Technical Report 2004-4

ADULT CHINOOK SALMON AND STEELHEAD FALLBACK AT BONNEVILLE DAM, 2000-2001

A report for Project ADS-00-1

by

C. T. Boggs, M. L. Keefer and C. A. Peery

U.S. Geological Survey
Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho, Moscow, Idaho 83844-1141

and

M. L. Moser

National Marine Fisheries Service
2725 Montlake Blvd, East, Seattle, Washington 98112

for

U.S. Army Corps of Engineers
Portland and Walla Walla Districts

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Preface

We began radio telemetry studies of adult salmon and steelhead passage through the lower Columbia River began with fish being tagged and released at Bonneville Dam in 1996. The objective was to observe behavior and assess potential sources of delay and mortality for adult salmon and steelhead during their upstream migration. In this report, we present information on salmon and steelhead fallback percentages, rates, routes of fallback and the influence of environmental variables on fallback at Bonneville Dam for the years 2000 and 2001.

Acknowledgements

Many people assisted in the field work and data compilation for this project. Notable among them was Steve Lee who tagged the fish, Ken Tollotti, Kevin Traylor and Travis Dick who maintained and downloaded the receivers, Megan Heinrich who handled all the recaptured tag information and Michael Jepson who supervised the coding of the data. Lowell Stuehrenberg, Alicia Matter and Sarah McCarthy assisted with management of the database.

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Abstract

In 2000 and 2001, we outfitted adult Chinook salmon *Onchorhynchus tshawytscha* and steelhead *O. mykiss* with radio transmitters at Bonneville Dam to monitor their survival and passage at the dams on the Columbia and Snake rivers and their survival to natal streams. This report presents information on the percentage of salmon and steelhead that fell back at Bonneville Dam, fallback rates, the relationship of fallback to environmental variables, final distribution and survival of fish that fell back, stock-specific fallback proportions and bias in escapement estimates based on counts of fish at dams.

In 2000 and 2001, we outfitted 1,857 spring–summer Chinook salmon, 1,306 fall Chinook salmon and 1,648 steelhead with transmitters and released them 10 km below Bonneville Dam. Of these fish, 1,740 spring–summer Chinook, 1,180 fall Chinook salmon and 1,586 steelhead were known to have passed the dam after release. We monitored passage and fallbacks at the dam using antennas and receivers in the tailrace, fishways, and forebay in both years, and supplemented that data with recapture records, telemetry records from receivers at upriver dams and the mouths of tributaries, and locations of fish found by tracking with antennas on trucks or boats.

In 2000, flow and spill were higher than average in April and near average during summer and fall with spill occurring from 6 April to 31 August (148 days). Overall fallback rates for fish released downstream of the dam were 16.8% for spring–summer Chinook salmon (160 fallback events), 5.2% for fall Chinook salmon (34 events) and 7.3% for steelhead (59 events). The fallback rate for fish that exited the Bradford Island fishway was 22.9% for spring/summer Chinook salmon, 5.7% for fall Chinook salmon and 13.6% for steelhead. Fish exiting the Washington-shore fishway fell back at rates of 7.7% for spring–summer Chinook salmon, 1.6% for fall Chinook salmon and 1.5% for steelhead. Fallback rates between the two fishways were significantly different (Z test, $P<0.01$) for both spring and summer Chinook and steelhead. Reascention rates for all fish that fell back were 93% for spring–summer Chinook salmon, 50% for fall Chinook salmon and 93% for steelhead.

In 2000, most (88%) fallbacks by spring–summer Chinook salmon occurred via the spillway with smaller proportions through the ice and trash sluiceway (6%), the navigation lock (4%), the juvenile bypass system (1%) and the fishways (1%). Fall Chinook salmon fell back through the navigation lock (41%), the ice and trash sluiceway (15%), the spillway (15%) or the fishways (1%) with 9% falling back by undetermined routes. Steelhead were most likely to fall back via the spillway (83%) with smaller proportions using the navigation lock (7%) and the ice and trash sluiceway (2%). Eight percent of all steelhead fallbacks were by an undetermined route.

In 2000, counts of salmon passing through the ladders were adjusted based on the proportion of radio-tagged fish that fell back and those that reascended. The adjustment factor for spring–summer Chinook salmon was 0.867 resulting in a dam count overestimate of about 28,000 fish. The fall Chinook adjustment factor was 0.998 (count bias ~ 400 fish) and the adjustment factor for steelhead was 0.965 (count bias ~ 12,000 fish).

We examined the correlation between environmental factors (river flow, dam spill, secchi visibility, dissolved gas and water temperature) and the proportion of radio-tagged fish that fell back at the dam within 24 h of passage. Spring–summer and fall Chinook salmon fallback was positively correlated with flow, spill and dissolved gas. Steelhead fallback was positively correlated with flow, spill, dissolved gas and water temperature. Regression analyses revealed no significant relationship between any environmental variable and spring–summer Chinook salmon fallback; fall Chinook salmon fallback was significantly related to spill ($P=0.02$, $r^2= 0.25$) and steelhead fallback was significantly related to flow, spill and dissolved gas levels ($P<0.01$, $r^2= 0.36$, 0.43 and 0.29, respectively).

During 2001, river flows were only 55% of the ten-year average and spill conditions occurred from 16 May to 15 June and from 24 July to 31 August (70 days). Overall, fallback rates for fish released downstream of the dam were 6.9% for spring–summer Chinook salmon (53 events), 6.9% for fall Chinook salmon (36 events) and 4.5% for steelhead (35 events). The fallback rate for fish that exited the Bradford Island fishway was 5.0% for spring–summer Chinook salmon, 6.3% for fall Chinook salmon and 7.8% for steelhead. Fish exiting the Washington-shore fishway fell back at rates of 7.7% for spring–summer Chinook salmon, 4.6% for fall Chinook salmon and 2.5% for steelhead. Steelhead fallback rates for the two fishways were significantly different (Z test, $P<0.001$). Overall reascension rates for all fish were 75% for spring–summer Chinook salmon, 60% for fall Chinook salmon and 79% for steelhead.

In 2001, fallbacks by spring–summer Chinook salmon occurred via the ice and trash sluiceway (34%), the spillway (32%), the navigation lock (17%), the juvenile bypass system (6%) or through the powerhouses (9%). Fall Chinook salmon fell back through the spillway (32%), the ice and trash sluiceway (19%), the navigation lock (17%), or the juvenile bypass system (6%) with 9% falling back through the powerhouses. Steelhead were most likely to fall back via the navigation lock (37%) with smaller proportions using the spillway (11%), the ice and trash sluiceway (11%), the juvenile bypass system (11%) or by an undetermined route (23%).

The count adjustment for spring–summer Chinook salmon was 0.940 resulting in a dam count overestimate of about 28,000 fish. The fall Chinook salmon adjustment factor was 0.961 (count bias ~ 16,000 fish) and the adjustment factor for steelhead was 0.978 (count bias ~ 14,000 fish).

In 2001, small numbers of spring, summer and fall Chinook salmon fell back within 24 h of dam passage, precluding analysis of the effects of environmental variables on those fallback events. Steelhead fallback was positively correlated with spill but no other relationship was significant.

In 2001, about 72% of the adult spring–summer Chinook salmon we radiotagged had been PIT tagged as juveniles allowing us to evaluate straying rates and stock-specific fallback. Spring and summer chinook from Snake River stocks strayed in estimated proportions of 2.0% and 1.4%, respectively. Summer chinook from stocks of the Columbia River upstream of McNary Dam strayed in estimated proportions of 0.8%. No spring–summer Chinook salmon from stocks downstream of McNary Dam were determined to have strayed. Chi-square analysis of proportions of spring–

summer Chinook salmon to fall back detected significant differences among stocks from the Snake River, the Columbia River upstream of McNary Dam and the Columbia River downstream of McNary Dam.

Fish that fell back at Bonneville Dam escaped to tributaries or hatcheries at lower rates than fish that did not fall back. This difference was significant for all run-years analyzed except for the 2000 fall Chinook salmon migration.

Introduction

Significant numbers of adult salmon and steelhead fall back at Bonneville Dam during periods of spill (Young et al. 1978; Ross 1983; Bjornn and Peery 1992; Bjornn et al. 2000a, 2000b). In prior studies, this problem was recognized but not fully evaluated (Monan and Liscom 1973, 1975; Liscom et al., 1977; Gibson et al. 1979; Turner et al. 1984). Fish that fall back and subsequently pass Bonneville Dam again are counted more than once which, together with those that do not reascend, leads to a positive bias in fish counts at the dam, the primary index of upriver escapement. With knowledge of fallback and reascension rates, counts can be adjusted to more accurately estimate escapement. Radio telemetry allows individual monitoring of large numbers of fish identify their behavior, movements, and fates for up to one year. One objective of monitoring initiated in 1996 was to estimate the percentage of adult salmon and steelhead that fell back at dams, calculate fallback rates and adjust counts at the dams to get more accurate escapement estimates. In this report we present our best estimates of the proportion of spring–summer and fall Chinook salmon and steelhead that fell back at Bonneville Dam during 2000 and 2001. Results from years were reported separately (Bjornn et al. 2000b).

In both years, we attempted to select a sample of fish for tagging in proportion to the daily counts of fish throughout the migration season at Bonneville Dam (Figures 1 and 2). We selected fish for tagging at the adult fish collection facility (AFF) after they had been diverted from the Washington-shore fishway. Trapping of salmon began in early April each year and continued to mid October with fish tagged and released nearly every day. We tagged spring–summer Chinook salmon from early April to 31 July, steelhead from 1 June to mid October and fall Chinook salmon from 1 August to mid-October. The only selection criteria was size; we did not put transmitters in “jack salmon” that had spent one year in the ocean. For a full description of tagging procedures see Bjornn et al. (2000a).

In 2000, the proportions of radio-tagged spring–summer and fall Chinook salmon and steelhead versus the fish counts at Bonneville Dam counting stations were similar (Figures 3, 4 and 5), an indication that our tagging was generally representative. In 2001, however, due to record numbers of returning adults and a run that started and peaked earlier than during past years, the early April segment of the spring Chinook run was under-represented while the late April and May segments of the run were over-represented (Figure 4). This was also the case with the steelhead run in 2001, where the run increased dramatically during mid-July, causing an under-sampling of that portion of the run (Figure 5).

Overall, spring–summer Chinook salmon with transmitters that passed Bonneville Dam made up 0.53% of the 2000 run and 0.20% of the 2001 run. Radio-tagged fall Chinook salmon made up about 0.36% of those counted at the dam in 2000 and 0.11% in 2001. Radio-tagged steelhead made up about 0.25% of the 2000 count and 0.12% of the 2001 count at Bonneville Dam.

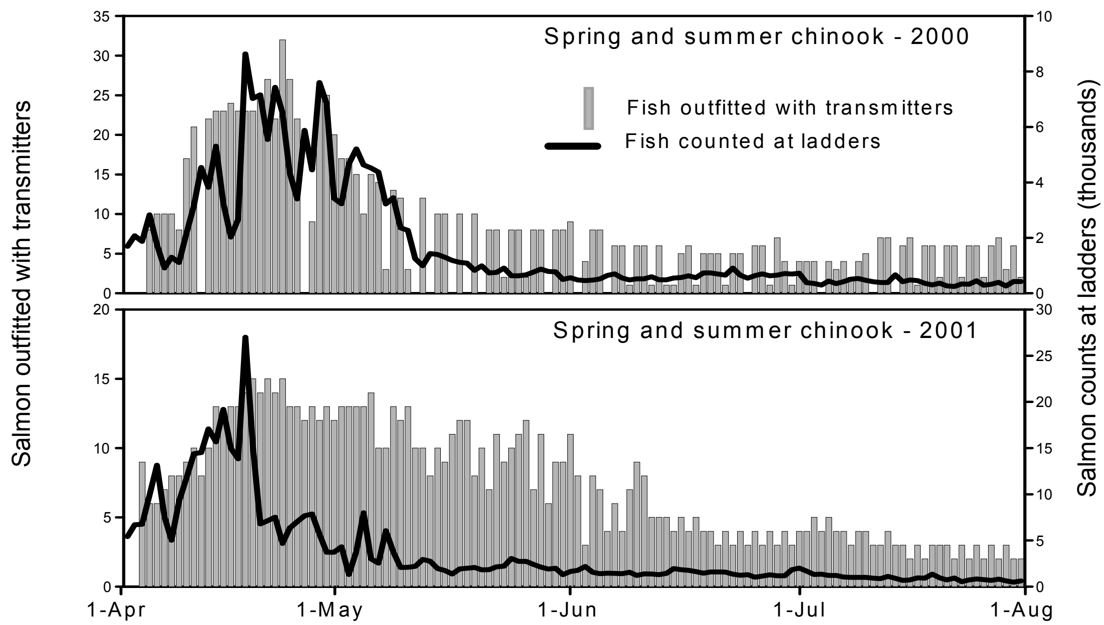

Figure 1. Daily spring–summer Chinook salmon counts at Bonneville Dam and the number of salmon outfitted with transmitters in 2000 and 2001.

Environmental conditions at Bonneville Dam differed substantially between 2000 and 2001. During the 2000 migration season (April through October) river flows at Bonneville Dam were 96% of the ten-year average (1990-1999) while river flows during 2001 were about 58% of the ten-year average (Figure 6 and 7). Spill volume during the 2000 migration season was 93% of the ten-year average, versus 20% during 2001. Spill typically begins at Bonneville Dam by early to mid-April and continues until mid- to late August, with a ten year mean of 136 spill days. During the 2000 migration season, spill occurred on 147 days. During 2001, spill occurred on 70 days (Figure 6). Dissolved gas levels were higher in 2000 than in 2001 as a direct result of spill volume (Figure 8). Secchi disk readings averaged over one foot more visibility in 2001 than in 2000 (Figure 8). Mean water temperatures were slightly higher (0.3°C) and remained warmer later during the 2001 migration season (Figures 8 and 9).

Timing of the spring–summer Chinook salmon run in 2000 was similar to the ten-year (1990-1999) average with the peak occurring in mid-April (Figure 10). The run size, however, was nearly three times the ten-year mean (88,258 salmon), with 243,731 spring–summer Chinook salmon counted passing Bonneville Dam. The 2001 spring–summer Chinook salmon run was one of the largest recorded since the construction of the Columbia River dams with 496,418 spring–summer Chinook salmon counted at Bonneville Dam. The 2001 run started approximately one week earlier than average but also peaked in mid-April (Figure 10). The 2000 steelhead run (275,178) was slightly larger than the ten-year mean, as was the 2000 fall Chinook salmon run (248,174). Both the 2001 steelhead (633,073) and the fall chinook salmon runs (474,701) were nearly three times the ten-year mean fish counts for those runs, respectively (Figure 10).

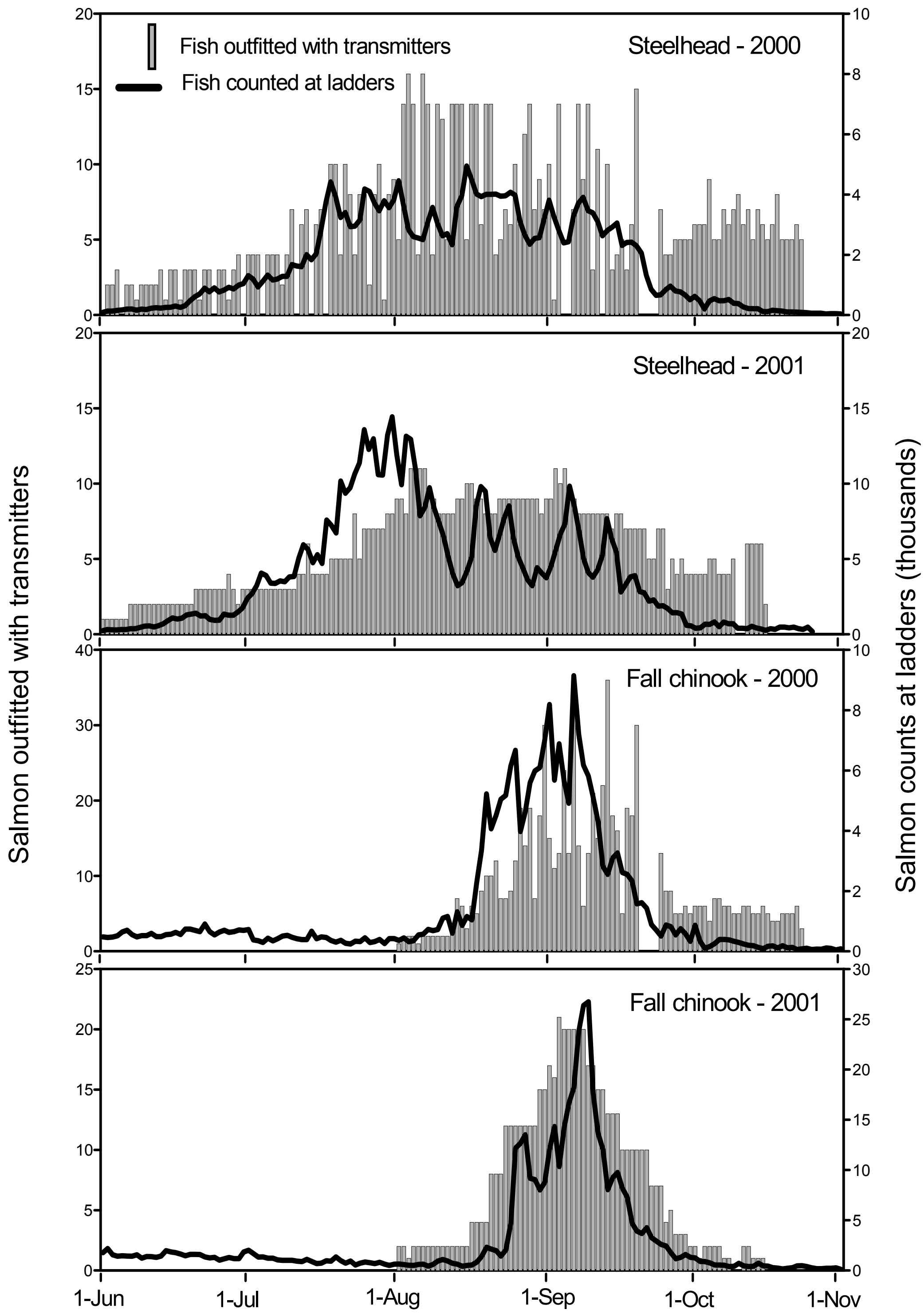

Figure 2. Daily steelhead and fall Chinook salmon counts at Bonneville Dam and the number of steelhead and fall Chinook salmon outfitted with transmitters in 2000 and 2001.

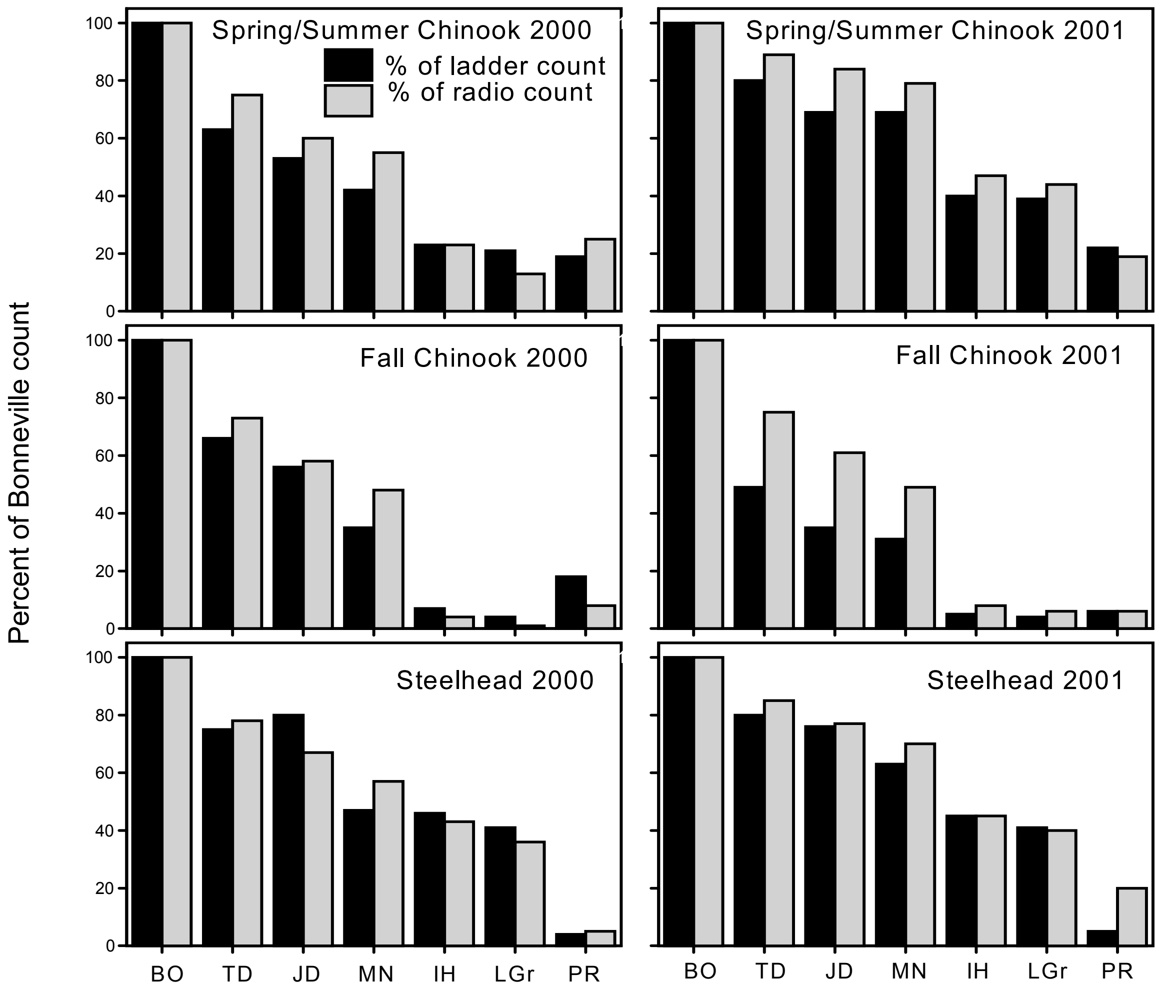

Figure 3. Percent of spring–summer and fall Chinook salmon and steelhead counted at Bonneville Dam and radio-tagged salmon and steelhead recorded at Bonneville Dam that were recorded upstream at other Columbia and Snake River dams in 2000 and 2001. Counts not adjusted for fallback and reascension or navigation lock passage.

Methods

Data used in these analyses were obtained by monitoring the movements of radio-tagged salmon and steelhead released downstream from Bonneville Dam as they passed the dam, moved through the forebay and migrated upriver. Radio receivers were located at each of the Columbia and Snake River dams and at the mouths of major tributaries and those data were supplemented by tracking areas between fixed receiver sites using boats and trucks. Information was also obtained from fish that were recaptured at hatcheries, in fisheries and from spawning areas. See Bjornn et al. (2000a) for a complete description of tagging methods, data acquisition, processing and analysis.

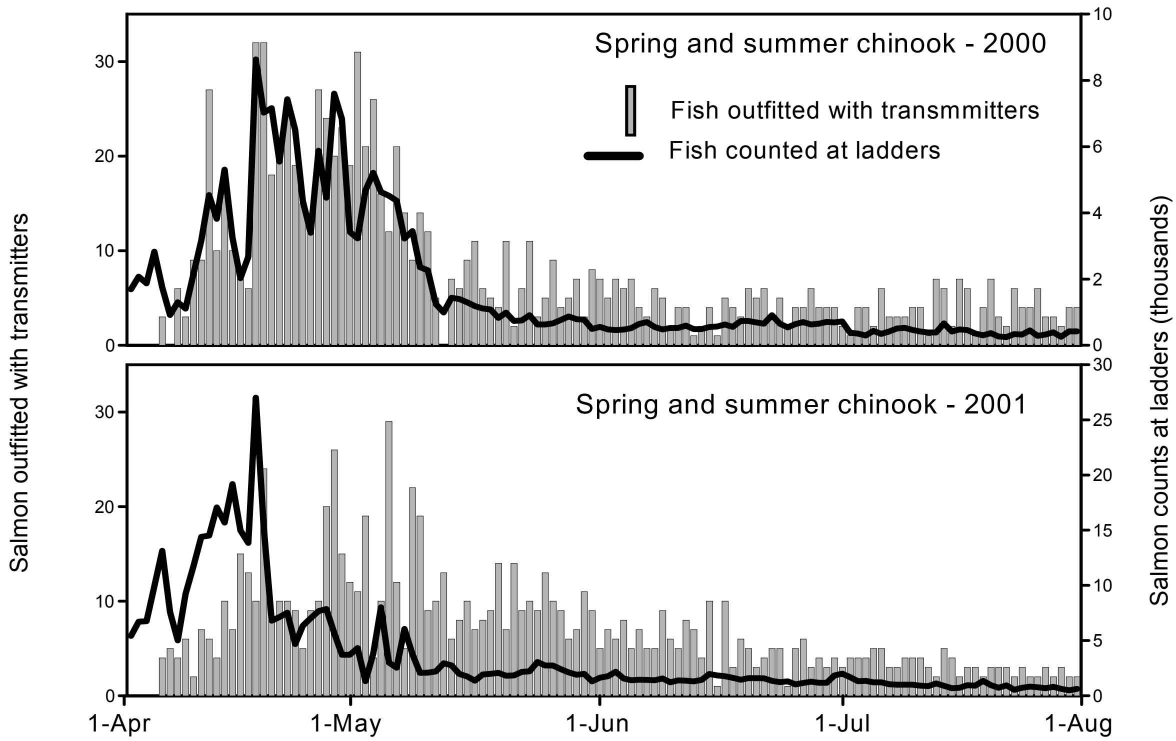

Figure 4. Daily spring–summer Chinook salmon counts at Bonneville Dam and the number of salmon outfitted with transmitters that passed the dam in 2000 and 2001.

Antenna coverage used to monitor fallback behavior at Bonneville Dam varied slightly between 2000 and 2001. During, 2000, the forebay of the spillway of Bonneville Dam was monitored with Yagi aerial antennas (Figure 11) mounted above the spillbays with elements oriented upriver. During 2001, this area was monitored with underwater dipole antennas attached to the pier noses of each spillbay and on the traveling screens of each turbine at both powerhouses. The navigation lock and the Powerhouse 2 ice and trash sluiceway were monitored in both years using underwater antennas. Also during both years, forebay receivers with underwater antennas located on the Oregon shore, the north and south side of Bradford Island and the south side of Cascades Island supplied data on fish movements in the forebay (Figure 11).

Results

Fallback Percentages and Rates

Spring–summer Chinook Salmon

The percentages of unique spring–summer Chinook salmon with transmitters that fell back over Bonneville Dam, determined from the number of unique fish with transmitters that fell back divided by the number of unique salmon with transmitters

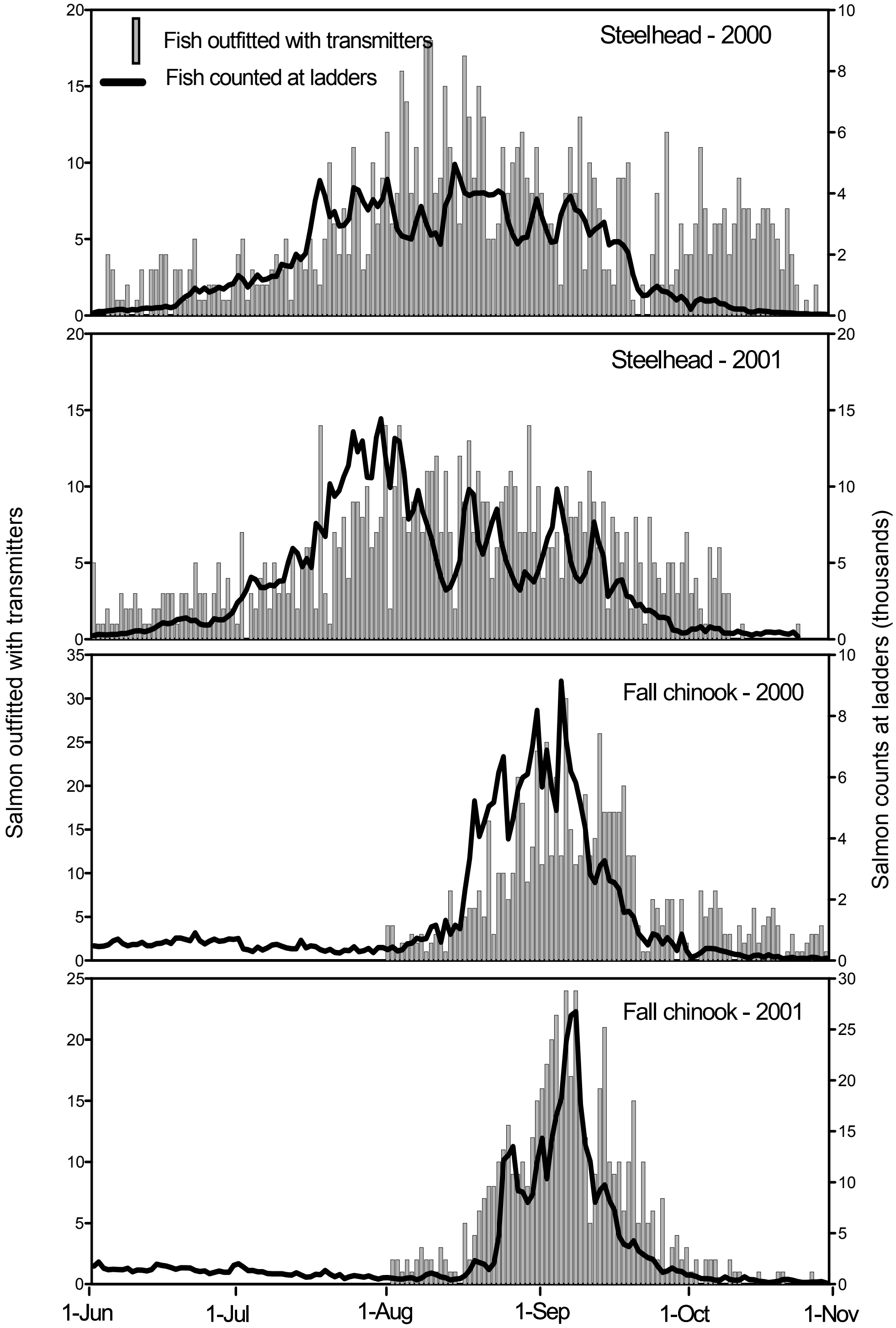

Figure 5. Daily steelhead and fall Chinook salmon counts at Bonneville Dam and the number of steelhead and fall Chinook salmon outfitted with transmitters that passed the dam in 2000 and 2001.

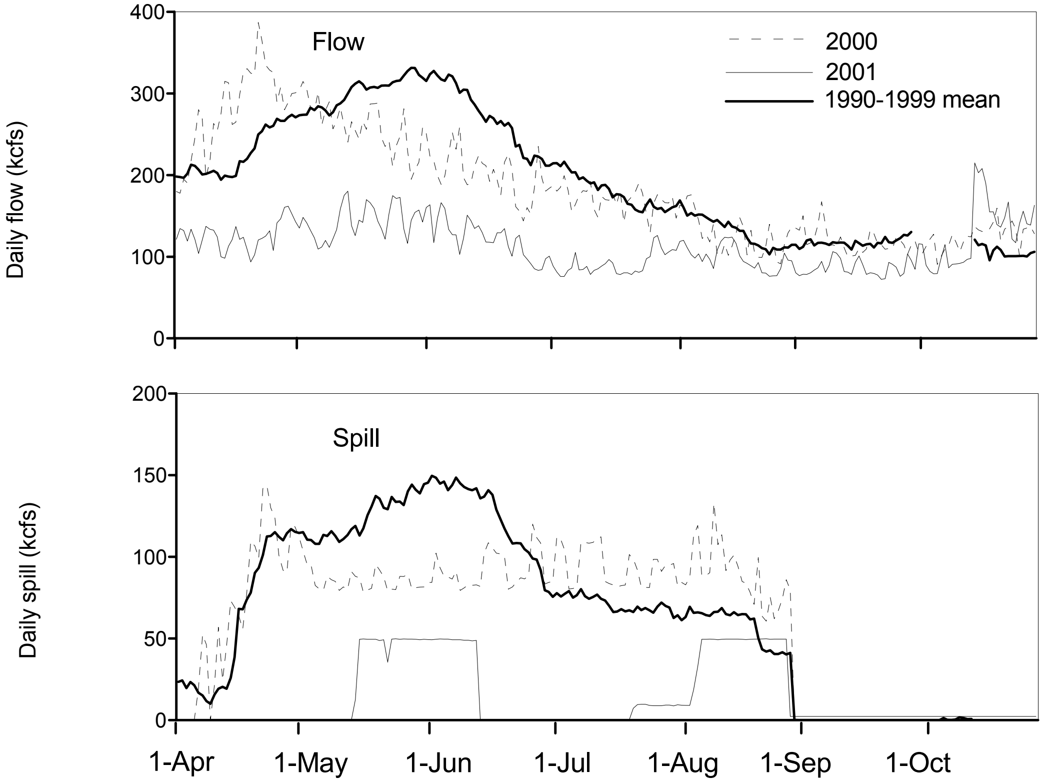

Figure 6. Daily flow and spill at Bonneville Dam in 2000 and 2001 with the 1990-1999 mean.

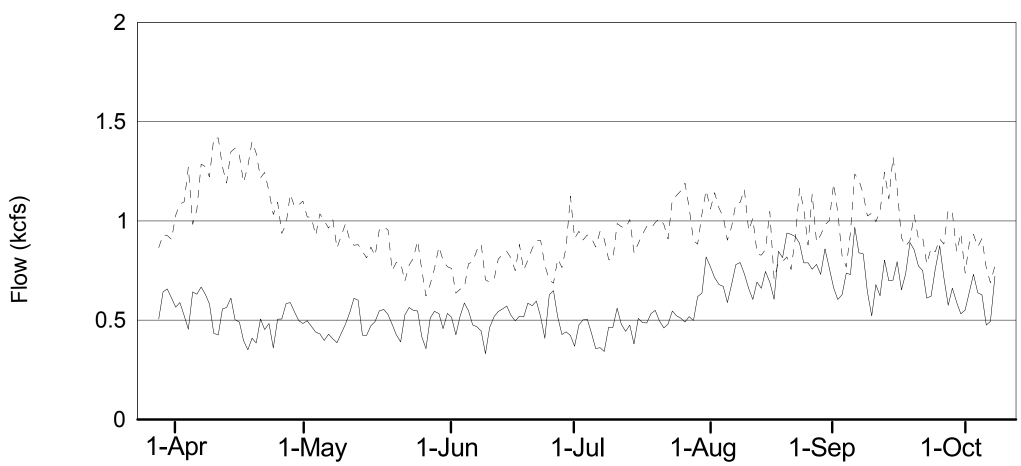

Figure 7. River flow at Bonneville Dam in 2000 and 2001 standardized to the 1990-1999 mean.

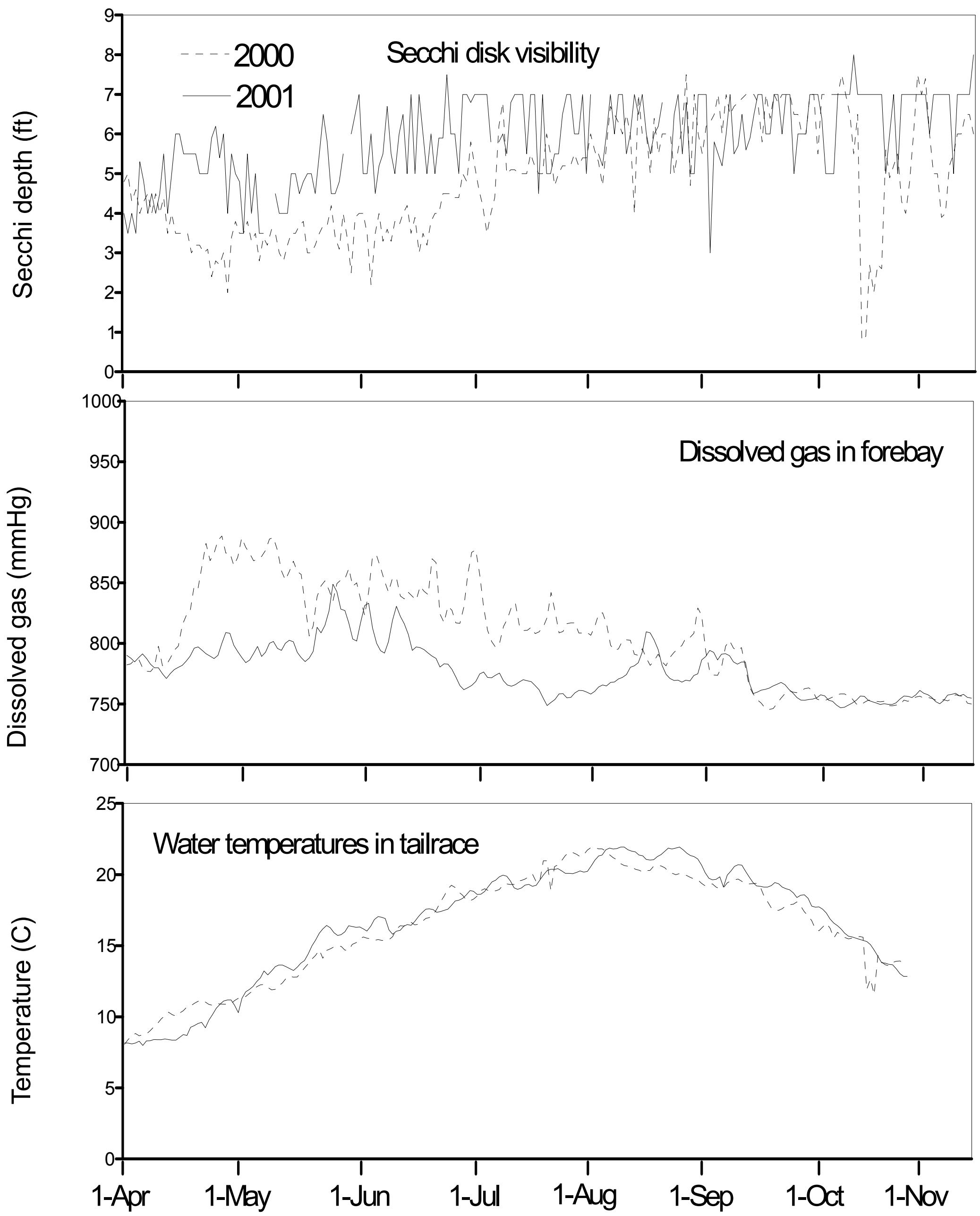

Figure 8. Daily Secchi disk visibility and dissolved gas levels in the forebay, and water temperature in the tailrace of Bonneville Dam in 2000 and 2001.

known to have passed the dam regardless of passage route, was 13.0% in 2000 and 4.1% in 2001 (Table 1). Fallback percentages for fish that passed the dam only via the fishways was 13.3% in 2000 and 4.2% in 2001. Differences between the two fallback values were small because few spring–summer Chinook passed the dam via the navigation lock.

Fish that fell back at Bonneville Dam after spawning in tributaries (one Chinook in 2001) were not included in fallback percentages or other fallback summaries.

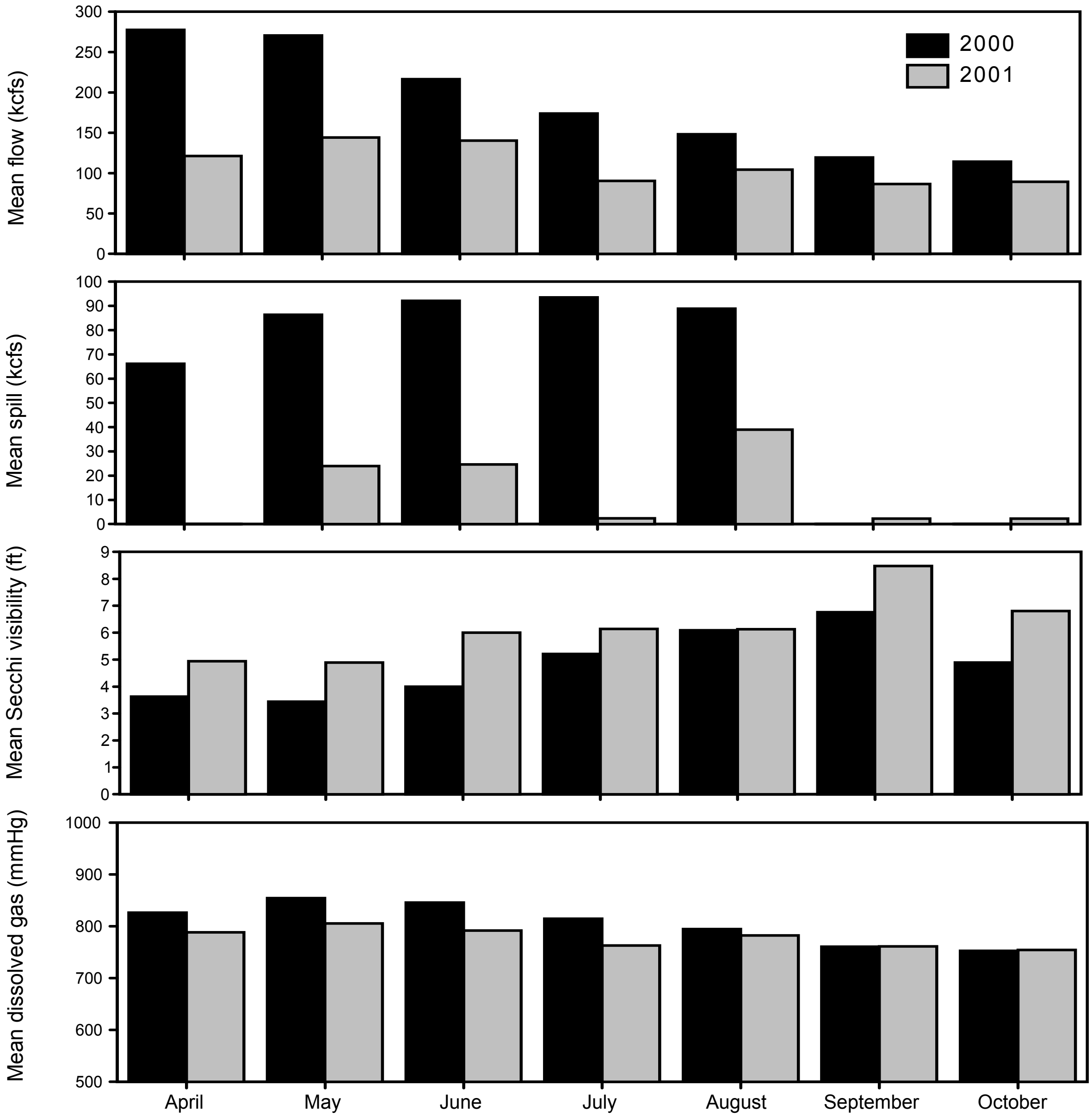

Figure 9. Monthly mean values for flow, spill, Secchi depth visibility and dissolved gas levels in the forebay of Bonneville Dam in 2000 and 2001.

Ninety-five percent confidence intervals for annual fallback percentages were determined assuming normally distributed errors and using a normal binomial approximation; intervals for Chinook salmon were +/- 2.2% or less in 2000 and 1.4% or less in 2001. These confidence intervals were based on pooled data for all radio-tagged fish of each species in each year.

Percentages of unique fish that fell back did not incorporate multiple fallbacks by individual fish or multiple passages of the dam and should not be used to adjust counts of fish passing through fishways. However, the percentages of salmon with

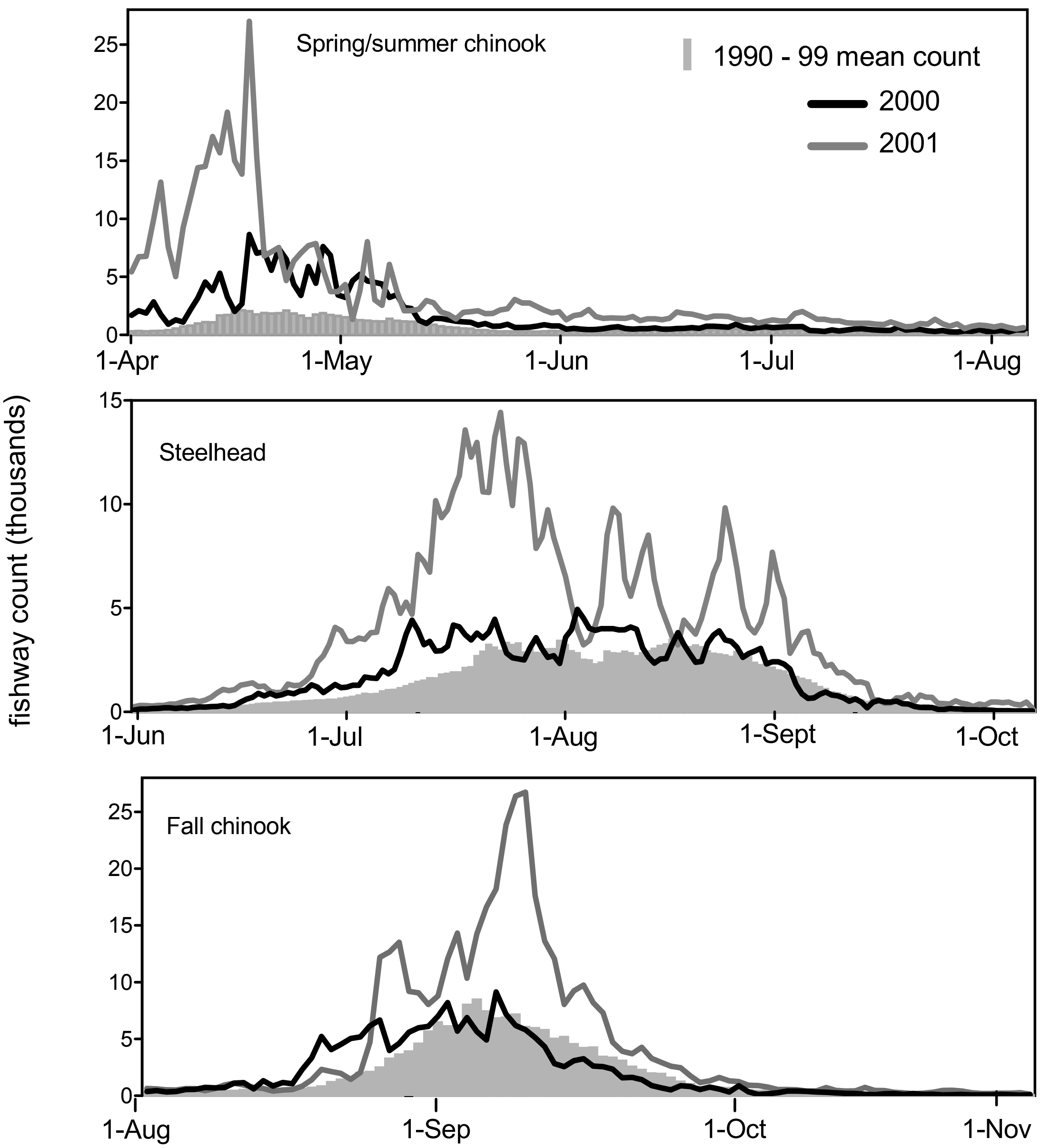

Figure 10. Daily fishway counts at Bonneville Dam in 2000 and 2001 with mean counts from 1990 – 1999.

radio transmitters that fell back is a reasonably good estimate of the proportion of Chinook salmon in each of the annual runs that fell back at Bonneville Dam.

Fallback rates, the number of fallback events divided by the number of unique Chinook salmon with transmitters known to have passed Bonneville Dam, were 16.8% in 2000 and 6.9% in 2001(Table 2). Fallback rates based only on fish that passed the dam via the fishways (no navigation lock passage) were 17.1% in 2000

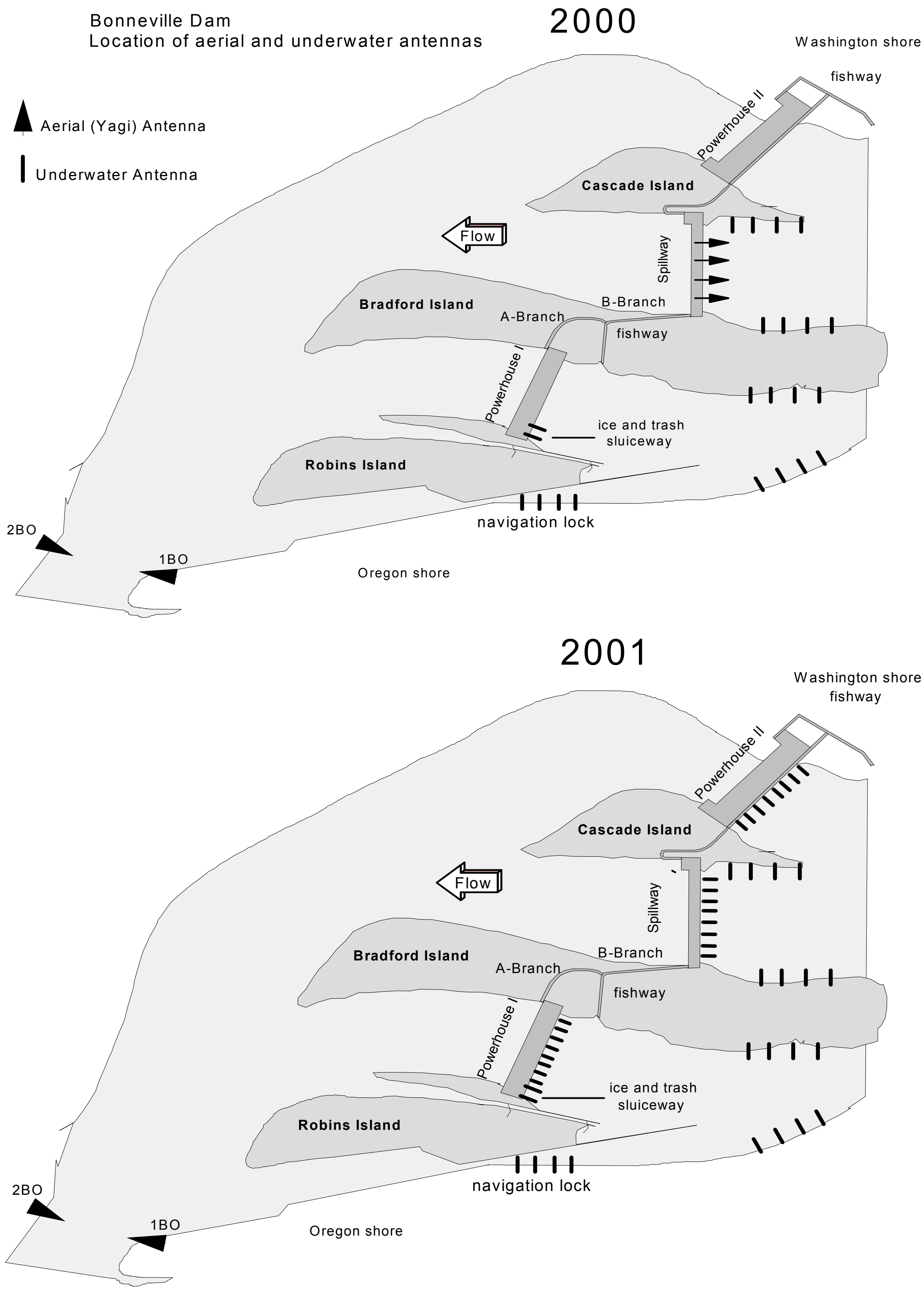

Figure 11. Location of selected antennas at Bonneville Dam in 2000 and 2001.

Table 1. Number of unique spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) with transmitters that fell back (FB) at Bonneville Dam, the number known to have passed the dam, the number that passed the dam via the fishways at the dam, and the percentage of fish that fell back in 2000 and 2001. Values in parentheses are confidence intervals (0.95) based on normal binomial approximation.

Year Species	Fish that fell back at dam	Number known to pass dam	Passed dam via fishway	FB as percent of fish known to pass dam	FB as percent of fish that passed dam via fishway
2000 CK	124	951	935	13.0 (10.9-15.1)	13.3 (11.1-15.5)
2001 CK	32	774	765	4.1 (2.7-5.5)	4.2 (2.8-5.6)
2000 SH	55	811	784	6.8 (5.1-8.5)	7.0 (5.2-8.8)
2001 SH	33	775	757	4.3 (2.8-5.8)	4.4 (2.9-5.9)
2000 FCK	26	659	630	3.9 (2.4-5.4)	4.1 (2.6-5.6)
2001 FCK	25	521	509	4.8 (3.0-6.6)	4.8 (3.0-6.6)

and 6.9% in 2001. The 95% confidence intervals, assuming normally distributed errors and a normal binomial approximation for Chinook salmon fallback rates were +/- 2.4% in 2000 and +/- 1.8% in 2001. Confidence intervals in Table 2 were based on pooled data for all radio-tagged fish in each year and did not address the variability in the ration of tagged and untagged fish during the course of the run.

We also calculated 95% confidence intervals using a stratified sampling method, where passage and fallback rates for consecutive 5-d blocks were weighted by total ladder counts at the dam during each block (Figures 12 and 13). We assumed that blocks were independent and computed standard errors for each block and a weighted average fallback rate during the time that radio-tagged fish were passing the dam. Confidence intervals for weighted fallback rates were within 1% of those based on pooled data in 2000 and within 1.4% in 2001 (Figure 14).

Fallback rates, as defined here, offer a more comprehensive view of fallback behavior by Chinook salmon at Bonneville Dam than percentages of fish that fell back because multiple fallbacks by individual fish were included. However, neither percent of unique salmon that fell back, nor fallback rates should be used to correct fishway count inflation caused by multiple passages of salmon that fell back. Fallback rates accounted for multiple fallbacks, but did not account for multiple reascensions after fallback or overestimates of escapement due to fish that fell back and did not reascend (see section on fishway count adjustment factors). Multiple passages over dams by individual fish add a positive bias to counts of fish passing through fishways, as do fish that fallback and do not reascend; thus fallbacks and reascensions must be used to correct dam fish counts.

Table 2. Number of fallback events by spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) with transmitters at Bonneville Dam, the number known to have passed the dam, the number that passed the dam via the fishways at the dam, and the fallback rates for 2000 and 2001. Confidence intervals, in parentheses, (0.95) are based on normal binomial approximation in parenthesis.

Year Species	Total FB events	Number known to pass dam	Passed dam via fishway	FB rate of fish known to pass dam	FB rate of fish that passed dam via fishway
2000 CK	160	951	935	16.8 (14.4-19.2)	17.1 (14.7-19.5)
2001 CK	53	774	765	6.9 (5.1-8.7)	6.9 (5.1-8.7)
2000 SH	59	811	784	7.3 (5.5-9.1)	7.5 (5.7-9.3)
2001 SH	35	775	757	4.5 (3.0-6.0)	4.6 (3.1-6.1)
2000 FCK	34	659	630	5.2 (3.5-6.9)	5.4 (3.6-7.2)
2001 FCK	36	521	509	6.9 (4.7-9.1)	6.9 (4.7-9.1)

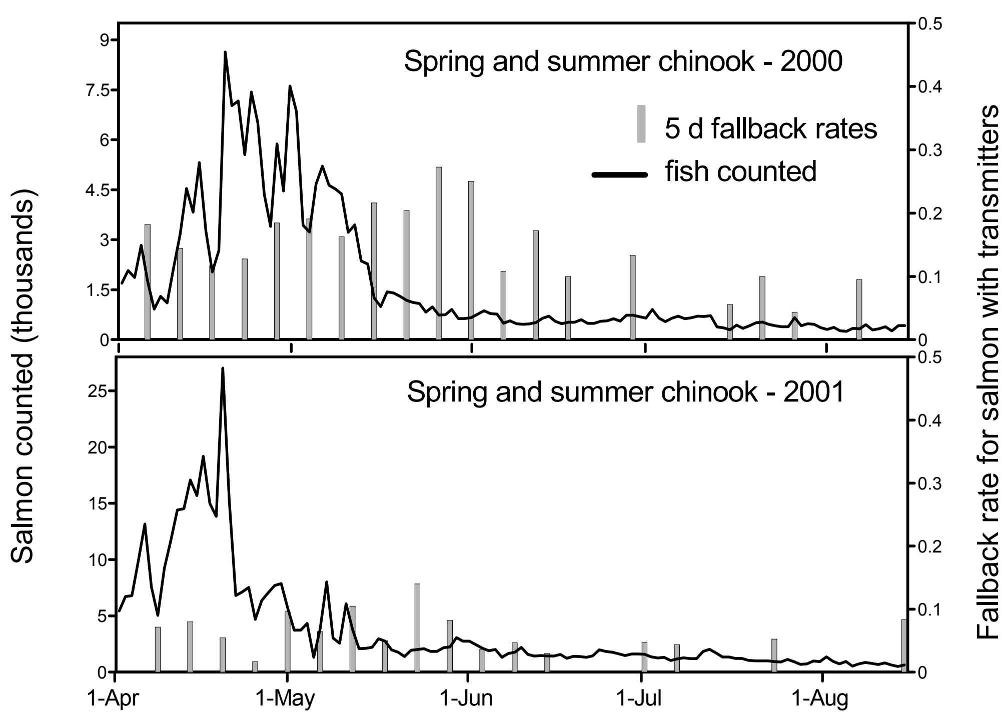

Figure 12. Fallback rates for spring–summer Chinook salmon with transmitters based on 5-d blocks with total salmon counted at Bonneville Dam in 2000 and 2001.

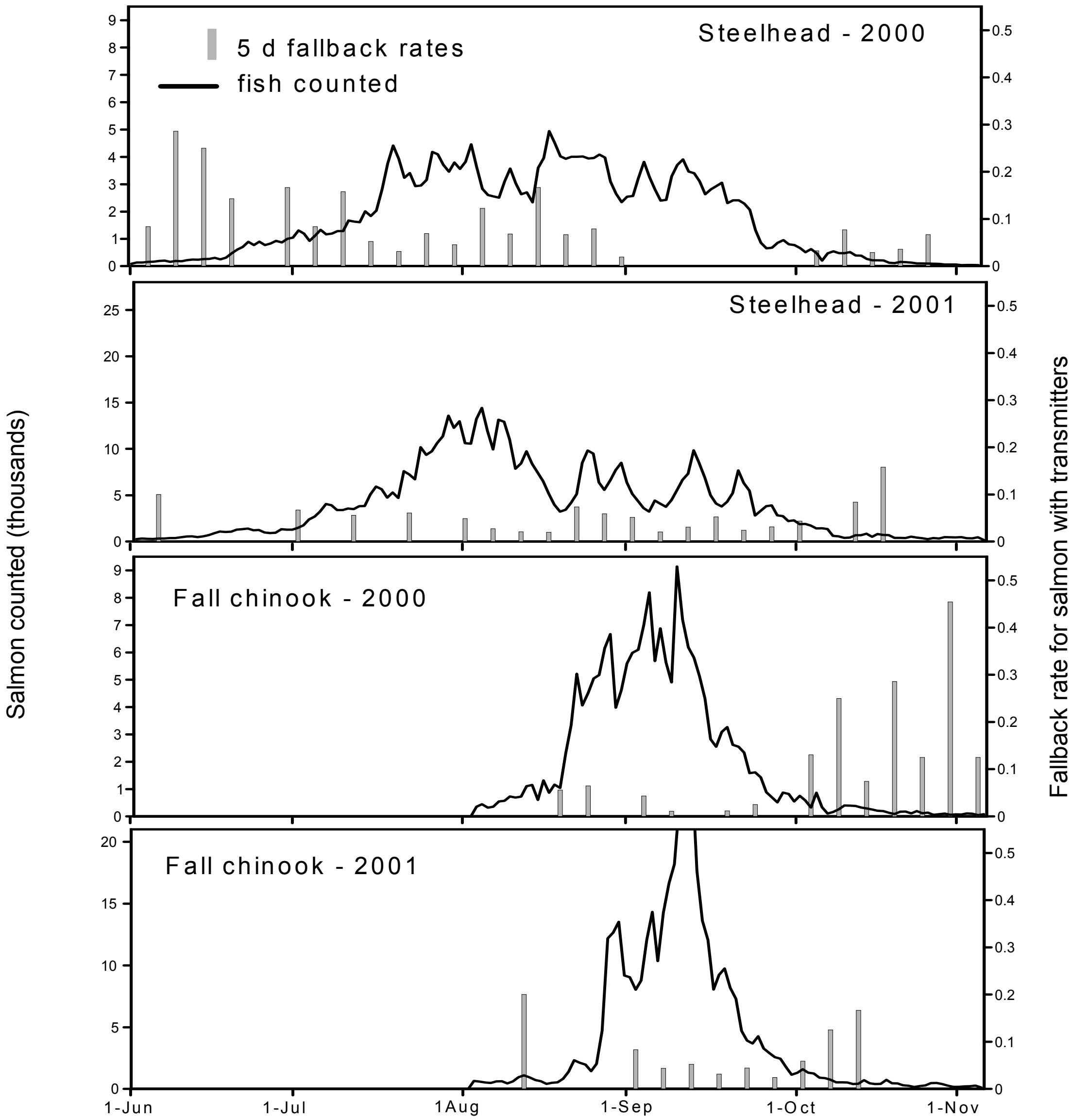

Figure 13. Fallback rates for fall Chinook and steelhead with transmitters based on 5-d blocks with total fall Chinook and steelhead passage at Bonneville Dam in 2000 and 2001.

Of 124 spring–summer Chinook salmon that fell back at Bonneville Dam in 2000, 101 (63%) fell back once, 16 (10%) fell back twice, 2 (1%) fell back three times, 4 (3%) fell back four times and one fish (1%) fell back five times. Ninety-three percent of the fish that fell back ultimately reascended and were last located upstream of Bonneville Dam. Of 32 Chinook salmon that fell back in 2001, 20 (63%) fell back once, 7 (22%) fell back twice, 3 (9%) fell back 3 times, one fell back 4 times, and one fell back 6 times; 75% ultimately reascended.

Chinook salmon with transmitters that fell back at Bonneville Dam had a variety of upriver movements and behavior in the forebay before they fell back. Although

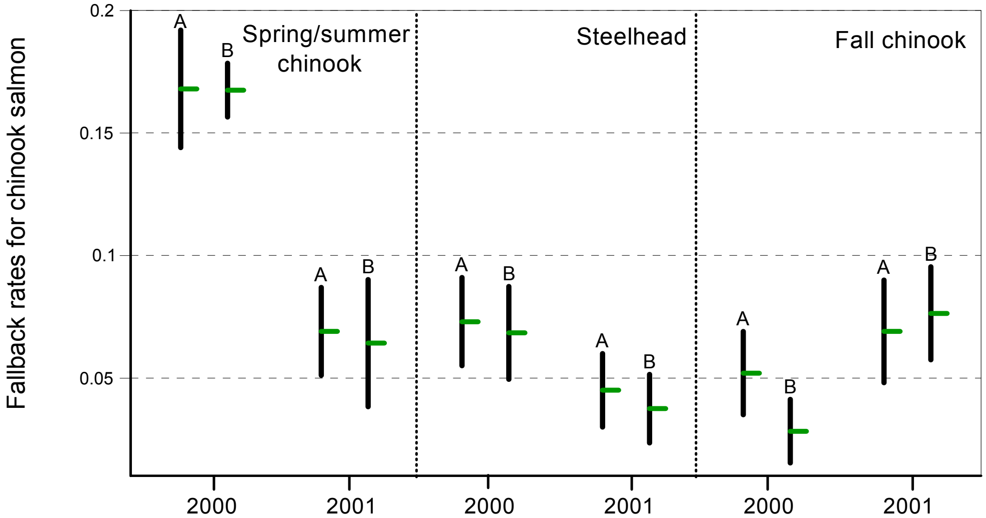

Figure 14. Fallback rates with 95% confidence intervals for radio-tagged spring–summer Chinook salmon, steelhead and fall Chinook salmon at Bonneville Dam in 2000 and 2001. Confidence intervals calculated by (A) pooling all telemetry data and (B) weighting 5-d blocks by total counts of salmon passing ladders and computing fallback rates and standard errors for each block.

we could not determine the exact time that fish fell back, in most cases we could estimate fallback times to within a few hours using forebay, tailrace and fishway telemetry records. Some fallback events were probably related to environmental conditions in the forebay when fish exited from the tops of fishways. We believe that flow and spill were most likely to affect fallbacks in the hours immediately after a fish exited, and less so after fish migrated upriver out of the forebay. For this reason, we identified all fallback events that occurred within 24 h of a fish's exit from the top of a fishway for use in statistical analyses. We also summarized telemetry records for Chinook salmon that were recorded upstream from the dam prior to fallback events at Bonneville Dam (Table 3).

About half (48%) of the 160 fallback events by Chinook salmon at Bonneville Dam in 2000 occurred less than 24 h after the fish exited from the top of a fishway, and 33% occurred less than 12 h after passage (Table 3). Forty percent of fallback fish were first recorded at fixed-site receivers at tributaries or at upriver dams before they moved back down river and fell back at Bonneville Dam. The remaining 12% of fallback events in 2000 occurred more than 24 h after passing, but fish were not recorded at receivers upriver from the dam (Table 3). During 2001, only 3 fallback events (6%) occurred less than 24 h after dam passage without the fish being recorded at an upriver site. No fallback events occurred less than 24 h of passage with the fish being recorded at an upriver site. The remaining 50 events (94%) occurred more than 24 h after dam passage and the fish was recorded at an upriver receiver. Nearly half (49%) of these fish were detected at sites between Bonneville and The Dalles dams (Table 3).

Table 3. Number of fallback (FB) events by spring–summer Chinook salmon (CK), steelhead (SH) and fall Chinook salmon (FCK) with transmitters at Bonneville Dam, the number and percent that fell back within 24 h of passing the dam, the percent recorded upriver before falling back and the percent that fell back more than 24 h after passing but were not recorded upriver in 2000 and 2001.

Year				Percent FB's > 24 h	
Species	Total FB events at dam	Number that FB in <24 h	Percent that FB in <24 h	Recorded upriver	Not recorded upriver
2000 CK	160	76	48	40	13
2001 CK	53	3	6	94	0
2000 SH	59	44	75	17	8
2001 SH	35	12	34	66	0
2000 FCK	34	7	21	74	6
2001 FCK	36	4	11	89	0

Ladder-specific fallback percentages for spring–summer Chinook salmon differed between years. In 2000, 18.8% of the unique spring–summer Chinook salmon recorded at the top of the Bradford Island fishway fell back compared to 4.3% that fell back after passing the Washington-shore fishway (*Z* test, $P < 0.0001$) (Table 4). During 2001, 3.9% of the unique fish that passed the Bradford Island fishway fell back, and 4.0% fell back after passing via the Washington-shore fishway values which were not significantly different (Table 4).

In 2000, the fallback rate was 22.9% for Chinook salmon that used the Bradford Island fishway and 7.7% for those that used the Washington-shore fishway (*Z* test, $P<0.0001$) (Table 5). During 2001, the fallback rate for Chinook salmon that used the Bradford Island fishway was 5.0% and 7.7% for fish that used the Washington-shore fishway, a difference that was not significant at P=0.05 (Table 5).

In 2000, a high percentage (80%) of fallback events were by Chinook salmon that passed Bonneville Dam via the Bradford Island fishway (Table 6). This was not the case in 2001 when 32% and 62% of all fallback events were by Chinook salmon that passed the Bradford Island and Washington-shore fishways, respectively, with the remaining 6% passing via the navigation lock. In 2000, of the 76 Chinook salmon that fell back within 24 h of passing the dam, 74 (97%) passed the dam via the Bradford Island fishway, one via the Washington shore fishway and one via the navigation lock. Of the three Chinook salmon that fell back within 24 h of passing the dam in 2001, two passed the dam via the Bradford Island fishway and one passed via the Washington shore fishway (Table 6).

Table 4. Number of unique spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) with transmitters recorded at the tops of the Bradford Island (BI) and Washington-shore (WA) fishways at Bonneville Dam, the number of unique fish that fell back (FB), and the percentage of fish that passed each fishway and fell back in 2000 and 2001.

Year Species	Unique fish at top of BI fishway	Unique fish that fell back	% past BI fishway that fell back	Unique fish at top of WA fishway	Unique fish that fell back	% past Wa ladder that fell back
2000 CK	559	105	18.8	376	16	4.3
2001 CK	338	13	3.9	427	17	4.0
2000 SH	382	50	13.1	402	4	1.0
2001 SH	308	22	7.1	449	11	2.4
2000 FCK	385	17	4.4	245	4	1.6
2001 FCK	206	10	4.9	303	9	3.0

Table 5. Number of unique spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) with transmitters recorded at the tops of the Bradford Island (BI) and Washington-shore (WA) fishways at Bonneville Dam, the number of fallback events (FB), and the fallback rate by fishway in 2000 and 2001.

Year Species	Unique fish at top of BI fishway	Fallback events	BI fishway FB rate	Unique fish at top of WA fishway	Fallback events	WA fishway FB rate
2000 CK	559	128	22.9	376	29	7.7
2001 CK	338	17	5.0	427	33	7.7
2000 SH	382	52	13.6	402	6	1.5
2001 SH	308	24	7.8	449	11	2.4
2000 FCK	385	22	5.7	245	4	1.6
2001 FCK	206	13	6.3	303	14	4.6

Steelhead

The percentage of unique steelhead with transmitters that fell back over Bonneville Damn based on the number of steelhead known to have passed the dam, regardless of route, was 6.8% in 2000 and 4.3% in 2001 (Table 1). Steelhead that fell back after likely spawning in tributaries (4 in 2000 and 9 in 2001) were not included in the analyses. Twenty-five (3%) radio-tagged steelhead passed the dam via the navigation lock in 2000, and 18 (2%) passed via the lock in 2001. The 95% confidence intervals for the percentage of steelhead that fell back were +/- 1.8% for 2000 and +/- 1.5% for 2001 assuming normally distributed errors and a normal binomial distribution (Table 1).

Table 6. Number of fallback (FB) events and fallback events within 24 h of when fish passed through the Bradford Island (BI) and Washington-shore (WA) fishways at Bonneville Dam, and the percentage of events that occurred after spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) passed each fishway in 2000 and 2001.

Year Species	Total number of FB events	Percent past BI fishway	Percent past WA fishway	Fallback events within 24 h		
				Number	% past BI fishway	% past WA fishway
2000 CK	160	80	18	76	97	1
2001 CK	53	32	62	3	67	33
2000 SH	59	88	10	44	100	0
2001 SH	35	69	31	12	83	17
2000 FCK	34	65	12	7	86	14
2001 FCK	36	36	39	4	75	25

Fallback rates based on all radio-tagged steelhead known to have passed the dam were 7.3% in 2000 and 4.5% in 2001. Fallback rates calculated using only fish known to have passed the dam via the fishways were 7.5% in 2000 and 4.6% in 2001 (Table 2). Confidence intervals for steelhead fallback rates were nearly identical to those for fallback percentages, +/- 1.8% in 2000 and +/- 1.5% in 2001 (Table 2). These confidence intervals were based on pooled data for all radio-tagged fish in each year and did not address over or under sampling or temporal differences. However, confidence intervals calculated using a 5-d stratified sampling method yielded similar results (Figures 13 and 14).

Of 55 steelhead that fell back at Bonneville Dam in 2000, 51 (93%) fell back once and 4 fish (7%) fell back twice; 93% of fish that fell back were later located upstream of Bonneville Dam. In 2001, 32 (97%) steelhead fell back once and one steelhead fell back three times; 79% of the steelhead that fell back in 2001 were later located upstream of Bonneville Dam.

Of 59 fallback events by radio-tagged steelhead in 2000, 75% occurred less than 24 h and 56% occurred less than 12 h after fish exited from the top of a fishway. In 2001, 34% of the 35 fallback events occurred less than 24 h and 26% occurred less than 12 h after dam passage. In 2000, 10 of 59 (17%) of the steelhead that fell back had been recorded at upriver receiver sites prior to falling back. In 2001, 23 of 35 (66%) steelhead were recorded at upriver receivers prior to fallback (Table 3).

Similar to spring–summer Chinook salmon in 2000, fallback percentages for steelhead that utilized the Bradford Island fishway (13.1%) were significantly (Z test, $P<0.0001$) higher than for those fish that passed the Washington-shore fishway (1.0%) in 2000. In 2001, the fallback percentage for steelhead that passed the Bradford Island fishway was 7.1% versus 2.4% for those that passed the Washington-shore fishway (*Z* test, $P<0.001$) (Table 4). Of the 59 fallback events in

2000, 88% occurred after the fish had exited the Bradford Island fishway, 10% after exiting the Washington shore fishway and 2% after passing the dam via the navigation lock. During the 2001 steelhead migration, 69% of the 35 fallback events occurred after the fish had exited the Bradford Island fishway, 31% after exiting the Washington shore fishway and no fish fell back after passing via the navigation lock (Table 6).

In 2000, fallback rates were also significantly (Z test, P<0.0001) higher for steelhead that passed the dam via the Bradford Island fishway (13.6%) than for fish using the Washington-shore fishway (1.5%). During the 2001 steelhead migration, fallback rates for fish that exited the Bradford Island fishway was 7.8%, the rate for fish exiting the Washington-shore fishway was 2.4% (*Z* test, *P*<0.001) (Table 5).

Fall Chinook salmon

The percentage of unique fall Chinook salmon with radio-transmitters that fell back at Bonneville Dam, regardless of dam passage route, was 3.9% in 2000 and 4.8% in 2001 (Table 1). When only fall Chinook that passed the dam via the fishways were used in the calculation, percentages were 4.1% in 2000 and 4.8% in 2001. The 95% confidence intervals associated with these percentages were +/- 1.5% for the 2000 estimate and +/- 1.8% for the 2001 estimate.

Fallback rates for fall Chinook, calculated using all radio-tagged fish known to have passed the dam, were 5.2% (+/- 1.7%) in 2000 and 6.9% (+/- 2.2%) in 2001. The fall Chinook fallback rate determined using only fall Chinook known to pass the dam via the fishways was 5.4% (+/- 1.7%) in 2000 and 6.9% (+/- 2.2%) in 2001 (Table 2). The second method excludes 29 fall Chinook that passed the dam through the navigation lock in 2000 and the 12 fall Chinook that used this route in 2001. The above confidence intervals were based on pooled data for all radio-tagged fish in each year and did not address over or under sampling or temporal differences. However, confidence intervals calculated using a 5-d stratified sampling method yielded similar results (Figures 13 and 14).

Of the 26 fall Chinook that fell back at Bonneville Dam during 2000, 19 (73%) fell back once, 6 (23%) fell back twice and one (4%) Chinook fell back three times and 50% of the fall Chinook that fell back in 2000 were last located upstream of Bonneville Dam. During 2001, 18 (50%) fall Chinook fell back once, 6 (17%) fell back twice and 12 (33%) fell back three times. Sixty-six percent of these fall Chinook were last located upstream of Bonneville Dam.

Of the 34 fallback events by radio-tagged fall Chinook in 2000, 7 (21%) occurred less than 24 h after the fish exited the top of the fishway and 5 (15%) events occurred less than 12 h after exit. Prior to fallback, 74% of the fish had been recorded at upstream receiver sites. In 2001, 4 (11%) of the 36 fallback events occurred within 24 h and 3 (8%) occurred within 12 h after dam passage and 89% had been recorded at upstream receiver sites prior to falling back.

During the 2000 migration, the percentage of fall Chinook that fell back after exiting the Bradford Island fishway (4.4%) was not significantly higher than the percentage of those that fell back after passing the dam via the Washington-shore fishway (1.6%) (Table 4). However, fall Chinook using the Bradford Island fishway did fall back at a significantly higher rate (*Z* test, *P*=0.01) than fish that used the Washington-shore fishway (5.7% and 1.6%, respectively) (Table 5). In 2001, 4.9% of the fall Chinook that passed Bonneville Dam via the Bradford Island fell back versus 3.0% that passed via the Washington-shore fishway (Table 4). Rates of fall Chinook fallback for the Bradford Island and Washington shore fishways were 6.3 and 4.6%, respectively (Table 5). Percentages and rates for the two ladders were not significantly different in 2001.

Overall, of the 34 fall Chinook fallback events that occurred in 2000, 65% occurred after the fish had exited the Bradford Island fishway, 12% after exiting the Washington-shore fishway and 24% after fish had passed the dam via the navigation lock. In 2001, these percentages were 36%, 39% and 25% (Table 6).

Escapement Past Bonneville Dam Based on Adjusted Counts

Fishway counts at the dams are used as indices of abundance for salmon and steelhead runs at that point in their migration. The counts are indices of upriver escapement, rather than complete counts, because some fish pass the dams via the navigation locks and because fish that fall back at the dams and do or do not reascend add a positive bias to the counts. Adjustment of the counts for fish that pass through the navigation locks and for fallbacks at Columbia and Snake river dams has been calculated only when adult radio-tagging studies have been conducted. In previous studies, fallback rates varied among species and years, with river flow and spill at dams, as well as with the configuration of top-of-ladder exits at specific dams (Bjornn et al. 2000; Bjornn and Peery, 1992; Liscom et al, 1979; Monan and Liscom, 1979). At Bonneville Dam, we monitored fallbacks, reascension and passage through the navigation lock for adult salmon and steelhead with transmitters and used that data to calculate adjustment factors in 2000 and 2001. Adjustments were then applied to fish counts reported in the Annual Fish Passage Reports (USACE, 2000, 2001) to obtain more accurate estimates of the number of fish that escaped upstream from the dam.

We believe the most accurate estimate of escapement past the dams includes counts of salmon in the fishways at the dam, the number of fish that fell back, the number that reascended through the fishways, and the number of fish that pass the dam via the navigation lock. Fallback and reascension through fishways creates a positive bias in the number of fish counted as they pass up the fishways, while passage through the navigation lock is not included in counts of fish passing up the fishways. Fish that pass through the lock may compensate for the positive bias in fish counts due to fallback and reascension, but the amount of compensation depends on the number of fallbacks and the number of fish passing through the lock.

We estimated escapement of fish past Bonneville Dam by calculating adjustment factors based on passage of fish with transmitters and then applied adjustments to the total number of fish counted at the dam. The adjustment factor (AF) was calculated by the formula:

$$AF_1 = (LP_K + NLP_K - FB_{UF} + R_{UF}) / TLP_K$$

where:

LP_K was the number of unique fish with transmitters known to have passed the dam via the fishways (assuming that unrecorded fish passed the dam via a fish ladder),

NLP_K was the number of unique fish with transmitters known to have passed the dam via the navigation lock,

FB_{UF} was the number of unique fish that fell back at the dam one or more times,

R_{UF} was the number of unique fish that reascended the dam and stayed upstream from the dam regardless of the number of times it fell back, and

TLP_K was the total number of times unique fish with transmitters were known to have passed the dam via fishways (includes all reascensions).

The TLP_K term was equivalent to the total USACE count of salmon that passed through the ladders. Adjusted counts were our best estimate of the total escapement of adult salmon and steelhead that passed the dam.

Estimates of escapement derived from the adjustment factors (AF) were based on the assumption that fish with transmitters were good surrogates for the remainder of the fish in the run passing the dam. We calculated an AF using pooled data for the entire time period of passage by radio-tagged fish and all fish that fell back were included. If there was temporal variability in fallback and reascension rates or the tagged fish were not representative of the run then the adjustment factors based on pooled data may be biased. To address this potential bias, we also calculated an AF using a stratified sampling method for consecutive 5-d blocks during the time that radio-tagged fish were passing Bonneville Dam. Each block was weighted by the total number of fish counted at fishways during that block. Both pooled and weighted AF values were most appropriate for the time period when radio-tagged fish were passing the dam, and less so during other times.

Spring–summer Chinook salmon

Pooled adjustment factors (AF) for spring–summer Chinook salmon at Bonneville Dam were 0.867 in 2000 and 0.935 in 2001 (Table 7). The weighted AF value and 95% confidence intervals based on all data for radio-tagged fish differed from pooled values by about 0.01 in 2000, an indication that our sampling was reasonably representative and that temporal variation in spring–summer Chinook salmon fallback and reascension rates were relatively minor. In 2001, record numbers of returning fish were coupled with low river flows and reduced periods and volume of spill. This resulted in 5-d blocks in which large numbers of Chinook passed the dam while experiencing low rates of fallback and probably reduced the accuracy of the weighted estimates. The weighted AF value and confidence intervals in 2001 differed from the pooled rate by approximately 0.035.

We calculated escapements of spring–summer Chinook salmon past Bonneville Dam by multiplying the USACE reported fish counts by pooled AFs (Table 7). In

Table 7. Unique fish with transmitters known to have passed Bonneville Dam via ladders (LP_K) and the navigation lock (NLP_K), unique fish that fell back one or more times (FB_{UF}), unique fish that reascended (R_{UF}), total number of times fish with transmitters were known to have passed through ladders (TLP_K), and pooled fish count adjustment factors (AF) for spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) with transmitters in 2000 and 2001.

Year-species	LPK	NLPK	FBUF	RUF	TLPk	Pooled AF
2000 CK	935	16	124	115	1086	0.867
2001 CK	765	8	32	24	819	0.934
2000 SH	784	25	55	51	834	0.965
2001 SH	757	18	32	26	785	0.978
2000 FCK	630	29	26	13	647	0.998
2001 FCK	509	12	25	15	532	0.961

2000, the USACE adult spring–summer Chinook salmon count at Bonneville Dam was 208,918 fish. After adjustment, the escapement of spring–summer Chinook salmon past Bonneville Dam was estimated to be 181,132 fish, 27,786 fish (13.3%) less than the count (Table 8). The 2001 USACE adult Chinook salmon count at Bonneville Dam was 467,523 fish and the adjusted escapement was 436,666 fish with a positive bias of 30,857 fish (6.6%). Standard 95% confidence intervals for the adjusted escapements were within +/- 2%, or approximately +/- 4,000 fish in 2000 and 8,000 fish in 2001.

Steelhead

Pooled adjustment factors (AF) for steelhead at Bonneville Dam were 0.965 in 2000 and 0.978 in 2001 (Table 7). Weighted AF values and 95% confidence intervals based on all data for radio-tagged fish differed from pooled values by 0.012 in 2000 and 0.04 in 2001. Again, 5-d blocks in which large numbers of steelhead passed the dam while experiencing low rates of fallback may have reduced the accuracy of the weighted estimates.

We calculated escapements of steelhead past Bonneville Dam using the same methods as described above for spring–summer Chinook. In 2000, the USACE adult steelhead count at Bonneville Dam was 351,370 fish. After adjustment, the escapement of steelhead past Bonneville Dam was estimated to be 339,072 fish, 12,298 fish less than the count (Table 8). The 2001 USACE adult steelhead count at Bonneville Dam was 633,073 fish and the adjusted escapement was 619,145 fish, with a positive bias of 13,928 fish. Standard 95% confidence intervals for the adjusted escapements were within +/- 1.4%, or approximately +/- 4,000 fish in 2000 and 9,000 fish in 2001.

Fall Chinook salmon

Pooled adjustment factors (AF) for fall Chinook salmon at Bonneville Dam were 0.998 in 2000 and 0.961 in 2001 (Table 7). Weighted AF values and 95%

Table 8. Reported USACE counts of adult spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FCK) passing through ladders at Bonneville Dam, estimated escapements using pooled adjustment factors, 95% confidence intervals, and bias in the counts in 2000 and 2001 as escapement indices. USACE fishway escapement estimates do not include night-time video counts.

	USACE Fishway Escapement	Pooled Adjustment		Weighted Escapement bias
		Estimated Escapement	Bias	
2000 CK	208,918	181,132 (+/- 4,178)	27,786	25,112
2001 CK	467,523	436,666 (+/-7,601)	30,857	14,213
2000 SH	351,370	339,072 (+/- 4,216)	12,298	8,081
2001 SH	633,073	619,145 (+/-8,863)	13,928	1,899
2000 FCK	192,793	192,407 (+/- 578)	386	-3,213
2001 FCK	400,205	384,597 (+/-6,403)	15,608	13,487

confidence intervals based on all data for radio-tagged fish differed from pooled values by 0.019 in 2000 and 0.005 in 2001, an indication that our sampling was reasonably representative and that temporal variation in fall Chinook fallback and reascension rates was minor.

We calculated escapements of fall Chinook salmon past Bonneville Dam using the same methods as described above for spring–summer Chinook. In 2000, the USACE adult fall Chinook count at Bonneville Dam was 192,793 fish. After adjustment, the escapement of fall Chinook past Bonneville Dam was estimated to be 192,407 fish, 386 fish less than the count (Table 8). The 2001 USACE adult fall Chinook count at Bonneville Dam was 400,205 fish and the adjusted escapement was 384,597 fish with a positive bias of 6,403 fish. Standard 95% confidence intervals for the adjusted escapements were +/- 0.3% in 2000 and +/- 1.6% in 2001 or approximately +/- 578 fish in 2000 and 15,608 in 2001.

Fallback Routes by Radio-Tagged Salmon and Steelhead

Technical limitations of antenna and receiver configurations at Bonneville Dam did not permit us to determine exact locations and times for fallback events, but we could determine the probable route of fallback (spillway, navigation lock, ice and trash sluiceway or powerhouses) and the approximate time of the event.

We identified routes of fallback with records from antennas in the forebay and the first telemetry records in the tailrace or at fishway entrances after the fallback event. The location of the first tailrace telemetry record was not definitive evidence of the fallback route but, when evaluated with the forebay telemetry records immediately preceding the fallback event, gave cogent evidence for the route of fallback.

Fallback events were classified according to the time and location of the telemetry records before and after the event and the environmental conditions at the dam at the time of fallback, namely the presence or absence of spill (Table 9).

Fallback events that could have occurred via the spillway (during spill conditions) were further classified into four categories according to several criteria: 1) Fallback events were considered *very likely* to have occurred via the spillway if the fish was recorded at fishway entrances adjacent to the spillway less than one hour after being recorded in the forebay of the spillway. 2) Fish recorded at any downriver receiver less than one hour after being recorded in the spillway forebay were considered to have *likely* fallen back over the spillway. 3) A time gap of more than one hour between the last forebay record and the first downriver record classified the event as a *probable* spillway fallback and 4) fish with no forebay records before being recorded at downriver sites were considered *possible* spillway fallbacks. Receiver records from antennas in the navigation lock, ice and trash sluiceways and the juvenile bypass system were used to determine fallback events that occurred at those locations.

For the 2001 research season, underwater antennas (dipole) were mounted to the pier noses of each spill bay and to the traveling screens of each turbine at both powerhouses to better determine fallback events via those routes (Figure 11). Powerhouse fallbacks are estimates only because fish recorded on antennas near turbine intakes did not necessarily enter the turbine. About 80% of the spring–summer Chinook recorded on these antennas did not fall back at the dam.

Spring–summer Chinook salmon

In 2000, 39% of the spring–summer Chinook salmon were first recorded on the receivers located about 3 km downstream of the dam, 21% were first recorded at receivers near the entrance to the B-Branch fishway, 16% at the north and south entrances to the Washington-shore fishway and 8% were first recorded at the entrance to the Cascades Island fishway after falling back (Figure 15).

The spillway was determined to be the likely route for nearly 90% of all fallback events by spring–summer Chinook during the 2000 migration with smaller proportions falling back via the navigation lock (4%), the ice and trash sluiceway (6%), the juvenile bypass channel (1%) and the fishways (1%). We were unable to determine a route of fallback for three fallback events (Table 9).

In 2001, 28% of the spring–summer Chinook salmon were first recorded on the receivers located about 3 km downstream of the dam, 4% were first recorded at receivers near the entrance to the B-Branch fishway, 8% were first recorded at the entrance to the Cascades Island fishway and no Chinook were first recorded at the north and south entrances to the Washington-shore fishway after falling back (Figure 16).

The spillway accounted for about half (49%) of all fallback events in 2001. The ice and trash sluiceway (34%) and the navigation lock (17%) accounted for more fallback events than in 2000. The underwater antennas attached to the traveling screens of the turbine intake were the last forebay records for 9% of the spring–summer Chinook salmon that were subsequently recorded downstream of the dam (Table 9).

Steelhead

In 2000, 39% of the steelhead were first recorded on the receivers located about 3 km downstream of the dam, 17% were first recorded at receivers near the entrance to the B-Branch fishway, 15% at the north and south entrances to the Washington-shore fishway located downstream of Powerhouse 2 and 5% were first recorded at the Cascades Island entrance to the Washington-shore fishway after falling back (Figure 15).

Routes of fallback for steelhead during the 2000 migration included the spillway (84%) the navigation lock (7%) and the ice and trash sluiceway (2%). We were unable to determine a route of fallback for five events, two of which occurred in late November after some of the receivers had been removed for winter maintenance (Table 9).

In 2001, 57% of the steelhead were first recorded on the receivers located about 3 km downstream of the dam and 20% were first recorded at receivers at the entrances to the A-Branch of the Bradford Island fishway. About 17% of the

Table 9. Percentage (N) of spring–summer Chinook (CK), steelhead (SH) and fall Chinook salmon (FCK) to fall back by each route in 2000 and 2001. Turbine intakes of powerhouses were monitored in 2001 only.

Fallback route	CK 00	CK 01	SH 00	SH 01	FCK 00	FCK 01
Spillway very likely Forebay of spillway to fishway entrance < 1 h	12.5 (20)	3.7 (2)	13.6 (8)	- -	- -	- -
Spillway likely Forebay of spillway to downriver receiver < 1 h	11.8 (19)	9.4 (5)	6.8 (4)	- -	2.9 (1)	2.9 (1)
Spillway probable Forebay of spillway downriver receiver > 1 h	61.3 (98)	17.0 (9)	61.6 (36)	11.4 (4)	11.8 (4)	5.6 (2)
Spillway possible No forebay records but spill occurring	1.8 (3)	1.9 (1)	1.7 (1)	- -	- -	- -
Navigation lock very likely	4.4 (7)	17.0 (9)	6.8 (4)	37.1 (13)	41.2 (14)	63.9 (23)
Ice/ trash sluiceway very likely	5.6 (9)	34.0 (18)	1.7 (1)	11.4 (4)	14.8 (5)	8.3 (3)
No nav lock or ice/trash sluiceway records no spill occurring	- -	1.9 (2)	8.5 (5)	22.9 (8)	26.5 (9)	8.3 (3)
Juvenile channel very likely	1.3 (2)	5.7 (3)	- -	11.4 (4)	- -	5.6 (2)
Fishway very likely	1.3 (2)	- -	- -	- -	2.9 (1)	5.6 (2)
Powerhouse likely	-	9.4 (5)	-	5.7 (2)	-	- -

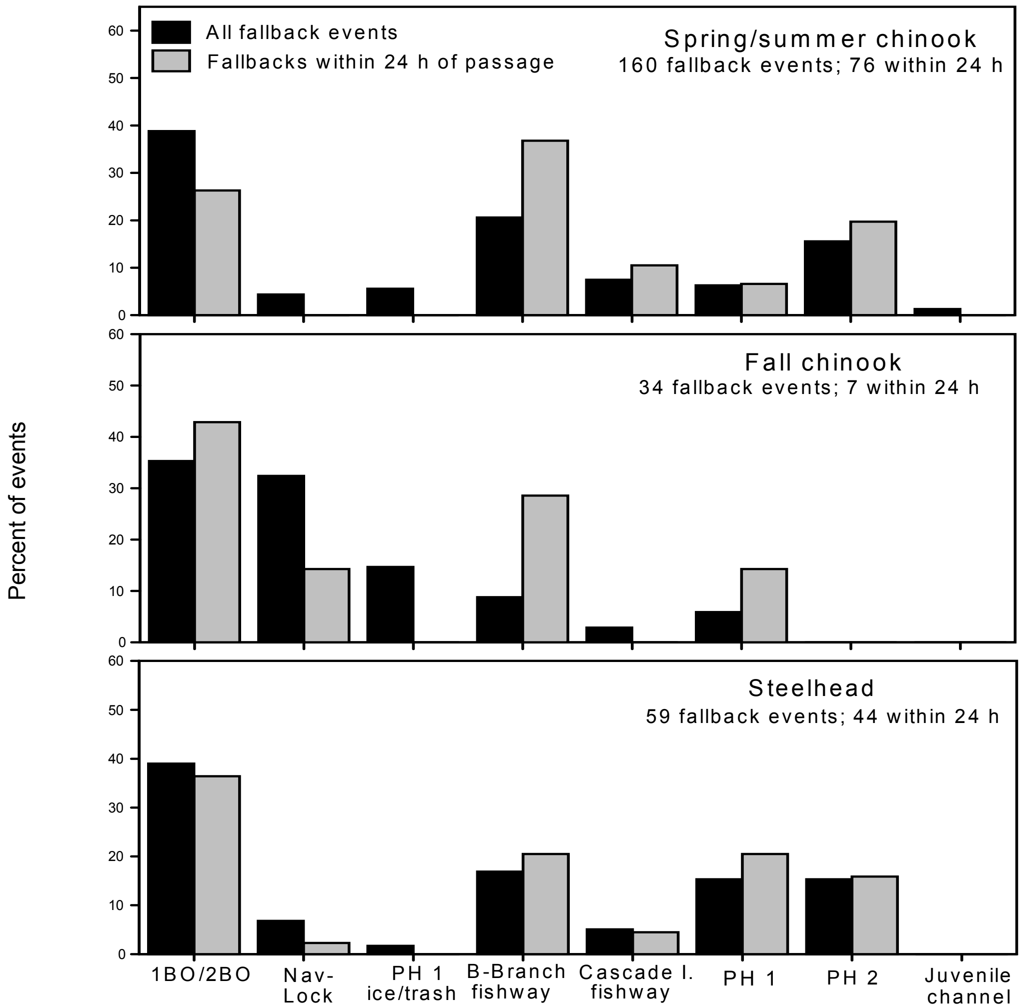

Figure 15. Location of first telemetry records of spring–summer and fall Chinook salmon and steelhead downstream from the dam after all fallback events and after fallback events that occurred within 24 h of passage at Bonneville Dam in 2000.

fallback steelhead were first recorded at the entrances to the Washington-shore fishway and only 6% were first recorded at receivers near the entrance to the B-Branch fishway adjacent to the spillway after falling back (Figure 16).

The spillway accounted for about 11% of all steelhead fallback events in 2001. Most steelhead fell back via the navigation lock (37%) or by an unknown route (23%). Four (11%) steelhead fell back through the juvenile bypass system and four (11%) through the ice and trash sluiceway. The underwater antennas attached to the traveling screens of the turbine intake were the last forebay records for 6% of the steelhead that were subsequently recorded downstream of the dam (Table 9).

Fall Chinook salmon

In 2000, 35% of the fall Chinook salmon to fall back were first recorded on the receivers located about 3 km downstream of the dam, 9% were first recorded at

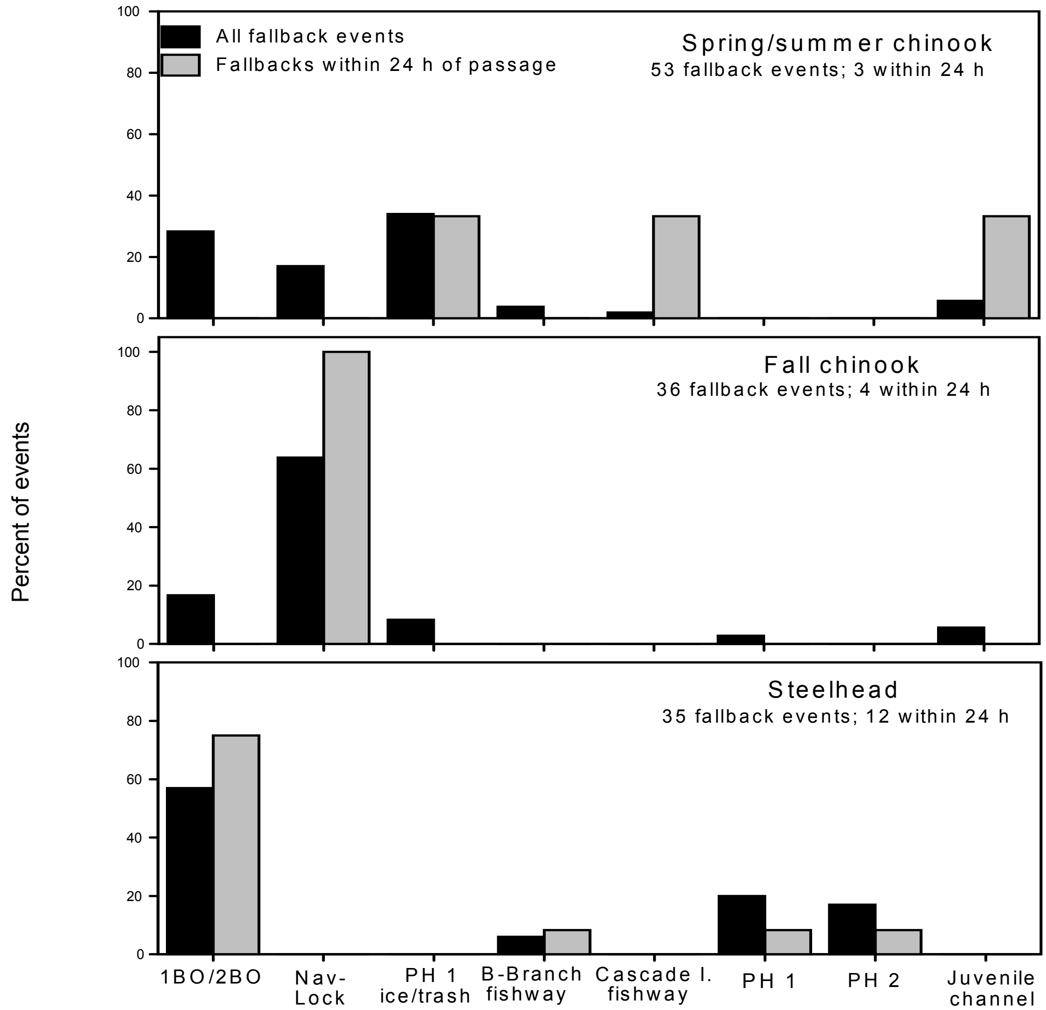

Figure 16. Location of first telemetry records of spring–summer and fall Chinook salmon and steelhead downstream from the dam after all fallback events and after fallback events that occurred within 24 h of passage at Bonneville Dam in 2001.

receivers near the entrance to the B-Branch fishway and 3% were first recorded at the Cascades Island entrance to the Washington shore fishway. Two (6%) fall Chinook salmon were first recorded at the entrances to the Powerhouse 1 collection channel (Figure 15).

The major routes of fallback for fall Chinook salmon during the 2000 migration were the navigation lock (41%) and the ice and trash sluiceway (15%). Five (15%) fall Chinook salmon fallback events were via the spillway. We were unable to determine a fallback route for 27% of the events (Table 9).

In 2001, 86% of the fall Chinook salmon were first recorded on receivers located about 3 km downstream of the dam and 11% were first recorded at receivers at the entrances to the A-Branch of the Bradford Island fishway after falling back. About 3% of the fallback fall Chinook salmon were first recorded at receivers near the entrance to the B-Branch of the Bradford Island fishway (Figure 16).

The spillway accounted for about 11% of all fall Chinook fallback events in 2001. Most fall Chinook salmon fell back via the navigation lock (64%) with smaller proportion using the ice and trash sluiceway (8%), the juvenile channel (6%) and the fishways (6%) (Table 9).

Effect of Environmental Factors on Fallbacks

We examined the interaction of flow, spill, turbidity, dissolved gas and temperature with fallback of spring–summer and fall Chinook salmon and steelhead using linear and logistic regression models. Previous research (see Bjornn and Peery 1992) concluded that fallback rates increased with increases in flow and spill; however, sample sizes of marked fish were usually small. Bjornn et al. (2000b) found statistically significant relationships between flow and spill and spring–summer Chinook fallback during 1996, 1997 and 1998. Turbidity, water temperature and dissolved gas levels were also correlated with fallback proportions during these years but relationships were not as strong. Bjornn et al. (2001) used a randomized block design test to evaluate effects of high and low spill on fallback rates of adult salmon and steelhead at Bonneville Dam in 2000, although analysis revealed no significant relationships during that test.

Flow, spill, turbidity and dissolved gas levels varied continuously within and between 2000 and 2001 making discreet comparisons of fallback rates with specific environmental conditions difficult. Also, daily passage and fallback rates by salmon with transmitters varied throughout the migration season. To address these concerns, we grouped dam passages during consecutive days until at least 25 fish with transmitters had passed the dam. The 25-fish blocks produced 27 to 35 bins, with a mean of 32 fish/bin (standard deviation ~ 3 fish) for the two years. Mean flow, spill, turbidity, dissolved gas, water temperature and a fallback were calculated for each bin and logistic, linear (weighted and unweighted) and stepwise multiple regression models were tested. Fallback events that occurred more than 24 h after a fish exited from the top of the fishway were excluded from the analysis because most fish that fell back more than 24 h after passage had migrated upriver and we believe environmental conditions at the dam were not the primary reason those fish fell back.

In a second approach, passages of salmon and steelhead with transmitters and fallbacks within 24 h of passing Bonneville Dam were grouped in consecutive 5-day blocks and 24 h fallback ratios and mean values for the independent variables were calculated and analyzed using linear, logistic and multiple regressions. The 5-day block method yielded similar results to the variable day bins and is not reported here.

Fallback Ratios and Environmental Factors in 2000

Spring–summer Chinook salmon

We created 35 bins for the 2000 spring–summer Chinook salmon dataset with a mean of 3.6 d/bin (median 3.0 d/bin) (Figure 17). Flow, spill and dissolved gas were positively correlated with fallback while Secchi visibility and water temperature were negatively correlated with fallback. However, regression analyses revealed no significant relationship between any environmental variable and Chinook fallback.

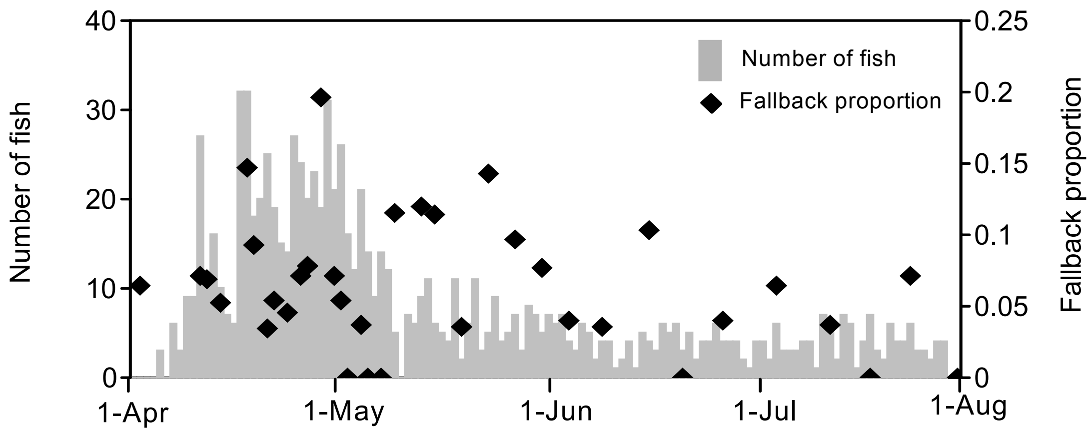

Figure 17. Daily number of radio-tagged spring–summer Chinook salmon that passed Bonneville Dam and the proportion of salmon in consecutive bins of at least 25 fish that fell back within 24 h of passage in 2000.

Weighted and unweighted linear models had r^2 values from 0.0001 to 0.06 with P values ranging from 0.2 to 0.9. Logistic and stepwise multiple regressions yielded similar results with no significant relationships between any environmental variable and fallback (Figure 18).

Steelhead

We created 29 bins for the 2000 steelhead data set with a mean of 4.9 d/bin (median 4.0 d/bin) (Figure 19). Flow, spill, dissolved gas and water temperature showed a positive correlation with fallback ratios while Secchi visibility was negatively correlated. Linear (both weighted and unweighted) and logistic models showed significant relationships between fallback ratios and flow, spill and dissolved gas at $P < 0.01$ (Figure 20). Weighted and unweighted linear models had r^2 values from 0.32 to 0.45 for flow and spill and 0.27 to 0.29 for dissolved gas. No linear or logistic models were significant for Secchi visibility and temperature, r^2 values ranged from 0.03 to 0.08 (Figure 20).

Spill conditions ended at Bonneville Dam on 31 August 2000 while the dataset used in the above analysis included fallback ratios and environmental factors running through 17 October 2000. To address this, we analyzed a truncated dataset of fallback ratios and environmental factors only when spill conditions were present. Using this dataset, linear regressions revealed significant relationships between fallback ratios and spill (unweighted $P=0.06$, $r^2=0.19$; weighted $P=0.04$, $r^2=0.22$) and Secchi visibility (unweighted $P=0.04$, $r^2=0.22$; weighted $P=0.07$, $r^2=0.18$). Logistic regressions revealed similar results between fallback ratios and spill ($P=0.01$) and Secchi visibility ($P=0.03$).

All models were based on variable-width time bins that included at least 25 fish. Multiple regression models using the dataset containing both spill and no spill conditions selected spill and water temperature as the most significant predictors of fallback with an r^2 value of 0.49. With spill removed, flow was the best remaining predictor with a model r^2 of 0.36 (Table 10).

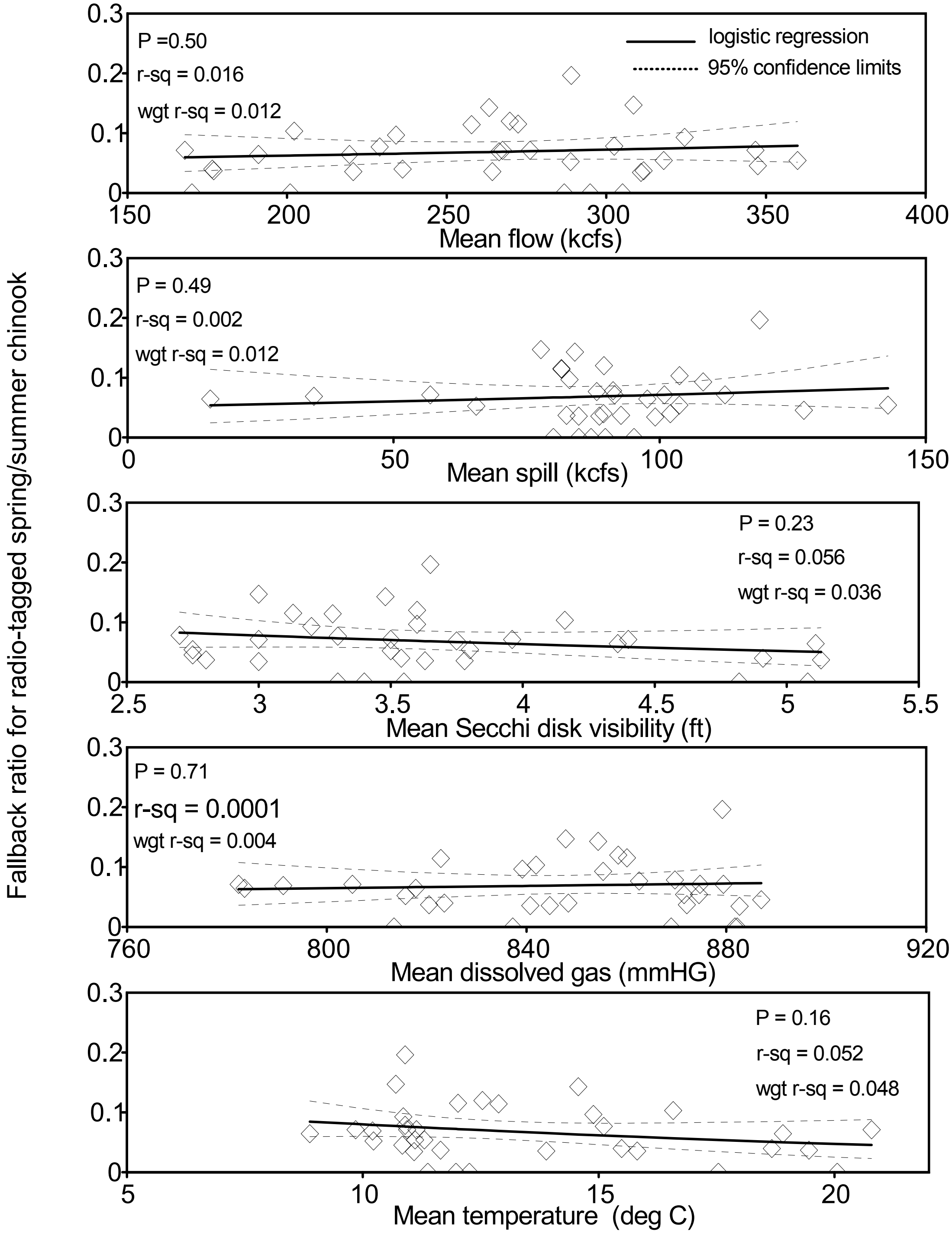

Figure 18. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring–summer Chinook salmon fallbacks within 24 h of passage at Bonneville Dam in 2000; includes r-sq values for weighted and unweighted linear regression models. All models based on variable-width time bins that included at least 25 fish.

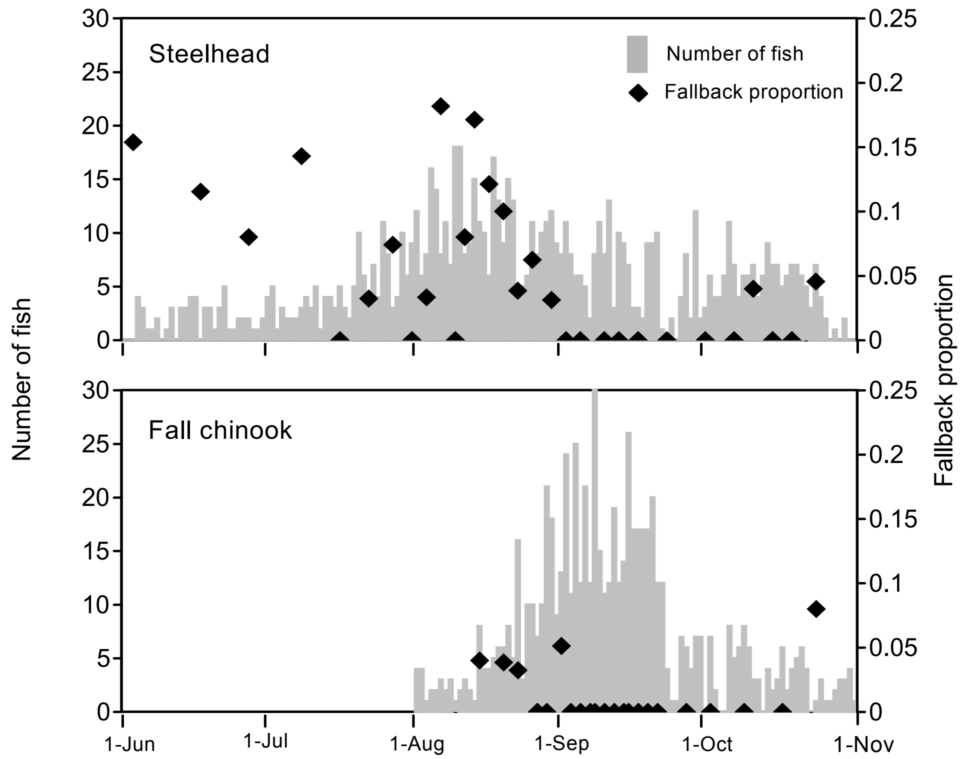

Figure 19. Daily number of radio-tagged steelhead and fall Chinook salmon that passed Bonneville Dam and the proportion of salmon and steelhead in consecutive bins of at least 25 fish that fell back within 24 h of passage in 2000.

When the truncated dataset was entered into the model, Secchi visibility and dissolved gas were selected as the best predictors of fallback (r^2=0.44). When secchi visibility was removed, spill and water temperature were best remaining predictors of fallback with a model r^2 of 0.30 (Table 10).

Fall Chinook salmon

We created 22 bins for the 2000 fall Chinook dataset with a mean of 3.5 d/bin (median 2.0 d/bin) (Figure 19). Flow, spill and dissolved gas were positively correlated with fallback ratios while Secchi visibility and water temperature were negatively correlated. While only seven fall Chinook fell back within 24 h of passing the dam during the study period, linear regression revealed a significant relationship between fallback and spill in both unweighted (P=0.02, r^2= 0.25) and weighted analyses (P=0.01, r^2= 0.29). The logistic model also suggested a relationship between fallback and spill (P=0.01) while flow and dissolved gas had P values of 0.09 and 0.07, respectively.

Multiple regression models using the fall Chinook fallback ratios selected spill followed by water temperature, Secchi visibility and flow (r^2= 0.72). Exclusion of spill from the model resulted in dissolved gas as the best remaining predictor of fallback with a model r^2 of 0.11 (Table 11). We emphasize that only seven fall Chinook fell back within 24 h of passing the dam and five of these fallbacks occurred during spill

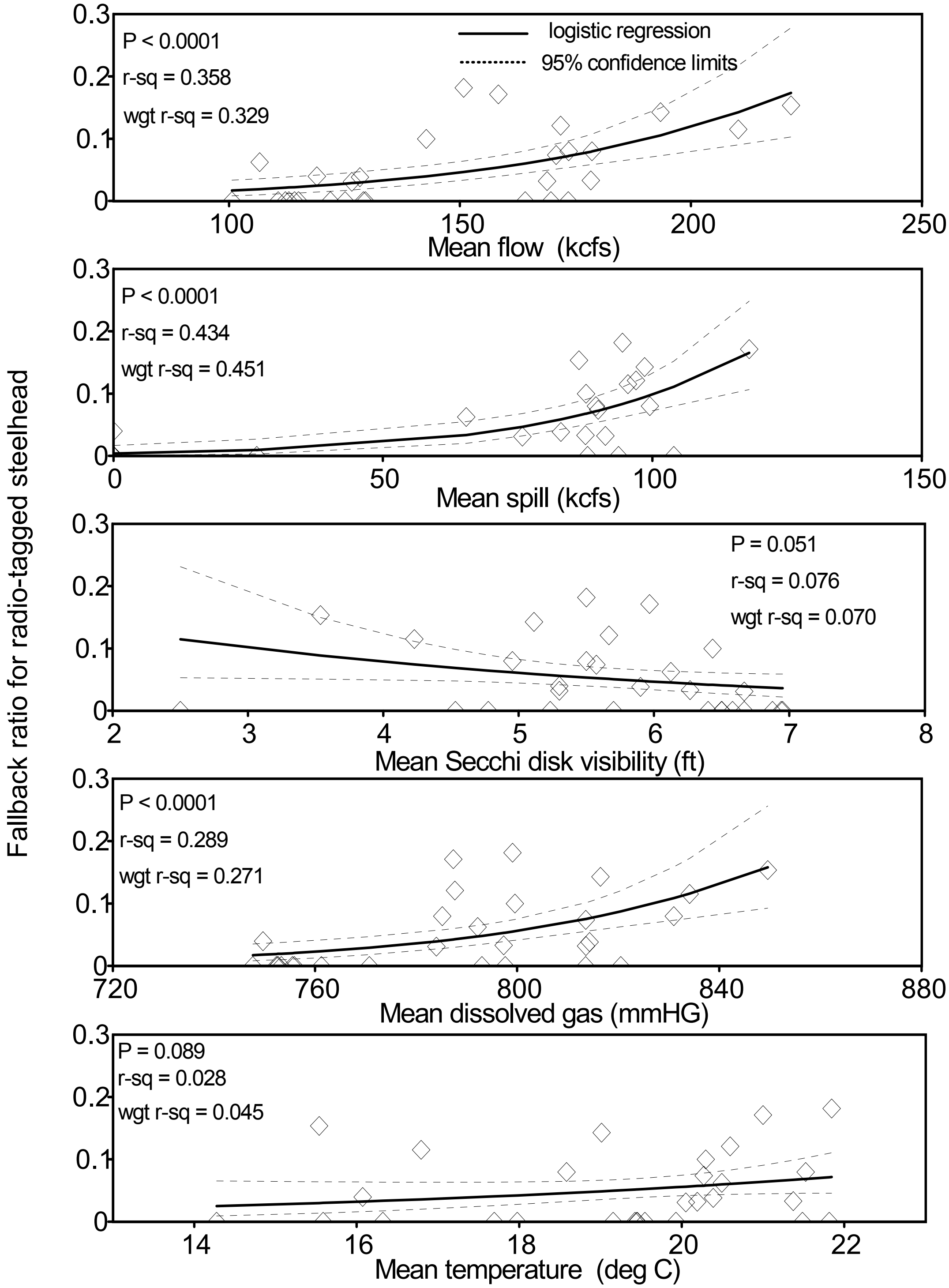

Figure 20. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of steelhead fallbacks within 24 h of passage at Bonneville Dam in 2000; includes r-sq values for weighted and unweighted linear regression models.

Table 10. Stepwise multiple regression model outputs for 2000 including models run, variables retained, variables removed and standard procedure outputs. All models have steelhead fallback ratios as their dependent variable. Data for this analysis were grouped in variable-day-bins according to ladder passage of radio-tagged fish.

Models Run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1 -	All variables, 1 Jun to 17 Oct					
	a. spill		0.4336	0.4336	20.67	0.0001
	b. water temperature		0.4936	0.600	3.08	0.0910
Model 2 -	Spill removed, 1 Jun to 17 Oct					
	a. flow		0.3581	0.3581	15.06	0.0006
Truncated dataset, spill conditions only						
Model 3 -	All variables, 1 Jun to 31 Aug					
	a. Secchi visibility		0.2213	0.2213	4.83	0.0421
	b. dissolved gas		0.4463	0.2250	6.50	0.0214
Model 4 -	Secchi visibility removed, 1 Jun to 31 Aug					
	a. spill		0.1943	0.1943	4.10	0.0589
	b. water temperature		0.2956	0.1013		0.1487

conditions. This small sample size precluded truncating the fall Chinook salmon dataset according to spill conditions as we did with the steelhead dataset. Of the two fallbacks occurring after spill conditions had ceased, one fall Chinook fell back through the navigation lock and one fell back by an undetermined route.

Fallback and Environmental Factors in 2001

Spring, Summer and Fall Chinook salmon

Near record low river flows and reduced periods of spill resulted in low overall rates of fallback for salmon and steelhead at Bonneville Dam in 2001. Of the 53 spring–summer Chinook salmon fallback events we recorded in 2001, only three occurred in less than 24 h after the fish passed the fishway. Of the 34 fall Chinook salmon fallback events, only four occurred less than 24 h after passage and one of those fish had been detected at an upstream receiver site prior to fallback. These small sample sizes precluded statistical analysis of 24 h fallback and environmental variables.

Steelhead

The 2001 steelhead dataset contained twelve 24 h fallbacks for which we created 27 bins with a mean of 5.6 d/bin (median 4.0 d/bin) (Figure 21). Flow, Secchi visibility, dissolved gas and water temperature showed a negative correlation with fallback while spill was positively correlated with fallback. Linear (both weighted and unweighted) and logistic models showed no significant relationships between fallback and the environmental factor tested (Figure 22). Weighted and unweighted linear models had r^2 values from 0.002 to 0.059 and P values ranged from 0.22 to 0.82. P values for multiple regression models ranged from 0.15 to 0.7 (Figure 22).

Table 11. Stepwise multiple regression model outputs for 2000 including models run, variables retained, variables removed and standard procedure outputs. All models have fall Chinook fallback ratios as their dependent variable. Data for this analysis were grouped in variable-day-bins according to ladder passage of radiotagged fish.

Models Run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1 -	All variables, 1 Aug to 23 Oct					
	a. spill		0.2467	0.2467	6.55	0.0187
	b. water temperature		0.5806	0.3339	15.13	0.0010
	c. Secchi visibility		0.6596	0.0790	4.18	0.0558
	d. flow		0.7245	0.0648	4.00	0.0617
Model 2 -	Spill removed, 1 Aug to 23 Oct					
	a. dissolved gas		0.1073	0.1073	2.41	0.1366

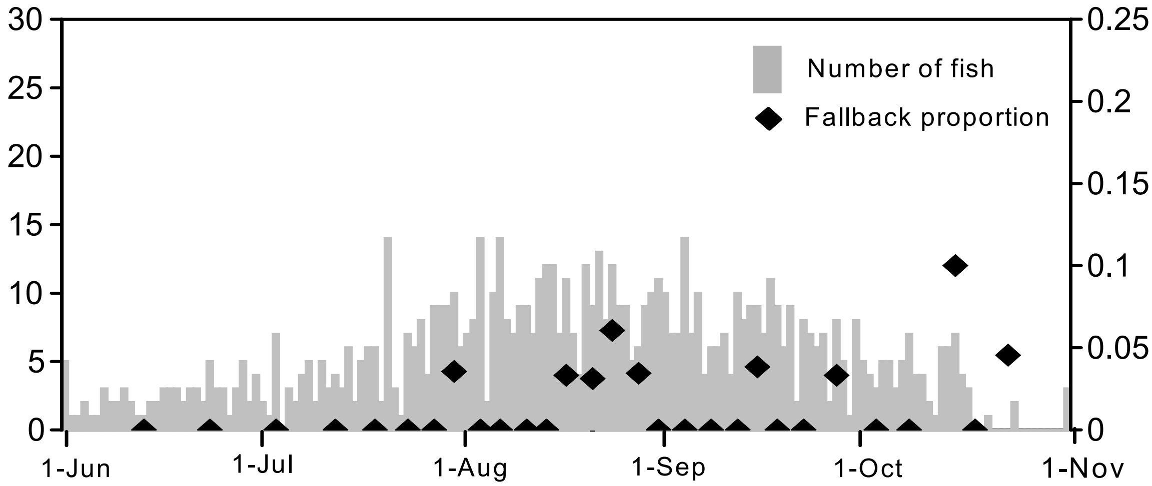

Figure 21. Daily number of radio-tagged steelhead that passed Bonneville Dam and the proportion of steelhead in consecutive bins of at least 25 fish that fell back within 24 h of passage in 2001.

Spill/No Spill Conditions and Chinook Salmon Fallback Rates in 2001

Spill conditions at Bonneville Dam occurred for 70 days in 2001 (ten year mean = 136 days), one block of 31 days from 16 May to 15 June and one block of 39 days from 24 July to 31 August (Figure 6). From 1 Sept to 29 November, between 1.2 and 2.6 kcfs was spilled from spillbays adjacent to fishway entrances as adult migrant attraction water. To examine the influence of spill on fallback rates, we compared passage rates and fallback rates for radio-tagged spring–summer Chinook salmon in the presence and absence of spill conditions.

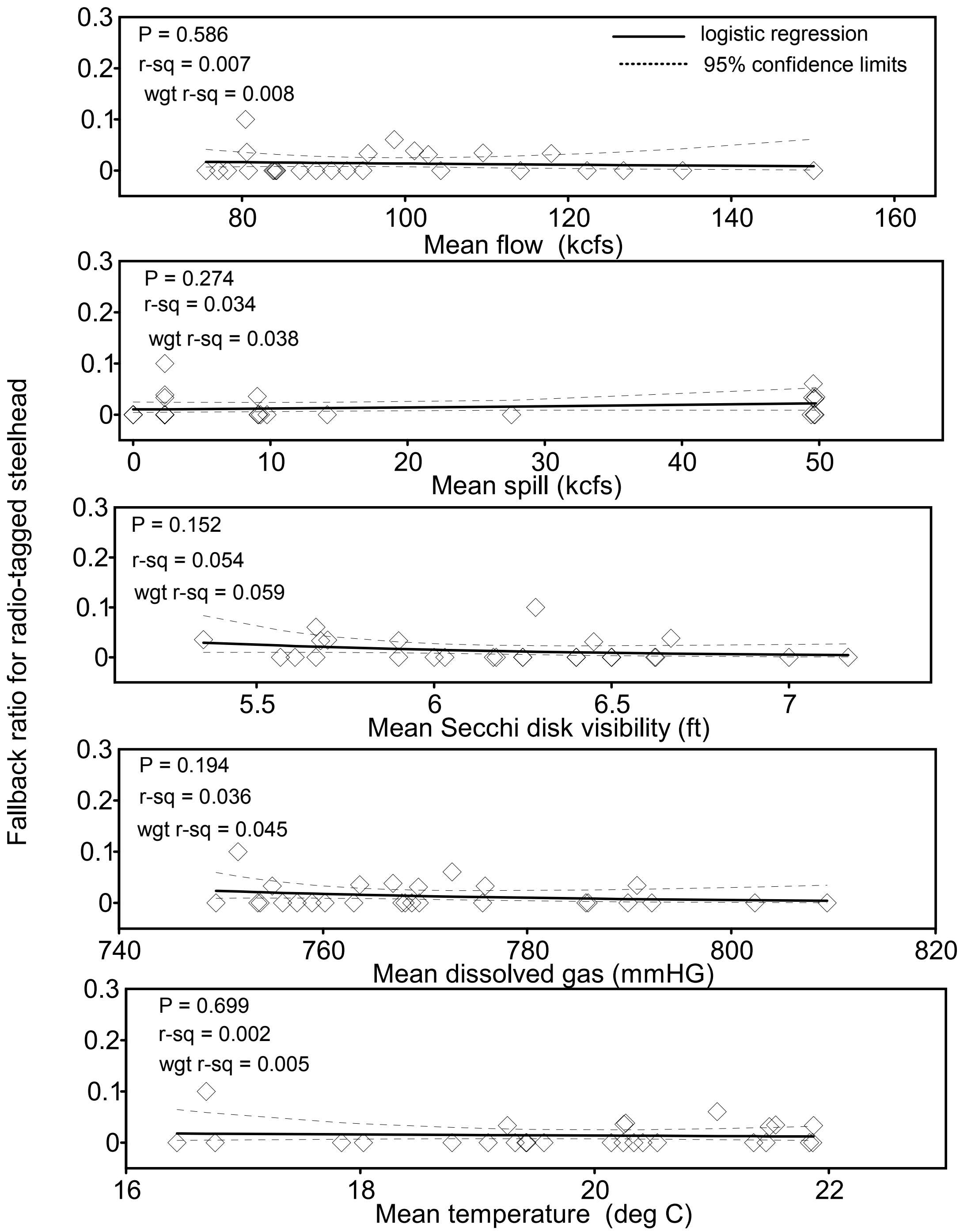

Figure 22. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of steelhead fallbacks within 24 h of passage at Bonneville Dam in 2001; includes r-sq values for weighted and unweighted linear regression models. All models based on variable-width time bins that included at least 25 fish.

In the previous analyses, the dates at which fish exited the fishway and entered the forebay were used to distribute the fallback events for analysis and only fallbacks that occurred within 24 h of ladder exit were used. In 2001, only 3 of the 53 Chinook fallback events occurred within 24 h with 72% of the radio-tagged fish being recorded at The Dalles Dam or farther upriver before returning to Bonneville Dam and falling back. In the following analysis, all fallback events were used regardless of the time between fishway exit and the fallback event.

During the no spill block (1 April to 15 May), using the date of fishway exit to distribute fallback events, 423 Chinook salmon passed Bonneville Dam (51% of all dam passages) of which 35 fell back (8.3%). During the spill block, 185 Chinook salmon entered the forebay (22% of all dam passages) of which 12 fell back (6.5%). These rates were not significantly different (X^2 test) (Figure 23). When fallbacks were distributed by the date the fallback event occurred, 25 Chinook salmon fell back during the no spill block, a rate of 5.9%, and 22 fish fell back during the spill block, a rate of 11.9%. These rates were significantly different (X^2 test, P=0.009) (Figure 23).

Final Distribution of Fish that Fell Back at Bonneville Dam

Migration summaries were derived from telemetry records of Chinook salmon and steelhead tagged in 2000 and 2001. These summaries were used to determine the final distribution of radio-tagged fish that fell back at Bonneville Dam and to identify fish that survived to tributaries or hatcheries during historical spawning times.

Spring–summer Chinook salmon

Of the 124 Chinook salmon that fell back at Bonneville Dam in 2000, 35 (28%) were recaptured in sport or tribal fisheries. About half (15) of the fish recaptured in fisheries were recaptured in the Bonneville pool, five were recaptured in the Dalles Dam pool and six were recaptured in tributaries of the Snake River above Lower Granite Dam. Four Chinook salmon were recaptured above Priest Rapids Dam (Table 12).

Twenty-seven (22%) Chinook salmon that fell back at Bonneville Dam in 2000 were recaptured at hatcheries or in weirs upstream from the dam. Eight Chinook salmon were recaptured at hatcheries located on tributaries to the Bonneville pool: seven at the Carson and Little White Salmon National Fish Hatcheries and one at the Klickitat Hatchery. Seven Chinook that fell back at Bonneville Dam were recaptured at the Warm Springs Fish Hatchery on the Deschutes River.

The last known location of 41 (33%) Chinook salmon that fell back was at tributary receiver sites or the top of Priest Rapids Dam. Of these fish, three were last located in tributaries of the Bonneville Dam pool, two in tributaries of The Dalles Dam pool. Eight Chinook were last located in the Yakima River drainage and 16 were last located in the Clearwater or Salmon Rivers or their tributaries. The last known location of eleven Chinook salmon was in the Columbia River above Priest Rapids Dam. Most of these were last recorded at the top of Rock Island Dam (4 fish) or the top of Rocky Reach Dam (5 fish).

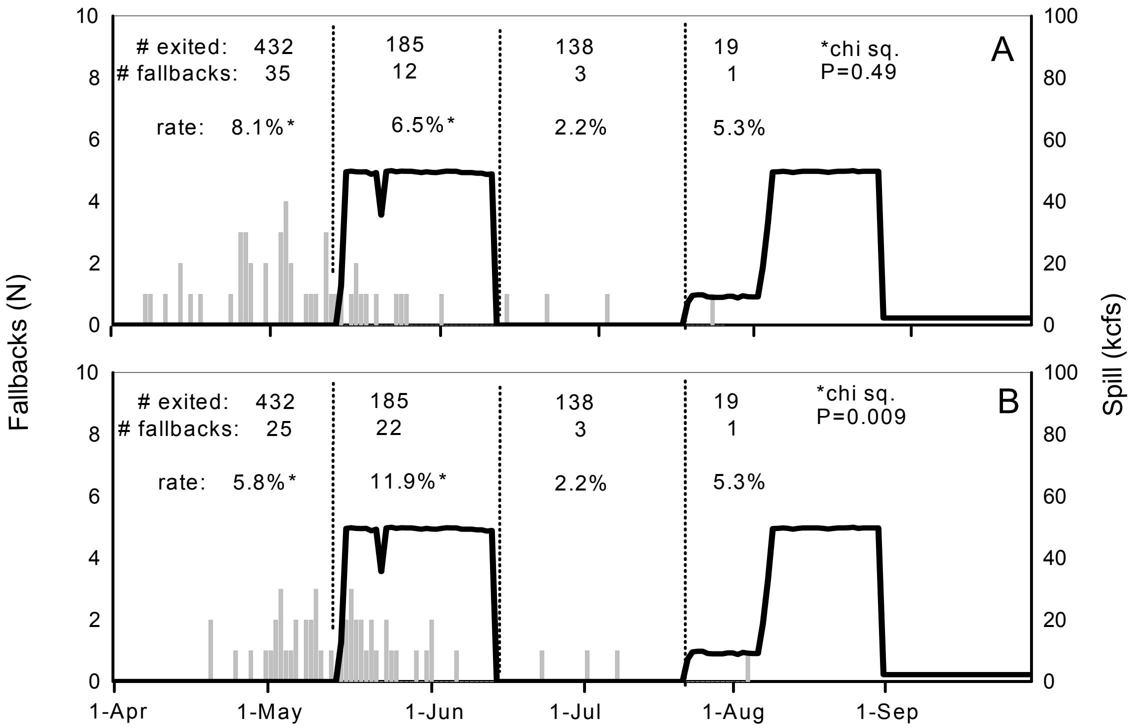

Figure 23. Numbers of spring–summer Chinook that exited fishways and fell back at Bonneville Dam during spill and no spill conditions in 2001. Fallbacks distributed by date of fishway exit (A) and by date of fallback event (B) with associated X^2 comparisons.

Twenty-one (17%) Chinook salmon that fell back were not recaptured at hatcheries or in fisheries and were not located in tributaries or other spawning areas. Eight fish did not reascend the dam, and the last telemetry record for seven of the eight fish was the fixed site receivers located about 3 km below Bonneville Dam; one fish had no records after falling back. Eleven Chinook salmon were last located in the Bonneville Dam pool and two were last located in The Dalles Dam pool.

In 2001, of the 32 spring–summer Chinook that fell back at Bonneville Dam, five (16%) were recaptured in sport or tribal fisheries. Two Chinook were recaptured below Bonneville Dam after falling back, one was recaptured in the Bonneville pool and two were recaptured above Lower Granite Dam.

Four (13%) Chinook salmon were recaptured at hatcheries or weirs, one at the Pelton Dam trap on the Deschutes River and three at Dworshak National Fish Hatchery on the Clearwater River.

Fifteen (47%) Chinook salmon were last located in tributaries and spawning areas. One Chinook was last located in the Wind River, one in the Deschutes River and one in the John Day River. One Chinook was last located in the Snake River above Asotin and one was in the Imnaha River. Two Chinook were last located in the Salmon River and eight were last located in the Clearwater River or its tributaries.

Table 12. Last known location of Chinook salmon(CK), steelhead (SH) and fall Chinook salmon (FCK) with transmitters that fell back at Bonneville Dam in 2000 and 2001 and percent that survived to tributaries.

	2000 CK	2001 CK	2000 SH	2001 SH	2000 FCK	2001 FCK
Total number of fallback fish	**124**	**32**	**55**	**33**	**26**	**25**
Recaptured in fisheries	**35**	**5**	**19**	**2**	**5**	**1**
Below Bonneville Dam		2	2		1	
Bonneville Dam to the Dalles Dam	15	1	7	1		1
The Dalles Dam to John Day Dam	5		3		2	
John Day Dam to McNary Dam			2		2	
McNary Dam to Priest Rapids Or Ice Harbor Dam	1		2	1		
Above Priest Rapids Dam	4					
Ice Harbor Dam to Lower Granite Dam	1		2			
Above Lower Granite Dam	9	2	1			
Recaptured at hatcheries	**27**	**4**	**1**	**1**	**3**	**3**
Bonneville Fish Hatchery					3	
Carson National Fish Hatchery	4					
Little White Salmon Fish Hatchery	3					1
Spring Creek Fish Hatchery						2
Klickitat Fish Hatchery	1					
Powerdale Dam Trap, Hood R.		1		1		
Warm Springs or Madras Hatchery, Deschutes R.	7	1		1		
Umatilla River Weir at Three Mile Dam	1		1			
Leavenworth National Fish Hatchery	1					
Lower Granite Dam Trap	1					
Imnaha River Weir	2					
Hell’s Canyon Dam	1					
South Fork of the Salmon R. Weir	1					
Rapid River Trap, Little Salmon R.	2					
Dworshak National Fish Hatchery		3				
Crooked River Weir, S.F. Clearwater R.	1					
Powell Weir, Lochsa R.	2					
Last located in tributaries	**40**	**15**	**20**	**15**	**7**	**5**
Wind River	1	1				
Little White Salmon River	1					
White Salmon River					1	1
Hood River			2	1		
Klickitat River	1		1	2	1	1
Deschutes River	2	1	1	2	1	
John Day River		1	3	1		
Umatilla River					1	1
Walla Walla River			1			

Table 12 Cont.	2000 CK	2001 CK	2000 SH	2001 SH	2000 FCK	2001 FCK
Yakima River	4					
Cle Elum River	1					
Naches River	3					
Hanford Reach of Columbia River					3	1
Above Priest Rapids Dam	11		1	2		
Tucannon River						
Snake River above Asotin		1	8			
Grande Ronde River			1	1		
Imnaha River		1				
Salmon River	1	1	1	3		
Little Salmon River	1	1				
South Fork Salmon	2					
Middle Fork Salmon			1			
Clearwater River	7	3		3		1
South Fork Clearwater	1	3				
Lochsa River	3	1				
Lolo Creek	1	1				
Last located in Columbia River	**21**	**7**	**14**	**15**	**11**	**16**
Below Bonneville Dam	8	6	3	7	9	10
Bonneville Dam to the Dalles Dam	11		5	1	2	5
The Dalles Dam to John Day Dam	2	1	2	2		
John Day Dam to McNary Dam			3	5		
McNary Dam to Priest Rapids Or Ice Harbor Dam			1			1
Last located between Little Goose and Lower Monumental dams	1	1	1			

Eight (25%) Chinook salmon were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries.

Steelhead

In 2000, 55 steelhead fell back at Bonneville Dam. Of those fish, 19 (35%) were recaptured in fisheries, 3 (5%) were recaptured at hatcheries or weirs, 19 (35%) were last located in tributaries or spawning areas and 14 (25%) steelhead were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries (Table 12).

Of the 19 steelhead recaptured in fisheries, two were recaptured below Bonneville Dam and 10 were recaptured between Bonneville and John Day dams. Two steelhead were recaptured between John Day and McNary dams and two more above McNary Dam in the main stem Columbia River. Two steelhead were recaptured in the Snake River between Ice Harbor and Lower Granite dams and one was recaptured above Lower Granite Dam.

Only one steelhead was recaptured at a hatchery or weir in 2000 (Umatilla River weir at the Three Mile Dam).

Nineteen steelhead were last located in tributaries and spawning areas. Most (12 fish) were last located in the Snake and Salmon rivers and their tributaries. One steelhead was last located at the top of Rock Island Dam and one steelhead entered the Walla Walla River. Three steelhead were last located in the John Day River and one was in the Deschutes River. One steelhead was last located in the Klickitat River.

Over 25% (14 fish) of the steelhead that fell back at Bonneville Dam were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries. Three of these 14 fish failed to reascend the dam, their last records were at the fixed site receivers located about 3 km below Bonneville Dam or at receivers near the entrance to the collection channel of Powerhouse II. Five steelhead were last located in the Bonneville Dam pool and two were last located in The Dalles Dam pool. Three steelhead were last located in the main stem Columbia River above John Day Dam.

In 2001, 33 steelhead fell back at Bonneville Dam. Two (6%) steelhead were recaptured in fisheries, one (3%) was recaptured the Pelton Dam Trap, 15 (45%) were last located in tributaries or spawning areas and 15 (45%) were last located in the Columbia River.

Of the two steelhead recaptured in fisheries, one was recaptured between Bonneville and The Dalles dams and one was recaptured between McNary and Priest Rapids dams.

Of the 15 steelhead last located in tributaries or spawning areas, five were located in the Hood (1), Klickitat (2), Deschutes (2) or John Day (1) rivers and two were last located exiting the Priest Rapids Dam fishway. One steelhead entered the Grande Ronde River, three entered the Salmon River and three were last located in the Clearwater River drainage.

About 45% of the steelhead that fell back at Bonneville Dam were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries. Seven of these fish did not reascend the dam and their last records were at the fixed site receivers located about 3 km below Bonneville Dam. One steelhead was last located between Bonneville and The Dalles dams, two were between The Dalles and John Day dams and five were last located between John Day and McNary dams.

Fall Chinook salmon

Of the 26 fall Chinook salmon that fell back at Bonneville Dam in 2000, 5 (19%) were recaptured in fisheries, 3 (12%) were recaptured at hatcheries or weirs, 6 (23%) were last recorded in tributaries or spawning areas and 12 (46%) fall Chinook salmon were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries (Table 12).

Five fall Chinook salmon were recaptured in fisheries, one downstream from Bonneville Dam, two were recaptured in The Dalles Dam pool and two in the John Day Dam pool. All three fall Chinook salmon recaptured at hatcheries were recaptured at the Bonneville Fish Hatchery. Of the six fall Chinook salmon that escaped to tributaries, two were last located in the Hanford Reach of the Columbia

River, and one fall Chinook salmon each escaped to the Umatilla , Deschutes , Klickitat and White Salmon rivers.

Eleven of the fall Chinook salmon that fell back at Bonneville Dam in 2000 were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries. Of these fish, nine failed to reascend the dam and two fall Chinook were last located in the Bonneville Dam pool.

In 2001, 25 fall Chinook salmon fell back at Bonneville Dam. One (4%) fall Chinook salmon was recaptured in a fishery, three (12%) were recaptured at hatcheries or weirs, five (20%) were last located in tributaries or spawning areas and sixteen (64%) were last located in the mainstem Columbia River.

One fall Chinook salmon was recaptured between Bonneville and The Dalles dams. Three fall Chinook salmon were recaptured at hatcheries or weirs, one at the Little White Salmon Fish Hatchery and two at the Spring Creek Fish Hatchery.

Five fall Chinook were last located in tributaries or spawning areas. One fall Chinook salmon entered the White Salmon River, one entered the Klickitat River and one was last located in the Umatilla River. One fall Chinook was last located in the Hanford Reach of the Columbia River and one fish was last located near the confluence of the Clearwater and Snake Rivers.

Sixteen fall Chinook salmon were neither recorded at tributary sites nor reported recaptured at hatcheries, weirs or in fisheries. Most (10) of these fish did not reascend Bonneville Dam after falling back. Five fall Chinook salmon were last located between Bonneville and The Dalles dams and one fall Chinook salmon was last recorded exiting a fishway at McNary Dam.

Fallback and Straying by Known Source Spring–Summer Chinook in 2001

In 2001, about 72% of the returning adult spring–summer Chinook we radio-tagged had originally been PIT-tagged as juveniles providing a pool of fish from known sources to evaluate stock-specific fallback. We divided radiotagged spring–summer Chinook from known stocks into three groups based on the site they were PIT-tagged as juveniles: those fish that originated from stocks of the Columbia River drainage upstream of McNary Dam, of the Columbia River drainage downstream of McNary Dam (including the Umatilla River) and of the Snake River drainage (Table 13). To account for variation in run timing and river environment, these groups were further separated into spring and summer components by their date of radio-tagging at Bonneville Dam. By comparing last known locations from telemetry records and recapture data to a fish's origin, as determined from PIT-tagging as a juvenile, we calculated that about 2.0% of tagged spring Chinook from Snake River stocks were last located in drainages other than that from which they originated. No spring Chinook from stocks of the Columbia River downstream or upstream of McNary Dam were determined to have strayed (Table 13). We calculated a straying rate of 1.4% for Snake River summer Chinook stocks and 0.8% for summer Chinook stocks of the Columbia River upstream of McNary Dam. No spring Chinook from stocks of the Columbia River downstream of McNary Dam were determined to have strayed though sample size was small (Table 13).

In an effort to increase statistical power and to evaluate fallback proportions of stocks under-represented in juvenile PIT-tagging efforts, we combined the information from our dataset on last known locations with juvenile PIT-tag data to develop a best estimate of stock-of-origin for all spring–summer Chinook radiotagged in 2001. Any Chinook that was not PIT-tagged as a juvenile was assigned a stock determined by the drainage in which it was last located (Table 13). Using unknown-source fish for this analysis increased sample sizes more than 25% but introduced estimated error in stock identification of from 0.6% to 1.1%.

Table 13. Number of spring and summer chinook radio-tagged in 2001 that were PIT-tagged as juveniles, number last located in drainages other than the one from which they originated (strays) and the number assigned a stock from a combination of PIT tag and telemetry data (best stock estimate). Table includes Chinook that were released in the forebay of Bonneville Dam that were not included in fallback analyses.

Stock group	Stock from PIT tag	Fish that strayed (%)	Best stock estimate
Spring Chinook (n=829)			
Columbia R. upstream MN	133	0	167
Columbia River downstream MN	33	0	85
Snake River	403	8 (2.0)	513
Unknown origin	260	-	64
Summer Chinook (n=288)			
Columbia R. upstream of MN	129	1 (0.8)	195
Columbia River downstream MN	0	0	6
Snake River	70	1 (1.4)	78
Unknown origin	89	-	9

Fallback data were integrated into the dataset and a contingency table and Pearson X^2 statistic was used to evaluate differences in fallback proportions for each group (Table 14). Only unique fallback events by Chinook released downstream of Bonneville Dam were used in the analysis and we also excluded from analysis fallbacks by Chinook we were unable to assign to a group (2 events). Though some cell counts were small, average expected frequency across all cells (n/(rc)) exceeded 10.0 as recommended by Zar (1999).

Spring Chinook from the three groups fell back at significantly different proportions (P=0.019). Standardized deviates indicated that spring Chinook stocks from the Columbia River upstream and downstream of McNary Dam groups fell back in lower than expected proportions while spring Chinook from the group of Snake River stocks fell back in higher than expected proportions (Table 14). Fallback by summer Chinook from the three groups was also significantly different ($P<0.0001$) with stocks from the Columbia River upstream of McNary Dam falling back less than expected and stocks from the Columbia River downstream of McNary Dam and from the Snake River falling back in higher than expected proportions (Table 14).

Table 14. Contingency tables, standardized deviates and X^2 statistics comparing proportions of radio-tagged spring Chinook and summer Chinook salmon from Columbia and Snake river stocks that did and did not fall back at Bonneville Dam in 2001. Only fish released downstream of, and then passed Bonneville Dam are included in analysis.

	Spring Chinook		
	Columbia River upstream of MN	Columbia River downstream of MN	Snake River
Did not fall back	114	47	334
Fell back	0	2	23
Standardized deviates			
Did not fall back	0.526	0.052	-0.317
Fell back	-2.341	-0.232	1.409
Test Statistic	Value	df	Prob.
Pearson X^2	7.899	2.0	0.019
	Summer Chinook		
Did not fall back	145	4	57
Fell back	0	1	1
Standardized deviates			
Did not fall back	0.116	-0.428	-0.058
Fell back	-1.181	4.341	0.592
Test Statistic	Value	df	Prob.
Pearson X^2	20.793	2.0	<0.0001

Escapement to Spawning Areas for Fish that did or did not Fall Back

We also compared escapement to monitored tributaries, hatcheries, spawning areas or the uppermost monitored sites for radio-tagged fish that did or did not fall back at Bonneville Dam. Salmon and steelhead were considered to have escaped if they were last located in spawning areas or recaptured at hatcheries during traditional spawning periods. Salmon and steelhead that successfully passed Lower Granite Dam were considered to have escaped as were those that successfully passed Priest Rapids Dam. Summer and fall Chinook salmon and steelhead were considered to have escaped if they were last located in the Hanford Reach. Fish that were recaptured in fisheries located in spawning areas were also considered to have escaped. Fish that were known or presumed to have regurgitated their transmitters at mainstem sites were excluded from this analysis.

For all years and species, escapement to tributaries, hatcheries, traps and weirs or spawning areas was higher for fish that did not fall back at Bonneville Dam than for those that did (Table 15). Spring–summer Chinook salmon that did not fall back at Bonneville Dam had escapement rates of about 85% for both 2000 and 2001 versus 77.4% and 65.6% for fish that did fall back. These proportions were significantly different (X^2 test, P<0.05). Steelhead escapement rates for fish that did not fall back were 68.9% and 74.4% in 2000 and 2001 versus 57.4% and 48.4% for fish that did fall back. The difference was significant in 2001 (P=0.001), but not in 2000 (*P* = 0.08). Fall Chinook salmon that did not fall back at Bonneville Dam had escapement rates of 56.4% and 60.4% in 2000 and 2001 versus 42.3% and 32.0% for fish that did fall back. This difference was significant in 2001 (P=0.005) but not in 2000 (*P* = 0.16) (Table 15).

Table 15. Number and percentage of unique spring–summer Chinook salmon (CK), steelhead (SH) and fall Chinook salmon (FCK) with transmitters that either did or did not fall back at Bonneville Dam, and the percentage that escaped to tributaries, hatcheries, traps, spawning areas or the top of Priest Rapids Dam in 2000 and 2001. Fish known or presumed to have regurgitated transmitters at mainstem sites were not included in the analysis.

	Did not fall back at Bonneville		Fell back at Bonneville		
Species	Number	Percent to escape	Number	Percent to escape	X^2 P
2000 CK	849	84.6	124	77.4	0.044
2001 CK	753	84.5	32	65.6	0.004
2000 SH	752	68.9	54	57.4	0.080
2001 SH	745	74.4	31	48.4	0.001
2000 FCK	713	56.4	26	42.3	0.156
2001 FCK	536	60.4	25	32.0	0.005

Discussion

River conditions and dam operation varied greatly between 2000 and the 2001, likely explaining the differences in fallback rates and routes between the two years. Past research has suggested that spill, the location of the fishway exit on Bradford Island and the tendency of upstream-migrating salmonids to follow the shoreline are the primary factors involved in fallbacks. The results of our analyses support those earlier findings.

During the 2000 migration season, near average river conditions were coupled with larger than average numbers of returning spring–summer and fall Chinook salmon and steelhead. Fallback rates for salmon and steelhead in 2000 were similar to those from earlier radio-telemetry studies. The fallback rates for fish passing the Bradford Island fishway were higher than rates for those fish that passed the Washington-shore fishway and, while spill was occurring at Bonneville Dam, the vast majority of fallbacks occurred via the spillway. Spill conditions existed for 147 days in 2000 with a mean volume of 88.4 kcfs (ten year mean = 136 days and 91.8 kcfs). Discharges from Powerhouse 1 and 2 were comparable during April and May with Powerhouse 1 having priority through June, July and August. About 59% of the radio-tagged spring–summer Chinook salmon, 47% of steelhead, and 58% of fall Chinook salmon passed the Bradford Island fishway

The 2001 salmon and steelhead migration took place under anomalous river conditions. Extremely low river flows, reduced periods and levels of spill and lopsided discharges from Bonneville Dam's two powerhouses created an unusual river environment in the vicinity of Bonneville Dam. Fallback rates for spring–summer Chinook salmon were roughly one third the average fallback rate for the previous four study years and spring–summer Chinook salmon that exited the Bradford Island and Washington-shore fishways had comparable fallback rates. Fallback rates for steelhead and fall Chinook salmon in 2001 were similar to rates during previous years but steelhead and fall Chinook salmon have historically experienced much less fallback than spring–summer Chinook salmon and would not be expected to be as affected by low flow conditions. Spill conditions existed for 70 days in 2001 with a mean volume of 39.5 kcfs. Between April and August of 2001, Powerhouse 2 accounted for more than 90% of all turbine discharge. About 44% of the radio-tagged spring–summer Chinook salmon, 39% of steelhead and 40% of fall Chinook salmon passed the Bradford Island fishway

Of the 160 spring–summer Chinook salmon fallback events that occurred in 2000, 76 occurred within 24 h of the fish's exit from the fishway. In 2001, just 3 of the 53 events occurred within 24 h. Most of these spring–summer Chinook salmon were likely not destined for tributaries and hatcheries downstream of Bonneville Dam (the reascension rate was 75%), but were fish that successfully migrated out of the forebay of Bonneville Dam, then returned for some reason and fell back. This "returnee" trend in 2001 was also apparent during the steelhead and fall Chinook salmon migrations. In 2000, 44 of 59 (75%) of steelhead fallback events and 7 of 34 (21%) fall Chinook salmon events occurred within 24 h of fishway exit. In 2001, only 12 of 35 (34%) of steelhead fallback events and 4 of 36 (11%) fall Chinook salmon events occurred within 24 h of exit.

Count adjustment factors calculated for the 2000 adult migration reflected positive biases in fish counts, ranging in excess of 13% of the run count for spring–summer Chinook salmon to only 0.2% for fall Chinook salmon. Adjustments were proportionally less in 2001 due to low overall fallback rates but, with the record returns of 2001, count biases exceeded 31,000 fish for spring–summer Chinook salmon, 27,000 fish for steelhead and 15,000 fish for the fall Chinook run. Escapement biases calculated using weighted 5-d blocks to account for variability in fish passage were similar to biases generated with pooled data in 2000. In 2001, the large returns and low overall fallback rates probably reduced the applicability of these weighted estimates.

The fallback routes used by salmon and steelhead were also quite different between the two years, an obvious but interesting effect of the spillway not being available as a route of fallback for much of 2001. In 2000, spill occurred April through August, and nearly 88% of the spring–summer Chinook salmon fallback events and about 84% of the steelhead fallback events took place via the spillway. In 2001, spill conditions only existed for a 31 day block from 16 May to 15 June and for a 39 day block from 24 July to 31 August. Spill volume also never exceeded 50 kcfs in 2001, a comparatively low level. The proportion of spring–summer Chinook salmon fallback events that occurred via the spillway dropped to 32% in 2001 as the spillway was only available as a fallback route for roughly one month of a four month migration season. However, only 11% of the steelhead fallback events in 2001 occurred via the spillway while about 72% of the steelhead that passed the dam between 1 June and 31 August did so during spill conditions. This suggests that steelhead were not as likely to fall back via the spillway while spill was occurring at these low levels.

The relationship between fallback ratios and environmental factors such as flow, spill, turbidity and dissolved gas levels has been difficult to describe statistically due to the continuous fluctuation in these factors compounded by daily variation in passage and fallback rates throughout the migration season. In 2000, spring, summer and fall Chinook salmon 24 h fallback was positively correlated with flow, spill and dissolved gas. Steelhead 24 h fallback was positively correlated with flow, spill, dissolved gas and water temperature. Regression analyses of spring–summer Chinook salmon fallback and environmental factors revealed no significant relationships, while steelhead fallback increased significantly with increasing flow, spill and dissolved gas, and fall Chinook salmon fallback was significantly related to spill. In 2001, low overall rates of fallback and the fact that most fish successfully migrated out of the forebay before returning to Bonneville Dam and falling back created small sample sizes for 24 h fallback ratios and precluded this analysis for spring–summer and fall Chinook salmon. Steelhead fallback was positively correlated with spill but regression analysis showed no significant relationships.

Spill patterns at Bonneville Dam in 2001 allowed us to block passage and fallback ratios of radio-tagged spring–summer Chinook salmon by spill and no-spill conditions. The “returnee“ trend of migrants in 2001 caused insufficient sample sizes for evaluation of 24 h fallbacks during this year but when all fallbacks were used in analysis and distributed by the date of the fallback event (not the date the fish exited the fishway), a significantly higher proportion of spring–summer Chinook salmon fell back during periods of spill than during periods of no spill.

The final distribution of fish that fell back at Bonneville Dam differed between the two years. In 2001, a smaller proportion of fish that fell back were later recaptured in fisheries, most likely because those fish represented a smaller proportion of the total run. The proportion of fish that fell back that were last located in tributaries was comparable between years with more than a third of spring–summer Chinook salmon and steelhead that fell back being last located in tributaries. This proportion was smaller for fall Chinook salmon but we did not monitor tributaries downstream of Bonneville Dam and some fall Chinook salmon that fell back may have reached downstream spawning areas. A higher proportion of fallback fish in 2001 were last located in the mainstem Columbia River with most of those fish failing to migrate as far as John Day Dam.

The return of large numbers of adult spring–summer Chinook salmon that had been PIT-tagged as juveniles presented us with a unique opportunity to evaluate straying rates and to relate fallback to specific stocks of fish. Integrating PIT-tag information with last known locations of fish as determined from telemetry records allowed us to estimate straying rates of Chinook salmon from stocks from the Columbia River upstream of McNary Dam, downstream of McNary Dam and from the Snake River. Snake River spring Chinook stocks strayed at an estimated 2% rate while no spring Chinook from stocks upstream or downstream of McNary Dam were determined to have strayed. Snake River summer Chinook had a 1.4% straying rate, stocks from the Columbia River upstream of McNary Dam strayed at a 0.8% rate and no summer Chinook from stocks downstream of McNary Dam were determined to have strayed.

By integrating information from our telemetry dataset on last known locations of fish with juvenile PIT-tag data, we developed a best estimate of stock-of-origin for more that 93% of spring–summer Chinook radiotagged in 2001. Straying rates indicated this method introduced estimated error in stock identification of between 0.6 and 1.1%. Spring and summer Chinook stocks from the three groups fell back at significantly different proportions. Standardized deviates indicated that spring Chinook stocks from the Columbia River upstream and downstream of McNary Dam fell back in lower than expected proportions while spring Chinook stocks of Snake River fell back in higher than expected proportions. Summer Chinook stocks from the Columbia River upstream of McNary Dam fell back less than expected and stocks from the Columbia River downstream of McNary Dam and from the Snake River fell back in higher than expected proportions. These results indicate stock-specific differences in fallback proportions and that spring–summer Chinook stocks from the Snake River are more likely to fall back. Given the reduced periods of spill, low overall fallback rates and prevalence of “returnee” fallbacks (fish migrating out of the forebay area then returning and falling back) this suggests that Snake River spring–summer Chinook stocks may be wandering more in the Lower Columbia River than Chinook stocks destined for the Columbia River drainage.

The proportion of fish that escaped to spawning areas or hatcheries after falling back one or more times at Bonneville Dam was lower than for fish that did not fall back in both years and for all runs. Differences were significant in all cases except for the 2000 fall Chinook salmon run. Comparing escapement by fallback fish for the two years, the percentage of fallback fish that escaped was lower in 2001 than in 2000 in all cases. This is probably an effect of the small overall number of fallback fish in 2001 although low flows and warmer than average water temperatures during this migration season could have further stressed fish that had fallen back and thus reduced escapement.

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