykiss* migration routes in the forebay of Bonneville Dam was undertaken to gain information that could be used to reduce the number of adults that fall back over the dam. Adult salmon and steelhead migrating back to spawning grounds must pass up to nine dams on their return to spawning areas and hatcheries (Figure 1). Passage of salmon at the dams takes longer than if the dams were not present, and if a fish falls back over the dam the delay is usually extended and may lessen the fish's chances of reaching its spawning area.

Fallback rates for salmon at Bonneville Dam are relatively high (Young et al. 1978; Ross 1983; Bjornn and Peery 1992), perhaps because it is the first dam that returning salmon must pass and because one of the two fishways is on Bradford Island and adults tend to migrate along shorelines (Monan and Liscom 1973; Gibson et al. 1979; Turner et al. 1984). As adults leave the exit of the Bradford Island fishway, some of the fish migrate upstream along the island and over into the forebay of the spillway. If there is spill, the fish may fall back over the dam through the spillways. Relatively few fish fall back through the dam past the turbines, and a limited number fall back via the ice and trash sluiceways when they are in use.

In two separate studies, a deflector net was used in an attempt to reduce fallback at Bonneville Dam. Liscom et al. (1977) placed a 46-m deflector net upstream of the Bradford Island fish exit to try to divert fish to the Oregon shore. They concluded the net was unsuccessful because the majority of the fish swam around the end of the net and continued up the Bradford Island shore. Young et al. (1978) conducted a similar study at the same location using a 76-m deflector net. Once again the net was deemed ineffective at diverting fish to the Oregon shore, and it was suggested the fishway exit be moved to the Oregon shore.

In 1996, spring runoff flows were higher than normal and Bjornn et al. (1998c) determined that 13.8% (112 of 809 fish) of all chinook salmon *O. tshawytscha* with transmitters that passed over Bonneville Dam fell back one or more times, and that 81% of the fish that fell back had passed through the Bradford Island fishway. In 1997,

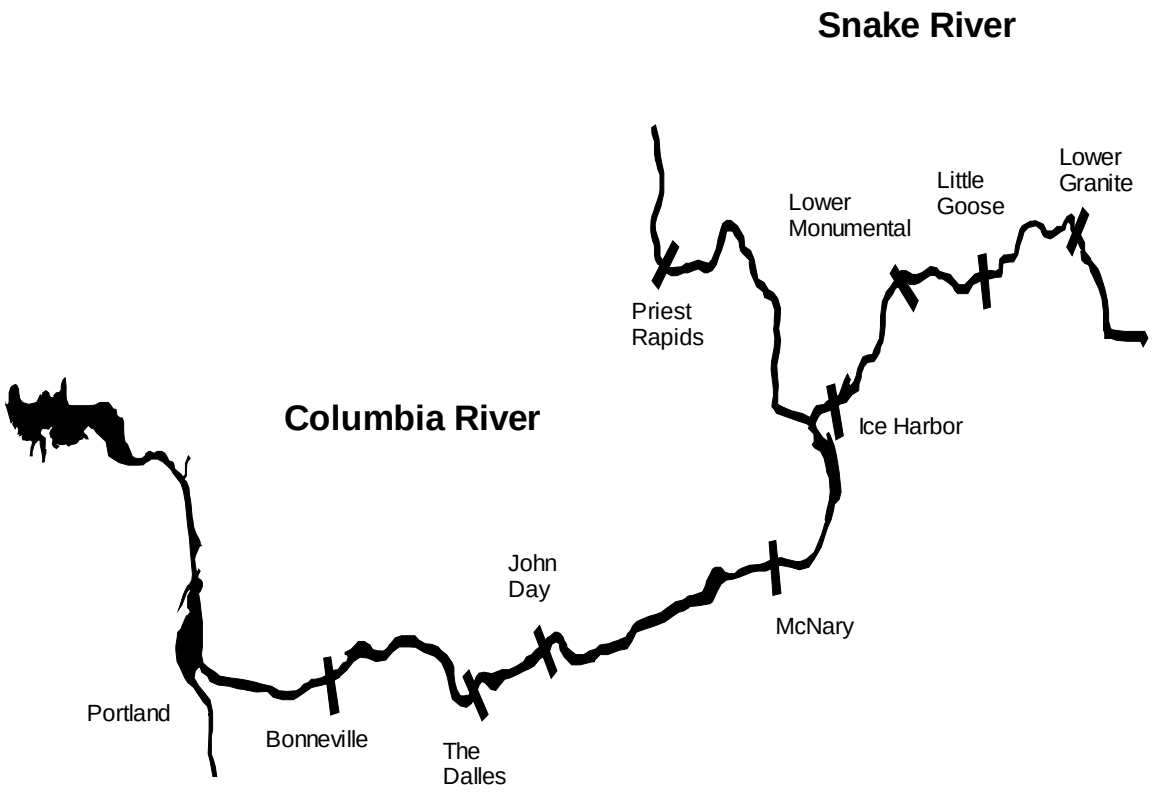

Figure 1. Map of the Columbia River basin with the location of Columbia and Snake River dams.

river flow was higher than in 1996, peaked at 556 kcfs, averaged 387 kcfs during the tracking period, and the large amount of spill (Figure 2) contributed to 15.1% (143 of 946) of the chinook salmon falling back over the dam, 71% of which had passed via the Bradford Island fishway. River flows were closer to normal in 1998 with a peak of 420 kcfs and average 256 kcfs during the tracking period. The percentage of chinook salmon falling back over Bonneville Dam was lower (12.3%, 114 of 925) than in 1996 or 1997, but a high percentage of salmon that fell back used the Bradford Island fishway (70%) as in prior years. In 1997, 11.5% of the tagged sockeye salmon *O. nerka* and 5.2% of the steelhead fell back at Bonneville Dam, and 97% of the fish that fell back used the Bradford Island fishway to pass the dam.

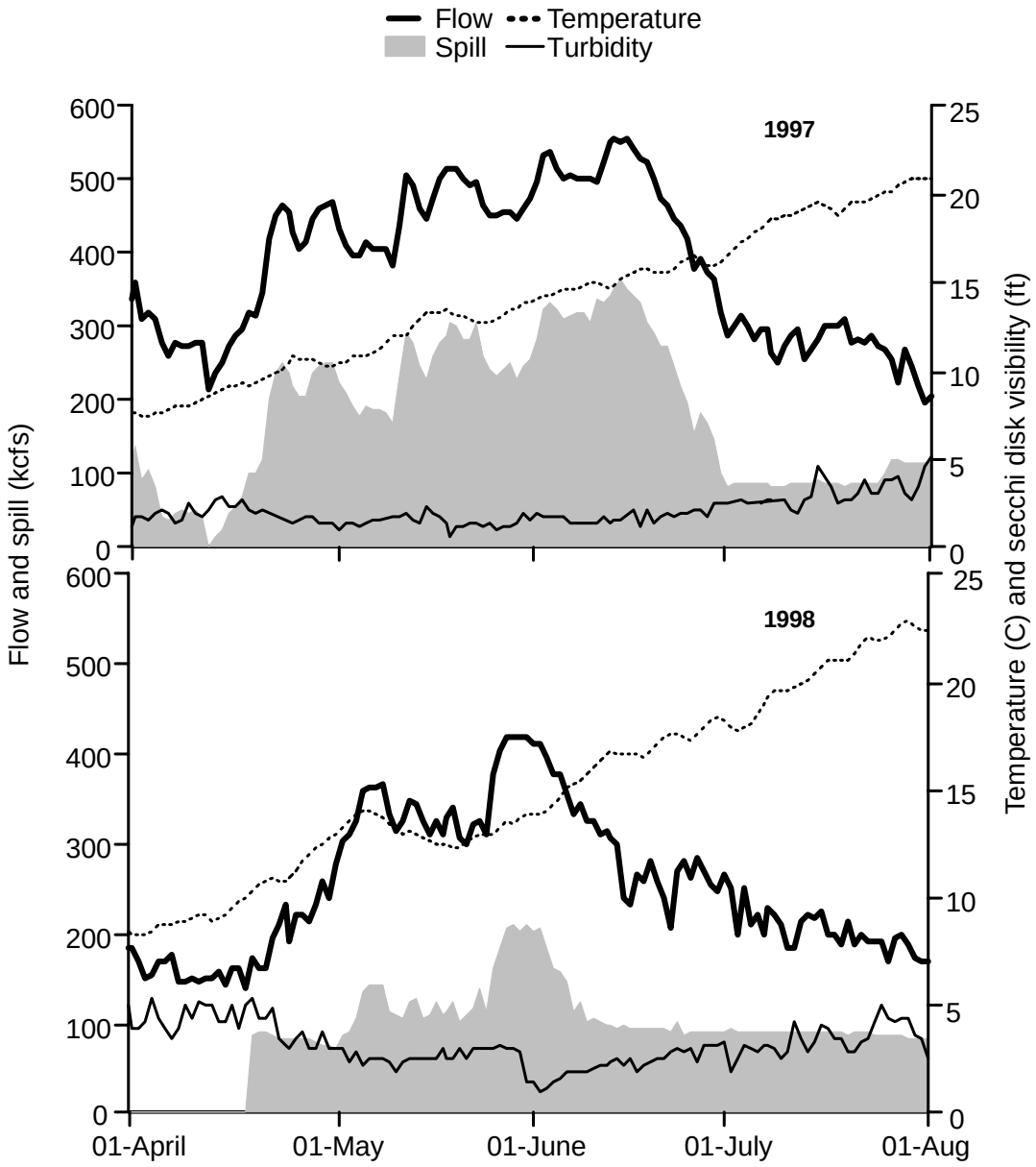

Figure 2. River flow, spill, water temperature, and turbidity at Bonneville Dam during April-July 1997 and 1998.

In the 1997 and 1998 studies, we assessed the routes salmon took after leaving the Bradford Island fishway and the proportion of fish that took each route. The purpose was to discover the migration patterns of adult salmon in order to reduce future fallback events. Fallback events inflate fish counts at the dam when the fish reascend the dam. The fish counts are important indexes of run size and provide information used to set harvest seasons and limits.

In past research on loss of fish between Bonneville and The Dalles dams few problems with fish passage were found once fish reached The Dalles Dam (Monan and Liscom 1979). Fish exiting the ladders at The Dalles Dam proceeded upstream along the shorelines and were not likely to fall back. At Bonneville Dam, however, they reported that fish spent a considerable amount of time passing the dam and delays from fallbacks.

Methods

Tagging

In 1997 and 1998, adult salmon and steelhead were captured and radio tagged at the adult fish collection lab at Bonneville Dam (rkm 235.1). Fish were diverted from the Washington-shore fish ladder into a large tank with two false weirs. After passing over a false weir, fish slid down a flume chute into a holding tank containing an anesthetic (MS-222). After the fish were immobile, they were placed in a wet bag and transferred to a trough where they were tagged, measured, sexed, inspected for marks and injuries, and the overall health of the fish was noted. An 80-mm long, 7-V or 45-mm long, 3-V radio transmitter (149 MHz) was placed in glycerol disinfectant and then inserted through the fish's esophagus into the stomach. A yellow, 1- x 3-mm numbered visual implant (VI) tag was injected in the clear tissue posterior to the eye and a coded wire tag was injected into the dorsal muscle. Fish were then placed in a 600-gallon recovery tank and transported to release sites downstream from the dam: Dodson Landing rkm 225.6 (Oregon shore) and Skamania Landing rkm 224 (Washington shore).

Radio Tracking

Salmon and steelhead outfitted with radio transmitters were tracked from the Bradford Island fishway exit through the forebays of powerhouse I and the spillway at Bonneville Dam. Two people tracked fish 8 h per day, 5 days per week, from April through July in a 17½ ft boat outfitted with a six-element yagi antenna and a Lotek SRX 400 receiver. From the fishway exit, fish were tracked 2 to 3 km upstream. The channel-code, exit time, and migration route of each fish were recorded on a map of the forebay area (Figure 3). In addition to mobile trackers, fish passages were monitored with antennas/receivers set up at and upstream of the dam (Figure 4).

Location and time were recorded periodically on a map of the forebay area for each fish tracked and the data were later entered into spreadsheet and graphical software. Travel rates were estimated using spreadsheet software and migration patterns were plotted to create individual and composite migration plots. Information on recaptured fish was obtained from upstream traps, hatcheries, and anglers.

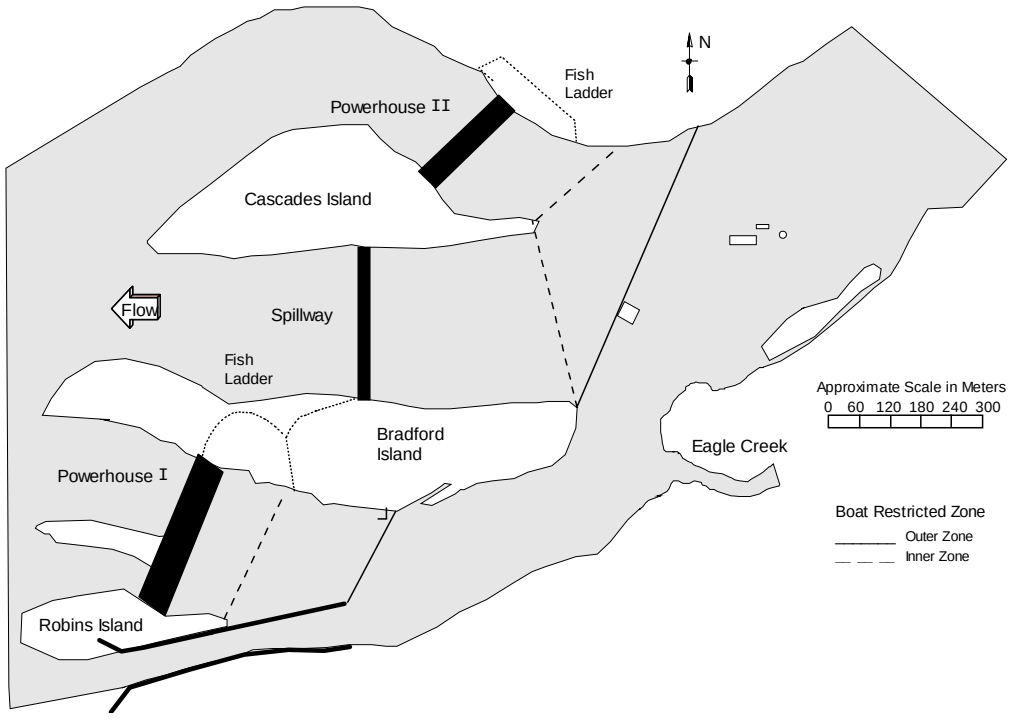

Figure 3. Map of Bonneville Dam study area.

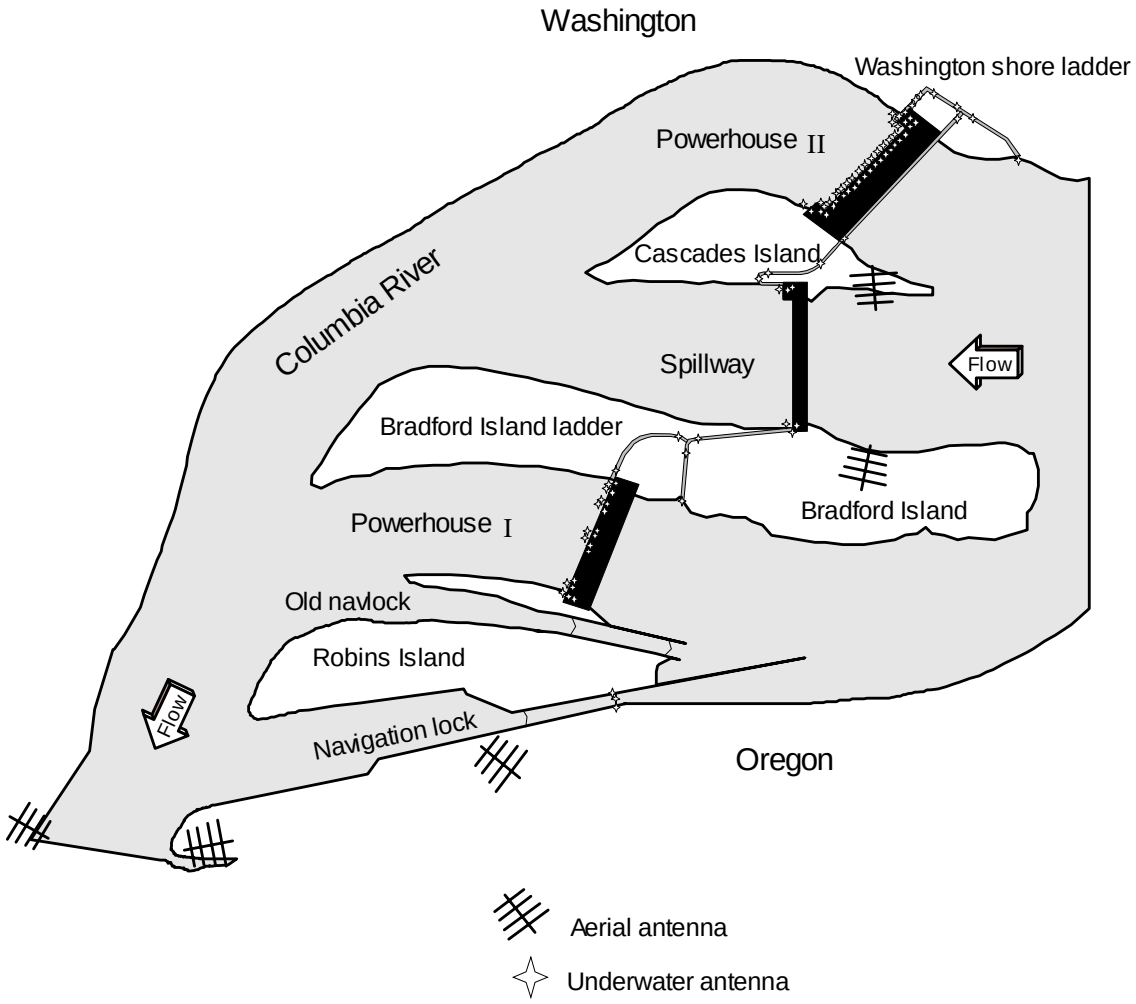

Figure 4. Location of radio-receiver antennas at Bonneville Dam in 1997 and 1998.

1997 Results

Migration Routes

In all 242 adult salmon and steelhead with transmitters were tracked in the forebay of Bonneville Dam in 1997: 122 spring/summer chinook salmon *O. tshawytscha*, 110 sockeye salmon *O. nerka*, and 10 steelhead (Table 1).

Most of the fish followed one of four routes after leaving the Bradford Island fishway: 1) upstream along Bradford Island shore to the forebay of the spillway (90 fish) where

they fell back over the dam (43 fish) or were lost (47 fish), 2) along Bradford Island shore then across the spillway forebay to the Washington shore and then upstream (56 fish), 3) along Bradford Island shore to the upstream end of the island then across the channel to the Oregon shore then upstream (71 fish), and 4) across the powerhouse I forebay to the Oregon shore then upstream (16 fish).

Table 1. Migration routes of salmon and steelhead in the forebay of Bonneville Dam, 1997.

Routes	Spring chinook	Summer chinook	Sockeye	Steelhead	Total
Bradford Island shore to spillway forebay	28	5	13	1	47
Bradford Island shore to spillway forebay - fallback	21	5	16	1	43
Bradford Island shore across spillway to Washington shore	15	9	30	2	56
Bradford Island shore across to Oregon shore	14	6	46	5	71
Bradford Island fishway across powerhouse I to Oregon shore	5	7	3	1	16
Other routes	7	0	2	0	9

Forty-seven fish were tracked from Bradford Island into the spillway area, but their routes after that are presently unknown; unknown routes may be determined when general migration analyses have been completed. Six fish were tracked twice; they had fallen back over the dam and reascended the Bradford Island fishway a second time. Of the 242 salmon and steelhead tracked in the forebay, 138 were recorded on the receiver at the Bridge of the Gods (rkm 238.6) and 72 were recaptured by anglers or at upstream hatcheries (Figure 5).

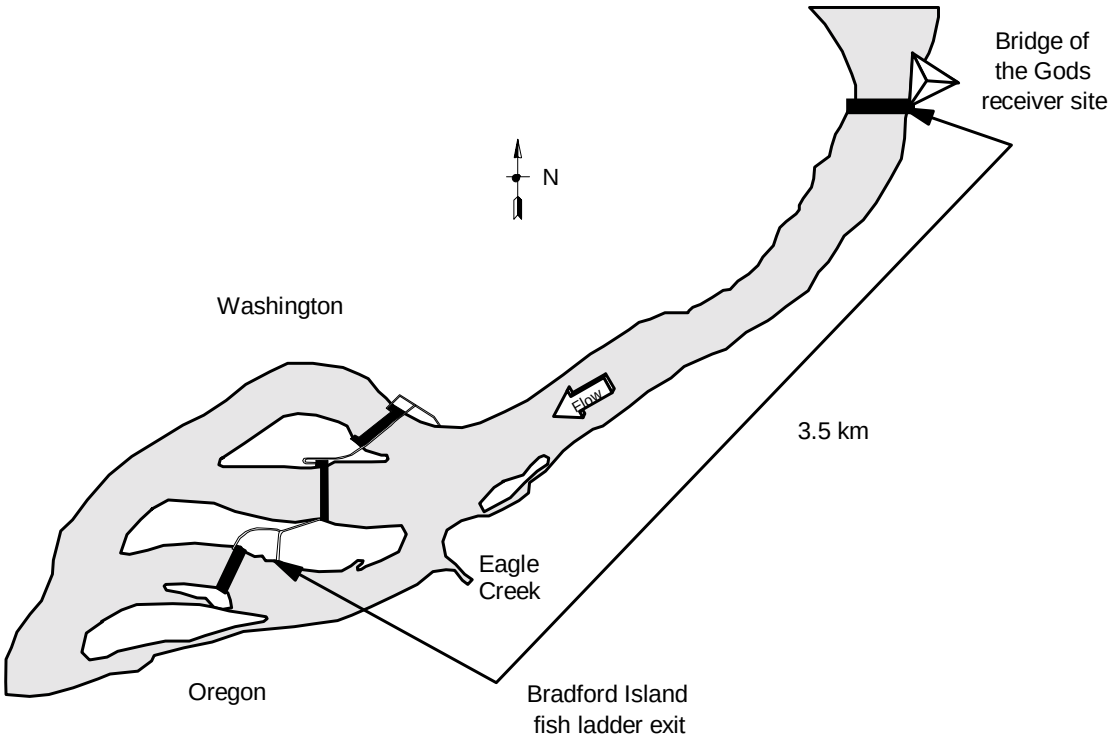

Figure 5. Location of the radio-receiver site at the Bridge of the Gods in 1997 and 1998.

Originally, 132 chinook salmon and 111 sockeye salmon were tracked, however ten chinook salmon and one sockeye salmon tracked in 1997 were not included the fallback analysis or in migration route totals. Four of the chinook salmon and one of the sockeye salmon tracked in the powerhouse I forebay had passed over the dam via the Washington-shore fishway, migrated across the forebay, and were found in the Powerhouse I forebay. The fish were located in front of the Bradford Island fish ladder and tracked as they moved upstream. They followed similar routes out of the powerhouse I forebay as fish that exited the Bradford Island fishway. The other six chinook salmon excluded from the analysis were fish that had exited the Bradford Island fishway a day or more before they were tracked.

Chinook salmon.-A total of 122 adult chinook salmon with transmitters were tracked in the forebay of Bonneville Dam in 1997. Most of the fish followed one of four routes (Figures 6-10) after leaving the Bradford Island fishway: 1) upstream along Bradford Island shore to the forebay of the spillway (59 fish with 26 fallbacks), 2) along Bradford Island shore then across the spillway forebay to the Washington shore and then upstream (24 fish), 3) along Bradford Island shore to the upstream end of the island then across the channel to the Oregon shore then upstream (20 fish), and 4) across powerhouse I forebay to the Oregon shore then upstream (12 fish). Four fish were tracked twice; they had fallen back over the dam and reascended the Bradford Island fishway a second time. Of the 122 salmon tracked in the forebay, 68 were recorded on the receiver at the Bridge of the Gods (rkm 238.6) and 52 were recaptured by anglers or at upstream hatcheries.

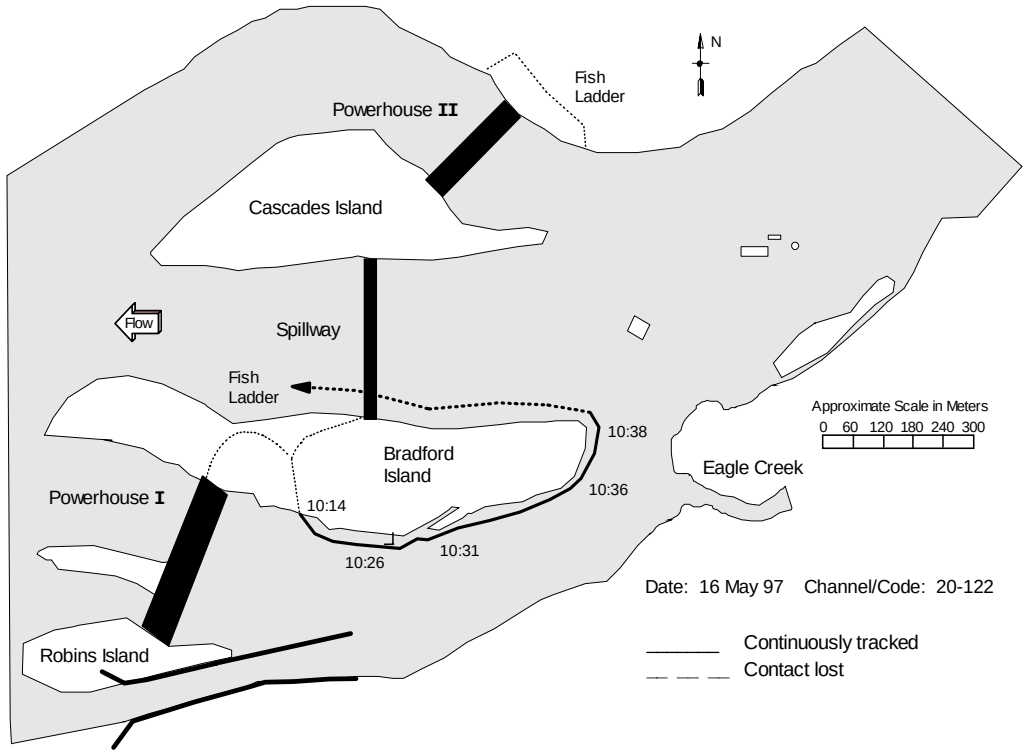

Figure 6. Movements of a chinook salmon following the Bradford Island shore into the spillway and falling back at Bonneville Dam, 1997.

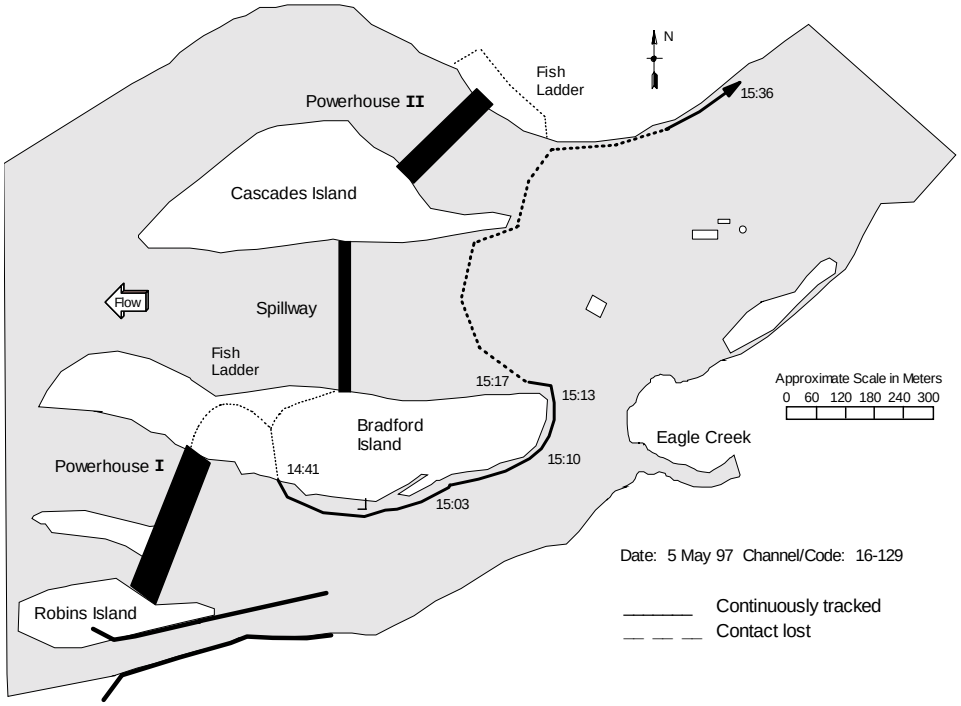

Figure 7. Movements of a chinook salmon from the Bradford Island shore crossing the spillway to the north shore in the forebay of Bonneville Dam, 1997.

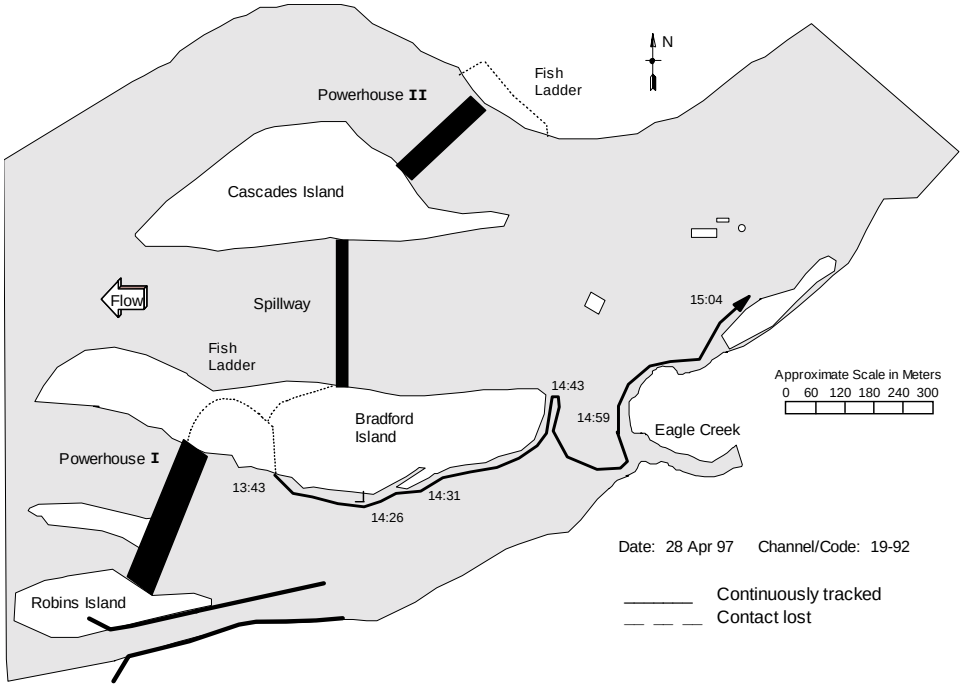

Figure 8. Movements of a chinook salmon along the Bradford Island shore crossing the channel to the Oregon shore in the forebay of Bonneville Dam, 1997.

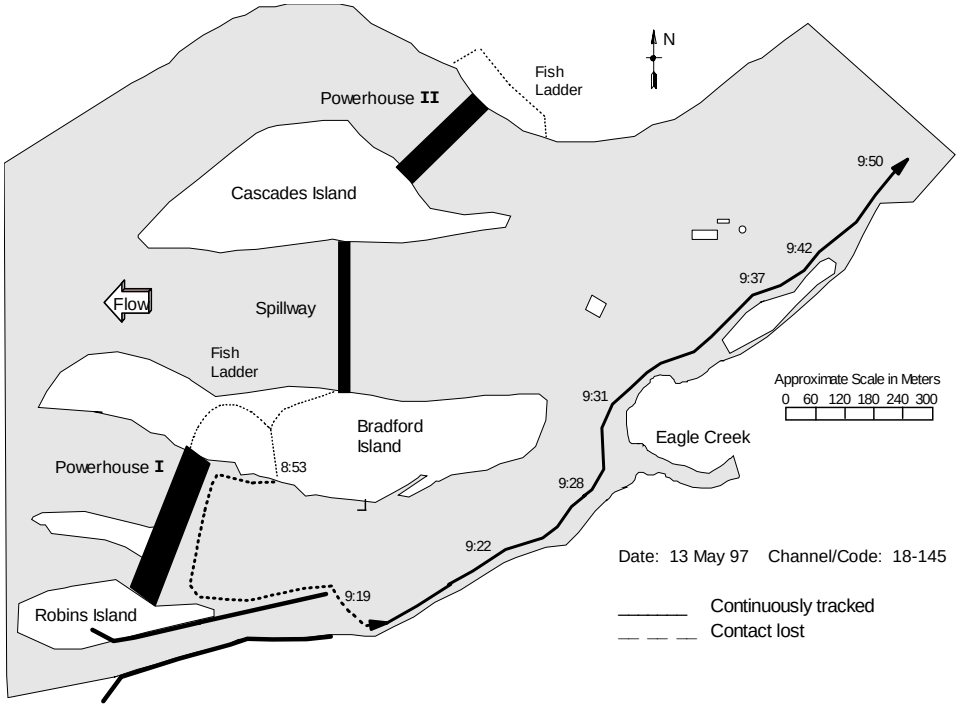

Figure 9. Movements of a chinook salmon crossing the face of powerhouse I to the Oregon shore in the forebay of Bonneville Dam, 1997.

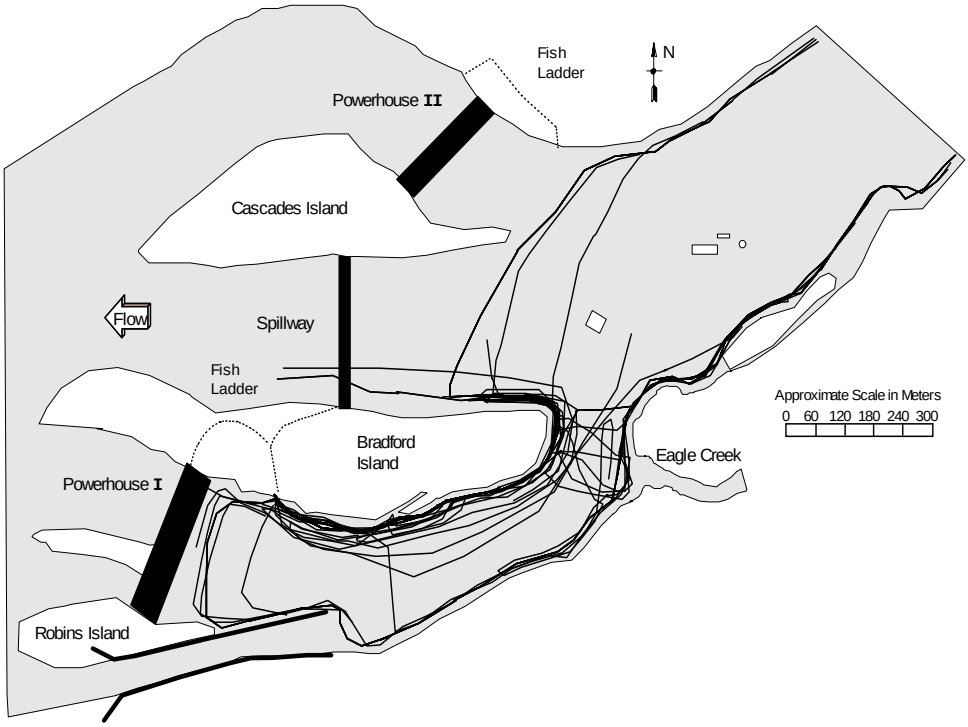

Figure 10. Composite map of chinook salmon movements in the forebay of Bonneville Dam, 1997.

Sockeye salmon.-A total of 110 adult sockeye salmon with transmitters were tracked in the forebay of Bonneville Dam in 1997. Most of the fish followed one of four routes (Figures 11-15) after leaving the Bradford Island fishway: 1) upstream along Bradford Island shore to the forebay of the spillway (29 fish with 16 fallbacks), 2) along Bradford Island shore then across the spillway forebay to the Washington shore and then upstream (30 fish), 3) along Bradford Island shore to the upstream end of the island then across the channel to the Oregon shore then upstream (46 fish), and 4) across powerhouse I forebay to the Oregon shore then upstream (3 fish). Two fish were tracked twice; they had fallen back over the dam and reascended the Bradford Island fishway a second time. Of the 110 salmon tracked in the forebay, 61 were recorded on the receiver at the Bridge of the Gods (rkm 238.6) and 14 were recaptured by anglers or at upstream hatcheries.

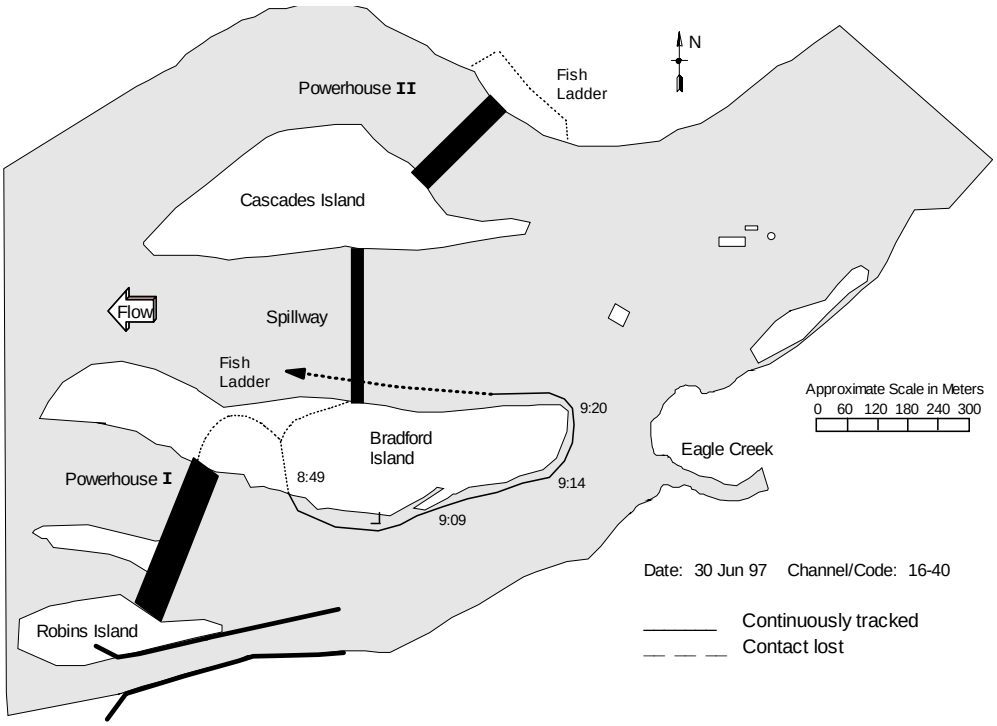

Figure 11. Movements of a sockeye salmon following the Bradford Island shore into the spillway and falling back at Bonneville Dam, 1997.

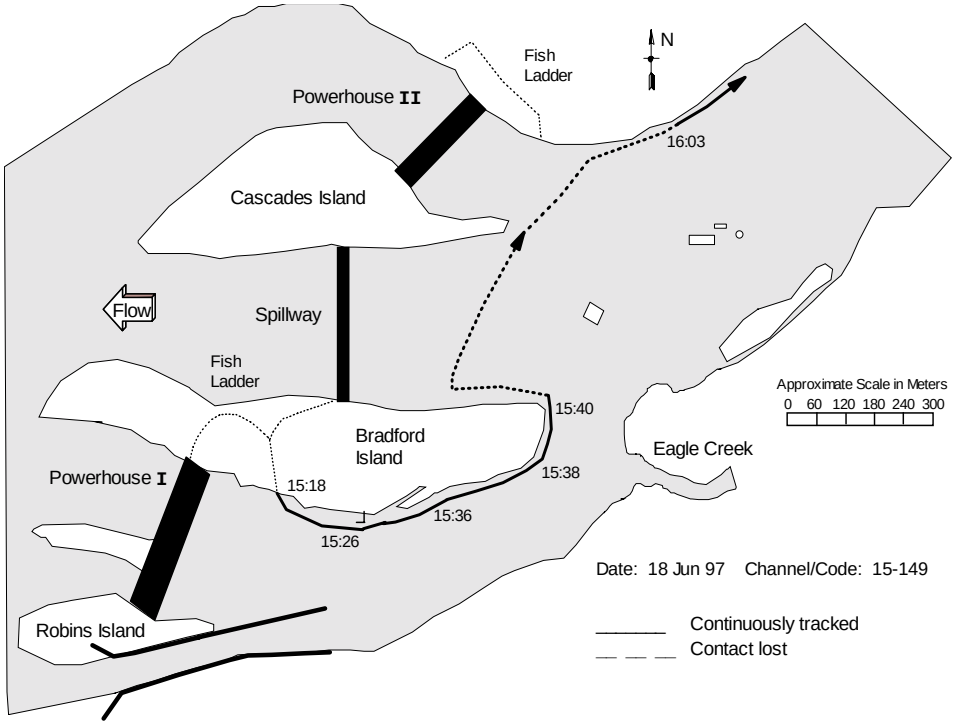

Figure 12. Movements of a sockeye salmon from the Bradford Island shore crossing the spillway to the north shore in the forebay of Bonneville Dam, 1997.

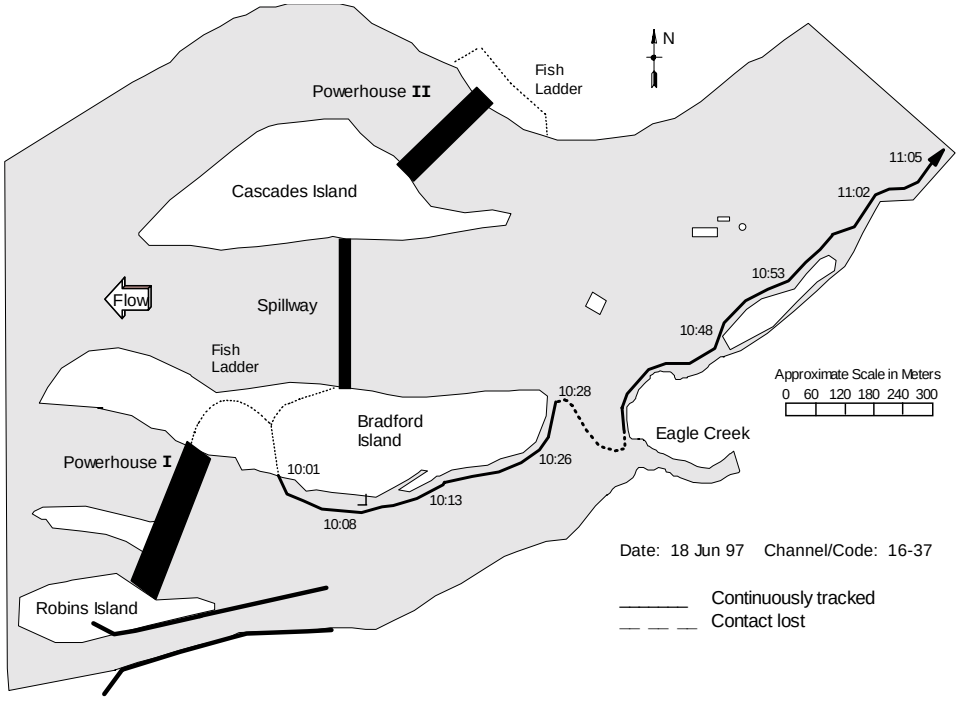

Figure 13. Movements of a sockeye salmon along the Bradford Island shore crossing the channel to the Oregon shore in the forebay of Bonneville Dam, 1997.

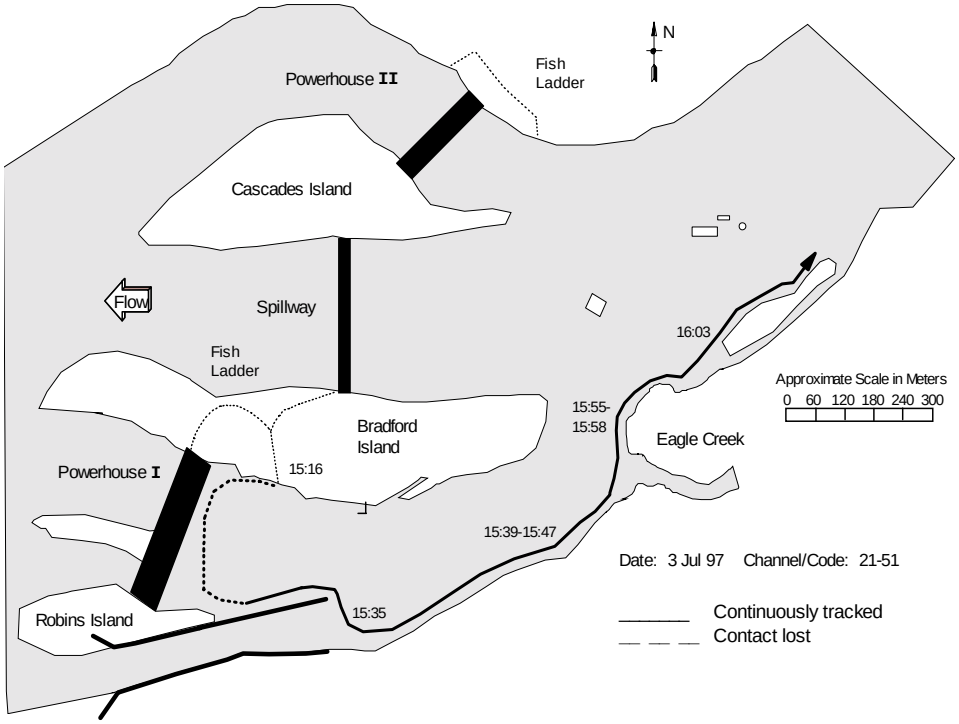

Figure 14. Movements of a sockeye salmon crossing the face of powerhouse I to the Oregon shore in the forebay of Bonneville Dam, 1997.

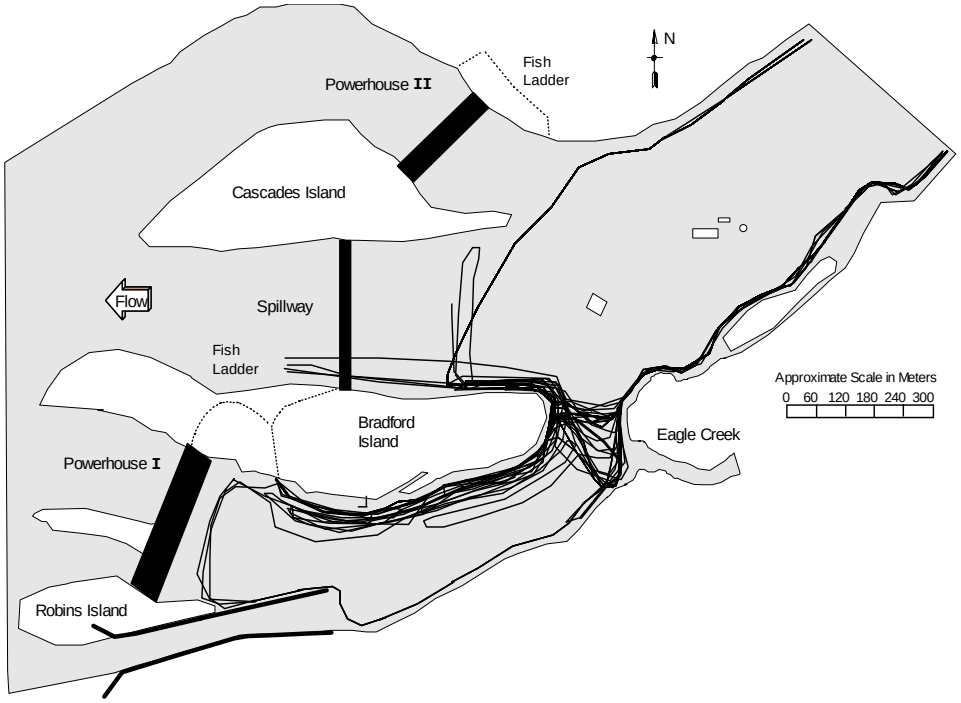

Figure 15. Composite map of sockeye salmon movements in the forebay of Bonneville Dam, 1997.

Steelhead.-Ten adult steelhead with transmitters were tracked in the forebay of Bonneville Dam in 1997. Most of the fish followed one of four routes (Figures 16-20) after leaving the Bradford Island fishway: 1) upstream along Bradford Island shore to the forebay of the spillway (1 fish and 1 fallback), 2) along Bradford Island shore then across the spillway forebay to the Washington shore and then upstream (2 fish), 3) along Bradford Island shore to the upstream end of the island then across the channel to the Oregon shore then upstream (5 fish), and 4) across the powerhouse I forebay to the Oregon shore then upstream (1 fish). Of the 10 steelhead tracked in the forebay, 9 were recorded on the receiver at the Bridge of the Gods (rkm 238.6) and 5 were recaptured by anglers or at upstream hatcheries.

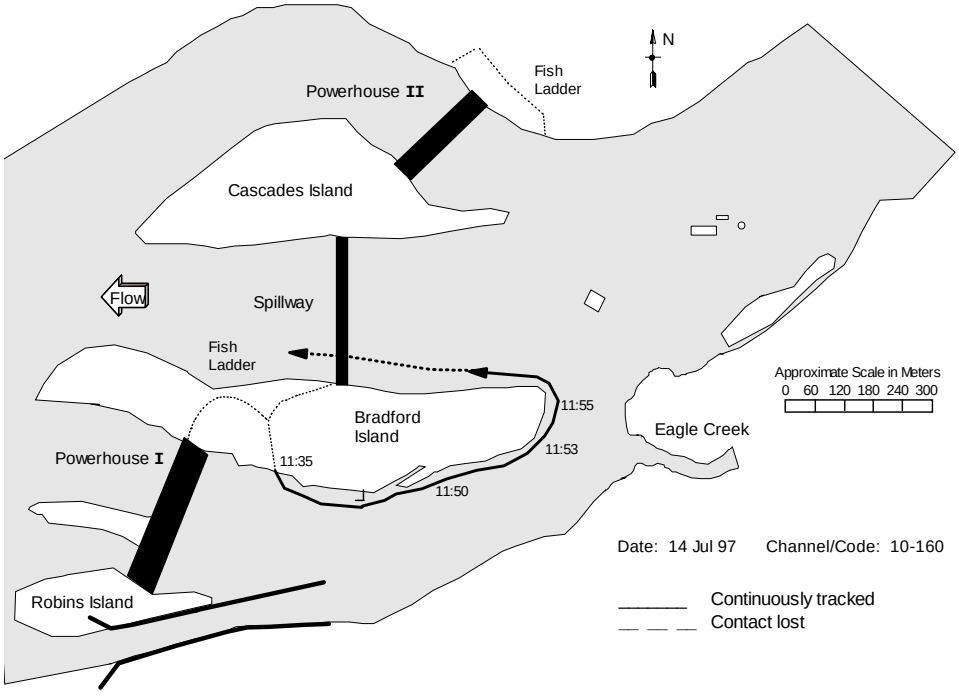

Figure 16. Movements of a steelhead following the Bradford Island shore into the spillway and falling back at Bonneville Dam, 1997.

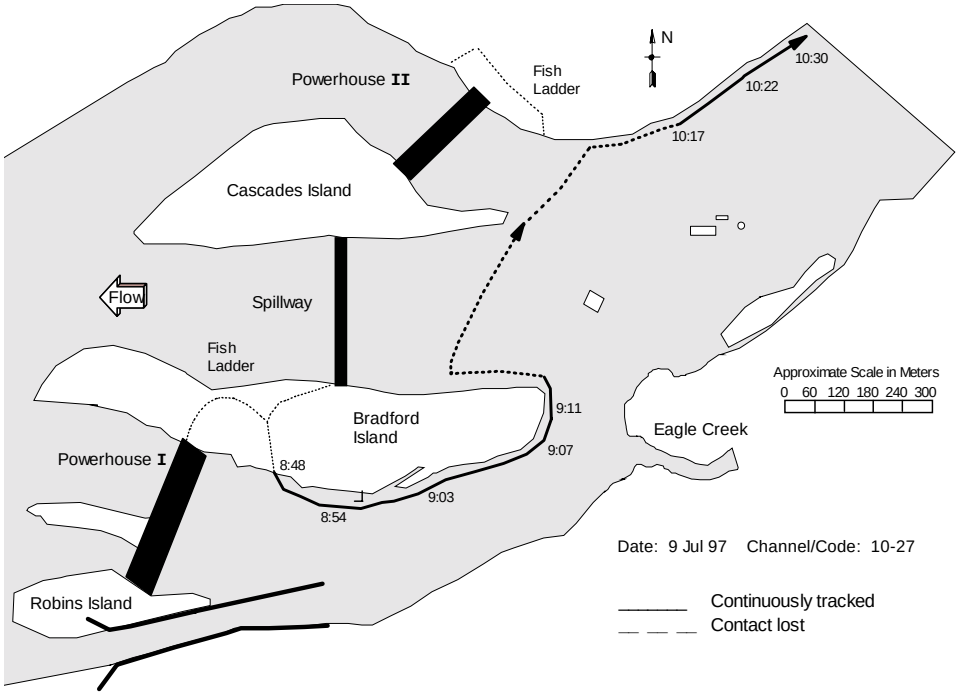

Figure 17. Movements of a steelhead from the Bradford Island shore crossing the spillway to the north shore at Bonneville Dam, 1997.

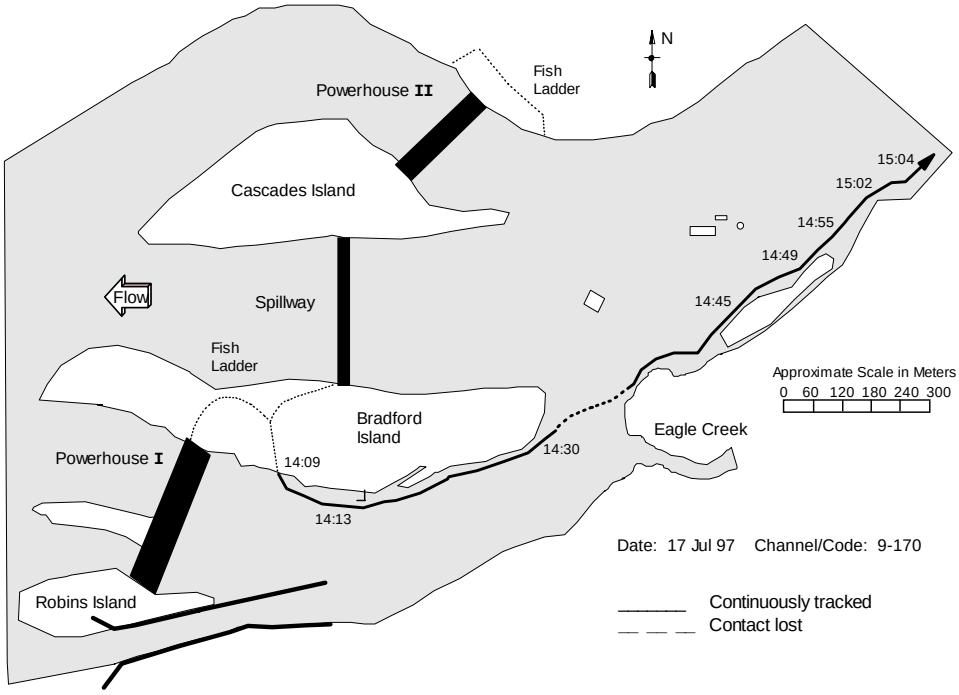

Figure 18. Movements of a steelhead along the Bradford Island shore crossing the channel to the Oregon shore at Bonneville Dam, 1997.

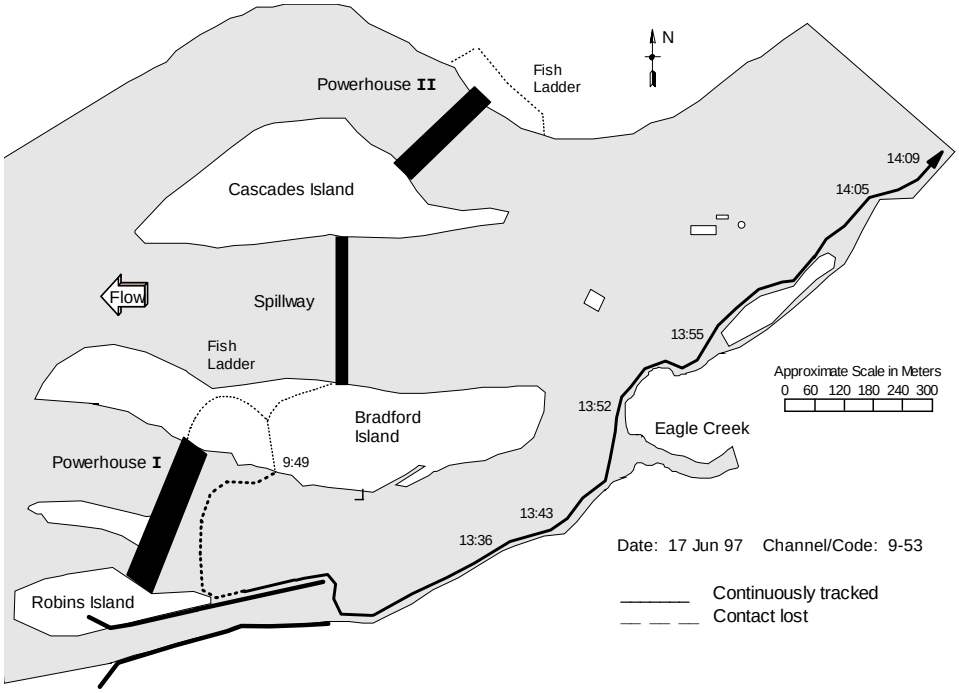

Figure 19. Movements of a steelhead crossing the face of powerhouse I to the Oregon shore in the forebay of Bonneville Dam, 1997.

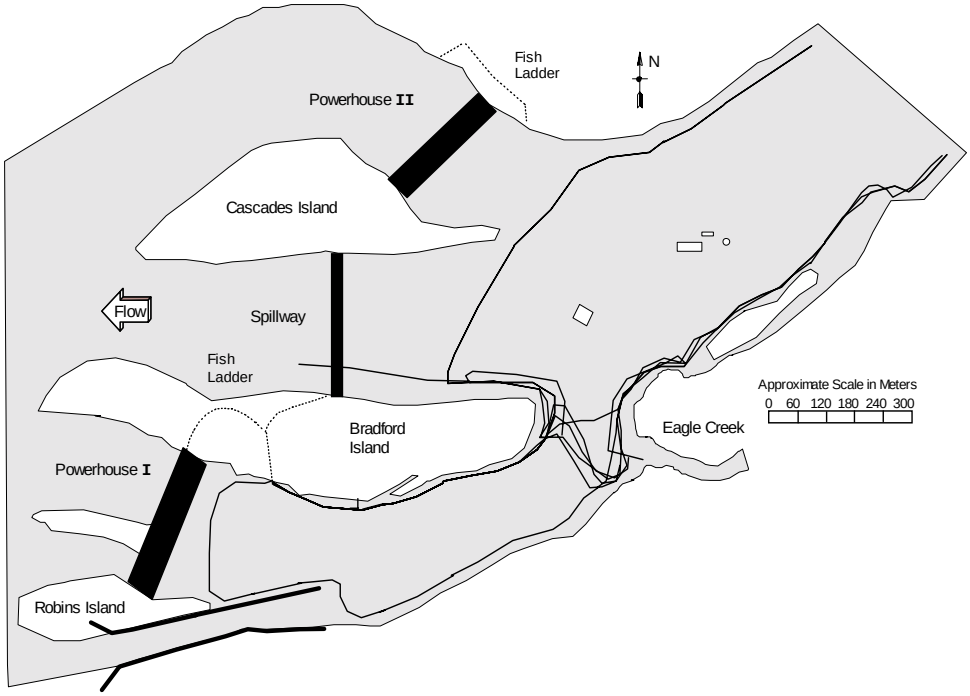

Figure 20. Composite map of steelhead movements in the forebay of Bonneville Dam, 1997.

Migration Times

Travel time to the Bridge of the Gods receiver site for all species from the Bradford Island fishway exit in 1997 ranged from 0.03 to 8.01 d and had a median travel time of 0.08 d. The median travel time from the Bradford Island fishway exit to the Bridge of the Gods site for all species of fish that did not fallback was 0.08 d and ranged from 0.03 to 2.16 d. The median travel time for fish that fell back one or more times was 1.31 d with a range from 0.03 to 8.01 d. Travel time was calculated using the first Bradford Island exit time when a fish was tracked and the first record at the Bridge of the Gods for that fish. Not all fish recorded at the Bridge of the Gods were used in the travel time analysis because some fish had records at the Bridge of the Gods before they fell back (i.e. a fish exited Bradford Island fishway, went upstream to at least the Bridge of the Gods, later came back downstream, and fellback).

Chinook salmon.- Travel time to the Bridge of the Gods receiver site from the Bradford Island fishway exit for chinook salmon ranged from 0.03 to 8.01 d and the median time was 0.09 d. Median travel time from the Bradford Island fishway exit to the upstream site for chinook salmon that did not fallback was 0.08 d and ranged from 0.03 to 2.16 d, versus 1.67 d with a range from 0.03 to 8.01 d for fish that fellback one or more times (Table 2).

Sockeye salmon.-Travel time to the Bridge of the Gods receiver site from the Bradford Island fishway exit for sockeye salmon ranged from 0.06 to 1.79 d and the median travel time was 0.08 d. Median travel time from the Bradford Island fishway exit to the upstream site for sockeye salmon that did not fallback was 0.08 d and ranged from 0.06 to 1.35 d, versus 1.30 d with a range from 0.37 to 1.79 d for fish that fellback one or more times (Table 3).

Steelhead.- Travel time to the Bridge of the Gods receiver site from the Bradford Island fishway exit ranged from 0.08 to 1.69 d and the median time was 0.12 d. The median travel time from the Bradford Island fishway exit to the upstream site for steelhead that did not fallback was 0.11 d and ranged from 0.08 to 1.69 d (Table 4). The median travel time for the one fish that fellback was 1.12 d.

Table 2. Migration rates of spring/summer chinook salmon from the Bradford Island fishway exit upstream to the receiver site at the Bridge of the Gods, 1997.

Route	Fell back	Number of fish	Mean number of days	Median number of days	Range of days	Confidence intervals (95%)
All routes	no	49	0.14	0.08	0.03-2.16	0.05-0.23
	yes	10	3.02	1.67	0.03-8.01	1.05-4.98
Bradford Island shore to spillway forebay	no	16	0.23	0.09	0.04-2.16	0.00-0.48
	yes	10	3.02	1.67	0.03-8.01	1.05-4.98
Bradford Island shore across spillway to Washington shore	no	13	0.14	0.09	0.06-0.69	0.05-0.23
Bradford Island shore across to Oregon shore	no	12	0.09	0.08	0.03-0.16	0.06-0.11
Bradford Island exit across powerhouse I to Oregon shore	no	8	0.06	0.06	0.04-0.08	0.05-0.07

Table 3. Migration rates of sockeye salmon from the Bradford Island fish exit upstream to the receiver site at the Bridge of the Gods, 1997.

Route	Fell back	Number of fish	Mean number of days	Median number of days	Range of days	Confidence intervals (95%)
All routes	no	53	0.11	0.08	0.06-1.35	0.07-0.16
	yes	4	1.19	1.30	0.37-1.79	0.60-1.78
Bradford Island shore to spillway forebay	no	4	0.08	0.08	0.07-0.08	0.07-0.08
	yes	4	1.19	1.30	0.37-1.79	0.60-1.78
Bradford Island shore across spillway to Washington shore	no	21	0.08	0.08	0.06-0.10	0.08-0.09
Bradford Island shore across to Oregon shore	no	25	0.14	0.08	0.06-1.35	0.04-0.25
Bradford Island exit across powerhouse I to Oregon shore	no	3	0.12	0.12	0.07-0.15	0.07-0.17

Table 4. Migration rates of steelhead from the Bradford Island fishway exit upstream to the receiver site at the Bridge of the Gods, 1997.

Route	Fell back	Number of fish	Mean number of days	Median number of days	Range of days	Confidence intervals (95%)
All routes	no	8	0.42	0.11	0.08-1.69	0.02-0.82
	yes	1	1.12	-	-	-
Bradford Island shore to spillway forebay	yes	1	1.12	-	-	-
Bradford Island shore across spillway to Washington shore	no	2	0.11	0.11	0.11-0.12	0.10-0.12
Bradford Island shore across to Oregon shore	no	4	0.66	0.44	0.08-1.69	0.00-1.40
Bradford Island exit across powerhouse I to Oregon shore	no	1	0.08	-	-	-
Other routes	no	1	0.13	-	-	-

Fallback Rates

Chinook salmon.-Of the 122 radio-tracked chinook salmon, 21% (26 of 122 fish) fell back over the dam after they were tracked. Ninety-six percent (25 of 26) of the fish that fell back reascended and passed over the dam a second time. Sixty-nine percent (18 of 26) of the fish that fell back did so within 24 hours after exiting the Bradford Island fishway. Fifteen of the 18 fish that fell back within 24 hours were tracked along the Bradford Island shore and into the forebay of the spillway prior to their fallback, one salmon traveled along the Bradford Island shore and crossed from the tip of Bradford Island to the Oregon shore, and the other fish traveled along the Bradford Island shore and was lost at the tip of the island. Ten of the fish that fell back within 24 hours fell

back over the spillway based on fixed site receiver data. The other eight fish probably fell back over the spillway based on mobile tracked records. More information will be available when the general migration analysis has been completed. Nine of the 26 chinook salmon (35%) that fell back, fell back more than 24 hours after exiting the Bradford Island fishway, and they traveled upstream out of the study area at least as far as the Bridge of the Gods receiver site before they returned downstream and fell back over the dam. Six of the 9 fish were tracked initially along the Bradford Island shore and into the forebay of the spillway, one was located moving in front of powerhouse I and up along the Oregon shore, and two took routes other than along the island out of the forebay. Eight of the 9 fish that fell back more than 24 hours after leaving the fishway fell back over the spillway based on fixed-site receiver and mobile tracking data. One fish fell back through the navigation lock based on fixed-site receiver data.

Sockeye salmon.-Of the 110 sockeye salmon with transmitters tracked in the Bonneville Dam forebay, 14% (16 of 110 fish) fell back over the dam after they were tracked. One hundred percent (16 of 16) of the fish that fell back reascended and passed over the dam a second time. Fourteen of the 16 fish that fell back did so within 24 hours after exiting the Bradford Island fishway, and they had been tracked along the Bradford Island shore and into the forebay of the spillway prior to their fallback. All 13 of the salmon probably fell back over the spillway based on records from fixed-site receivers and mobile tracking.

Of the 16 sockeye salmon that fellback, 2 (13%) fell back more than 24 hours after exiting the Bradford Island fishway, traveled upstream out of the study area at least as far as the Bridge of the Gods receiver site before they returned downstream and fell back over the dam. Both fish were tracked initially along the Bradford Island shore to the upstream end and then across the channel to the Oregon shore. Both fish also fell back through the spillway based on data from fixed-site receivers.

Steelhead.-One of the 10 steelhead that were radio tracked fell back over the spillway based on mobile track data. A more complete assessment of fallbacks by steelhead is presented in Bjornn et al. (1998c) and more will be available when data in the general migration file has been analyzed.

1998 Results

Migration Routes

In 1998, 129 adult spring and summer chinook salmon with transmitters were tracked in the forebay of Bonneville Dam (Table 5). Most of the fish followed one of four routes (Figure 20) after leaving the Bradford Island fishway: 1) upstream along Bradford Island shore to the forebay of the spillway (39 fish) where they fell back over the dam (20 fish) or were lost (19 fish), 2) along Bradford Island shore then across the spillway forebay to the Washington shore and then upstream (60 fish), 3) along Bradford Island shore to the upstream end of the island then across the channel to the Oregon shore then upstream (19 fish), and 4) across the powerhouse I forebay to the Oregon shore then upstream (8 fish).

Nineteen fish were tracked from the Bradford Island fishway exit into the forebay of the spillway, but we were unable track or follow them there and their routes are presently unknown. More information on the salmon that were last recorded in the forebay of the spillway may be found in the general migration analysis. Two fish were tracked twice; they had fallen back over the dam and reascended the Bradford Island fishway a second time. Of the 129 salmon tracked in the forebay, 113 were recorded on the receiver at the Bridge of the Gods (rkm 238.6) and 48 were recaptured by anglers or at upstream hatcheries.

Originally 132 chinook salmon were tracked, however three chinook salmon exited the Bradford Island fish ladder a day or more before they were tracked and were not included the fallback analysis or in migration route totals. We were concerned that their passage through the forebay might be atypical.

Table 5. Migration routes of spring and summer chinook salmon with transmitters that were tracked through the forebay of Bonneville Dam after they exited from the Bradford Island fishway, 1998.

Routes	Spring chinook	Summer chinook	All salmon
Bradford Island shore to forebay of spillway	4	16	20
Bradford Island shore to forebay of spillway - fallback	3	17	20
Bradford Island shore across forebay of spillway to Washington shore	21	39	60
Bradford Island shore across to Oregon shore	6	13	19
Bradford Island fishway exit across powerhouse I to Oregon shore	2	6	8
Other routes	1	1	2

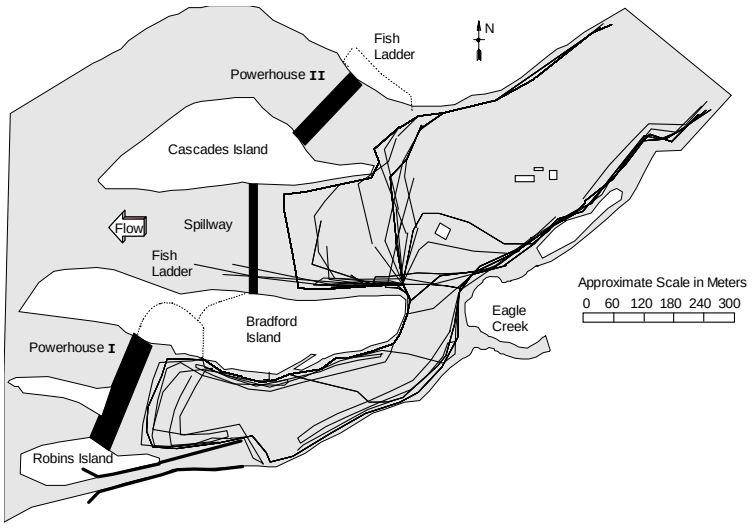

Figure 21. Composite map of chinook salmon movements in the forebay of Bonneville Dam, 1998.

Migration Times

Travel time to the Bridge of the Gods receiver site from the Bradford Island fishway exit for all chinook salmon in 1998 ranged from 0.03 to 4.80 d and median travel time was 0.07 d. Median travel times for chinook salmon that did not fallback was 0.07 d and ranged from 0.03 to 0.22 d, versus 0.87 d with a range from 0.09 to 4.80 d for salmon that fell back before proceeding upstream (Table 6). Travel time was calculated using the first Bradford Island exit time when a fish was tracked and the first record at the Bridge of the Gods for that fish. Not all fish recorded at the Bridge of the Gods were used in the travel time analysis because some fish had records at the Bridge of the Gods before they fell back (i.e. a fish exited Bradford Island fishway, went upstream to at least the Bridge of the Gods, later came back downstream, and fellback).

Table 6. Migration rates of spring and summer chinook salmon from the Bradford Island fish exit to the upstream receiver site at the Bridge of the Gods, 1998.

Route	Fell back	Number of fish	Mean number of days	Median number of days	Range of days	Confidence intervals (95%)
All routes	no	94	0.08	0.07	0.03-0.22	0.03-0.13
	yes	9	1.30	0.87	0.09-4.80	0.34-2.26
Bradford Island shore to spillway forebay	no	17	0.10	0.10	0.05-0.22	0.08-0.12
	yes	8	1.46	0.95	0.34-4.80	0.42-2.49
Bradford Island shore across spillway to Washington shore	no	50	0.07	0.07	0.03-0.09	0.06-0.07
Bradford Island shore across to Oregon shore	no	19	0.07	0.07	0.04-0.09	0.07-0.08
	yes	1	0.09	-	-	-
Bradford Island exit across powerhouse I to Oregon shore	no	8	0.09	0.08	0.06-0.12	0.07-0.10

Fallback Rates

Of the 129 chinook salmon tracked in 1998, 15% (20 of 129 fish) of the fish fell back over the dam after they were tracked. Seventy percent (14 of 20) of fish that fell back reascended and passed over the dam based on our preliminary data. Ten of the 20 fish that fell back did so within 24 h after exiting the Bradford Island fish exit. All of the fish that fell back within 24 h were tracked initially along the Bradford Island shore and into the forebay of the spillway. All of the fish that fell back within 24 h, apparently fell back over the spillway based on fixed-site receiver and mobile track data.

Ten of the 19 fish that fell back, fell back more than 24 h after exiting the Bradford Island fishway exit, and they traveled upstream at least as far as the receiver site at Bridge of the Gods. Six of the 10 fish that fell back more than 24 h after exiting were tracked along the Bradford Island shore and into the forebay of the spillway, and the other 4 were tracked along Bradford Island shore, across the spillway forebay and to the Washington shore. All 10 of the fish that fell back more than 24 h migrated back down river and apparently fell back over the spillway based on fixed-site receiver and mobile track data.

Discussion

Most adult salmon and steelhead followed four routes when migrating upstream from the exit of the Bradford Island fishway in both 1997 and 1998. Our analyses only included tracked fish that exited from the Bradford Island fishway and migrated upstream out of the powerhouse I forebay the day they left the fishway. Fish that were not included in the analyses consisted of four chinook salmon and one sockeye salmon that had passed over the dam via the Washington-shore fishway in 1997, moved across the forebay to powerhouse I, then moved upstream and followed similar routes as fish that exited the Bradford Island fishway. Plus four chinook salmon in 1997 and two chinook salmon in 1998 that exited the Bradford Island fishway a day or more before they were tracked; evidence that a few fish do not move upstream immediately after exiting the fishways.

Migrations patterns for adult salmon at Bonneville Dam similar to those observed in 1997 and 1998 were reported in previous studies (Gibson et al. 1979; Monan and

Liscom 1973; 1979; Ross 1983; Turner et al. 1984). The fallback rate for fish that used the Washington-shore fishway was higher before powerhouse II was constructed than at present because the fishway exited into the forebay of the spillway.

Present-day fallback problems at Bonneville Dam are associated mostly with the Bradford Island fishway because it is located on an island and fish follow the shoreline of the island into the forebay of the spillway. Most fish fall back over Bonneville Dam when water is spilled through the spillway. River flows during spring and early summer in 1997 and 1998 were large enough to cause periods of forced spill, and water was also spilled for juvenile passage. Twenty-one percent of the chinook salmon, and 14% of the sockeye salmon tracked at Bonneville Dam in 1997, and 15% of the chinook salmon tracked in 1998 fell back at the dam after being tracked. Ninety-six percent of the chinook salmon, and 100% of the sockeye salmon in 1997, and 70% of the chinook salmon in 1998 that fell back reascended the fishways and passed over the dam a second time. Reascention rates for fish that fell back, were variable and reflect injury rates and perhaps temporary straying for fish that were destined for tributaries downstream from Bonneville Dam that migrated upstream past their natal stream. Once the general migration analysis has been completed for 1997 and 1998 more information will be available to determine what happened to the fish that did not reascend after they fell back.

Fallback has also been documented at other dams. In 1984 at Ice Harbor Dam 9.3% (4 of 43 fish) and at Lower Monumental Dam 11.1% (4 of 36 fish) of the radio-tagged fish that passed over the dam fell back (Turner et al. 1984). In more recent studies (1991-1993) at the four Lower Snake River dams with larger numbers of radio-tagged salmon, fallback rates were less than 6% (Bjornn et al. 1998).

Median migration rates through the forebay to the receiver site at Bridge of the Gods were similar for fish tracked in 1997 (0.08 d) and 1998 (0.07 d). Fish that fell back in 1997 and 1998 took a day longer to reach the Bridge of the Gods receiver site, based on median travel times, compared to fish that did not fall back. Therefore, fish that fallback one or more times have delayed migration rates compared to fish that do not fallback.

The studies discussed in this report were conducted during years with spill throughout the migration season. Patterns of migration may be different in low flow conditions. Salmon and steelhead will likely continue to follow along the shoreline of Bradford Island after they leave the fishway, but they may be less likely to enter the forebay of the spillway and proceed to the spillway if there was little or no spill. Based on salmon tracked in 1997 and 1998, a significant proportion of the adult salmon and steelhead that pass through the Bradford Island fishway will fall back over the dam if there is more than about 50 kcfs spill during the period of migration. Fallbacks and reascentions inflate counts of fish at the dams, delay fish migration, and may result in injuries or moralities.

If the fallback rates at Bonneville Dam associated with passage through the Bradford Island fishway are high enough to warrant corrective action there are two obvious potential solutions. The first is to install a guidance structure in the forebay of powerhouse I to guide fish to the Oregon shore after they exit the fishway. The second is to attach a flume to the present fishway that would cross the forebay to the Oregon shore. In both cases, we would be trying to take advantage of the fish's natural tendency to stay close to shorelines as they migrate upstream. By getting the fish over to the Oregon shore there should be fewer fish entering the forebay of the spillway and hence fewer fallbacks. Neither solution is a sure or easy fix. Guidance nets 46 m and 76 m long have already been tried and judged unsuccessful (Liscom et al. 1977; Young et al. 1978). Perhaps a longer structure that would guide fish closer to the Oregon shore would be successful. The constraint of not interfering with barge traffic along the Oregon shore of powerhouse I forebay is a complicating factor for both solutions. Submergence of a flume connected to the fishway under the barge route, coupled with modification of the upper end of the fishway to take care or the hydraulic head differences should be considered.

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