Technical Report 2000-1

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

ADULT CHINOOK AND SOCKEYE SALMON, AND STEELHEAD FALLBACK RATES AT BONNEVILLE DAM, - 1996-1998

A report for Project MPE-P-95-1

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for

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

and

Bonneville Power Administration
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Preface

Recent studies of adult salmon and steelhead migrations past dams, through reservoirs, and into tributaries with radio telemetry began in 1990 with planning, purchase and installation of equipment for studies at the Snake River dams. Adult spring and summer chinook salmon were outfitted with transmitters at Ice Harbor Dam in 1991 and 1992, at John Day Dam in 1993 and reports of those studies are available (Bjornn et al. 1992; 1994; 1995; 1998a; 1998b). The focus of adult salmon passage studies was shifted to the lower Columbia River dams in 1995 when telemetry equipment was set up at the dams and tributaries and spring/ summer chinook salmon were outfitted with transmitters at Bonneville Dam in 1996, 1997, and 1998. Steelhead, sockeye salmon, and fall chinook salmon were also outfitted with transmitters during some years. In this report we present information on fallback behavior by spring, summer, and fall chinook salmon, sockeye salmon, and steelhead at Bonneville Dam for the years 1996 to 1998. Additional reports will be issued on detailed analysis of passage at dams that had a full complement of receivers and antennas to monitor use of fishway entrances and passage through transition pools. General migration patterns, minimum survivals, and distributions will also be presented in reports for all groups tagged.

Acknowledgments

Many people assisted in the field work and data compilation for this project and the successful completion was made possible by John Ferguson, Bob Dach, Teri Barila, and Rebecca Kalamacz of the Corps of Engineers. Michelle Feeley, Brian Hastings, Michael Jepson, Steve Lee, and Alicia Matter assisted with data processing and analysis.

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Abstract

Starting in 1996, we outfitted large numbers of adult spring and summer chinook salmon *Onchorhynchus tshawytscha*, sockeye salmon *O. nerka*, and steelhead *O. mykiss* with radio transmitters at Bonneville Dam to monitor their passage at the dams in the Columbia and Snake rivers and survival to natal streams. In this report, we present information on the percentage of salmon and steelhead that fell back at Bonneville Dam, fallback rates (includes multiple fallbacks by individual fish), relations to environmental variables, survival of fish that fell back, and bias in escapement estimates based on counts of fish at the dams. In the three years 1996, 1997, and 1998 we outfitted 2,825 spring and summer chinook salmon with transmitters, 577 sockeye salmon in 1997, 1,745 steelhead with transmitters in 1996 and 1997, and 1,032 fall chinook salmon in 1998. Of these, 3,605 chinook salmon, 562 sockeye salmon, and 1,640 steelhead passed the dam after they were released 10 km downstream from the dam. We monitored passage and fallbacks at the dam using antennas and receivers in the tailrace, fishways, and forebay in all 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 truck or boats.

We calculated the percentage of steelhead, and chinook and sockeye salmon that fell back, fallback rates that account for multiple fallback events by individual fish, and escapement adjustment factors to adjust counts of fish passing through the fishways. We also calculated fallback percentages and rates separately for fish that passed the Bradford Island and Washington-shore fishways. We summarized fallback routes and fallback timing and related salmon and steelhead behavior in the forebay and upriver from the dam to fallback events. We also explored the effects of environmental conditions (flow, spill, Secchi disk visibility, water temperature, and dissolved gas pressure) on fallback rates for spring and summer chinook and sockeye salmon and steelhead with a variety of techniques. Summary information for the 1996 steelhead and 1998 fall chinook salmon data was more limited because of the relatively small number of fallbacks.

The percentages of spring/summer chinook and sockeye salmon that fell back over the dam ranged from 11.3% to 14.6% during the three years, and was highest for 1997 chinook salmon. Fallback rates that included multiple fallbacks, ranged from 13.7% to 19.9%, and was also highest for 1997 chinook salmon. Fallback percentages and rates were less than 6% for steelhead tagged in 1996; the percentage was 9.1% and the rate 9.9% for steelhead tagged in 1997. The percentage was 3.6% and the rate 4.2% for fall chinook salmon tagged in 1998. Fallback percentages and rates were two to more that four times higher for spring/summer chinook salmon that passed via the Bradford Island fishway than for those that passed via the Washington-shore fishway. The percentage of sockeye salmon and their fallback rate were more than 30 times higher for fish that passed the dam via the Bradford Island fishway. Almost all steelhead tagged in 1996 that fell back passed via the Bradford Island fishway, and about 80% of the steelhead tagged in 1997 that fell back passed through the Bradford Island fishway. Between 93% and 97% of steelhead, spring/summer chinook and sockeye salmon that

fell back within 24 h of passing Bonneville Dam had passed through the Bradford Island fishway prior to falling back. Sixty-nine to 95% of the salmon and steelhead that fell back reascended and passed over the dam a second time (or more).

Counts of salmon passing through the ladders, an index of upriver escapement, were adjusted based on pooled data for spring/summer chinook salmon, and were 0.864 in 1996, 0.838 in 1997, and 0.869 in 1998. Weighted correction factors were similar for spring/summer chinook salmon. Based on our estimates of fallback rates, counts of chinook salmon at the dam overestimated the upriver escapements by about 9,200 adult salmon in 1996, 23,000 in 1997, and 7,800 in 1998. The adjustment factor for sockeye salmon in 1997 using pooled data was 0.969, and the positive bias was about 1,500 fish. For steelhead tagged in 1996, the pooled correction factor was 0.992 and the positive bias was about 1,600 fish. The pooled correction factor was 0.939 for steelhead tagged in 1997, with a positive bias of about 15,800 fish. The pooled correction factor was 0.999 for fall chinook salmon in 1998, with a positive bias of about 200 fish.

Based on telemetry records, we believe most spring/summer chinook and sockeye salmon and steelhead that fell back at Bonneville Dam did so via the spillway. A small percentage of fish fell back through the navigation lock in all years (except at least 60% of fall chinook salmon fell back via the navigation lock) and some spring/summer chinook salmon fell back via ice and trash sluiceways at both powerhouses in 1997 and 1998. Sluiceways were not monitored in 1996. It was not clear how many radio-tagged fish fell back through powerhouses because turbine intakes were not monitored, but we believe few fish fell back via that route because we could account for most fish that fell back as entering the spillway channel, navigation lock, or sluiceways.

Chinook salmon fallback percentages and rates were highest in 1997, the year with highest flow and spill. In single factor analyses, the proportion of radio-tagged spring/summer chinook salmon that fell back increased significantly with flow and spill in each year ($r^2 = 0.12$ to 0.22). Secchi disk visibility, water temperature, and dissolved gas levels were also correlated with fallback proportions, but the relations were less important. Fallback ratios based on both consecutive 5-d blocks and variable-day bins of fish that passed the dam had r^2 values of 0.23 to 0.52 with flow and spill for fish that fell back within 24 h of passing the dam. Fallback of sockeye salmon was not strongly related to environmental variables, although higher fallback rates tended to occur during high spill. Fallback ratios for steelhead tagged in 1997 were near zero when there was no spill and increased as spill increased. Few steelhead fell back when there was no spill in both 1996 and 1997.

We also used multiple regression models to evaluate the relation of fallback ratios and environmental factors. For spring/summer chinook salmon, flow and/or spill were the most significant predictors of fallback rates in each year. The inclusion of water temperature (a surrogate for passage date) in regression models improved model fit more than Secchi disk visibility or dissolved gas pressures. For sockeye salmon, water temperature, Secchi disk depth, spill, and flow provided the best models to predict fallback rates in 1997, but none of the models produced high r^2 values. Spill levels were the best predictor of fallback rates for steelhead tagged in 1997.

We used complete migration information to determine the final distribution of fish that fell back at Bonneville Dam. Approximately 68% to 72% of spring/summer chinook salmon, 60% (1996) and 34% (1997) of steelhead, 64% of sockeye salmon, and 63% of fall chinook salmon that fell back at Bonneville Dam survived to enter tributaries, were recorded at the uppermost monitoring sites, or were transported from adult traps to hatcheries. With the exception of fall chinook salmon (31%), few fish that fell back entered tributaries downstream from Bonneville Dam, an indication that less than 5% of the fallbacks were caused by fish that migrated past their home stream and had to return downstream. A significant proportion of the spring/summer chinook salmon (19% to 32%) and steelhead (14% to 23%) that fell back at Bonneville Dam were recorded in tributaries upriver from Lower Granite Dam or were transported from the adult trap at Lower Granite Dam to hatcheries. More than half (56%) of the sockeye salmon that fell back at Bonneville Dam were last recorded in tributaries to the upper Columbia River, mostly in the Wenatchee and Okanogan rivers. Fish not recorded in tributaries or at the uppermost monitoring sites (28% to 36% of spring/summer chinook and sockeye salmon, 46% to 66% of steelhead, 38% of fall chinook salmon) were last detected primarily at dams or in reservoirs throughout the lower-Columbia River/Snake River hydrosystem.

Introduction

Significant numbers of adult salmon and steelhead fall back at Bonneville Dam when there is forced or deliberate spill (Young et al. 1978; Ross 1983; Bjornn and Peery 1992). In prior studies (Monan and Liscom 1973, 1975; Liscom et al., 1977; Gibson et al. 1979; Turner et al. 1984), the problem had been identified but not fully evaluated. Recent developments in radio telemetry allowed us to put transmitters in large numbers of fish and precisely monitor their movements for up to a year. An objective of studies that began in 1996 was to estimate the percentage of adult salmon and steelhead that fell back over the dams, calculate fallback rates, and adjust the counts at the dams to get more accurate estimates of upriver escapements. In this report, we present our best estimates of the proportion of spring/summer chinook salmon, sockeye salmon, steelhead, and fall chinook salmon that fell back at Bonneville Dam in the years 1996-1998. An analysis of fallback rates at other dams in the Columbia River basin is presented in reports that cover the entire migration of each stock (the first of such reports is for the 1996 run of spring/ summer chinook salmon, Bjornn et al. 2000a), and in reports of fallback behavior at The Dalles and John Day dams (Bjornn et al., 2000b; 2000c).

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 the fallback rates, the estimates of escapement can be adjusted and made more accurate.

For this report, we analyzed three years of radio-telemetry data for spring and summer chinook salmon (1996 to 1998), one year (1997) for sockeye salmon and fall chinook salmon (1998), and two years (1996 and 1997) for steelhead to characterize and evaluate fallback behavior at Bonneville Dam. Data for all years and species were fully coded at the dams and for the overall migration. Full migration analyses were complete for spring/summer chinook salmon and steelhead tagged in 1996, and underway for fish tagged in subsequent years. As migration studies are completed, we expect some minor changes in fallback analyses, but those changes will not materially change results.

In all 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 in the adult fish collection facility after they had been diverted from the Washington-shore fishway. Trapping of salmon began in early April each year and continued to mid July with fish tagged and released 10 d out of every 14 d period. We tagged steelhead from mid June through mid October, and fall chinook salmon from early September through October. The only selection criteria was size; we did not put transmitters in “jack salmon” that had only spent one year in the ocean. With the exception of fall chinook salmon in 1998, proportions of radio-tagged fish versus the normal fish counts at the windows at each dam were similar (Figure 3), an indication that our tagging was generally representative. In each year, the last part of the summer chinook run was probably under represented in

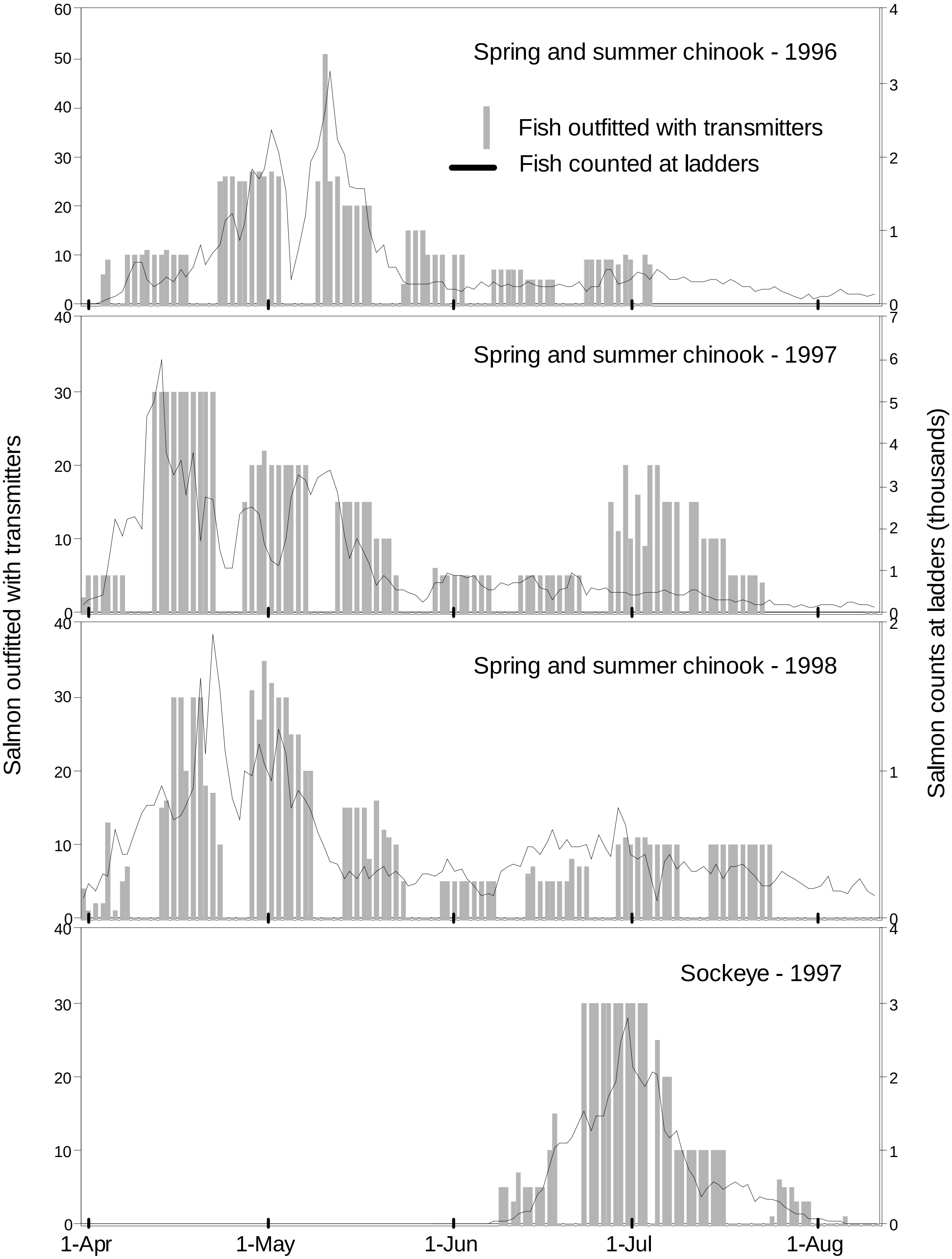

Figure 1. Daily spring and summer chinook salmon and sockeye salmon counts at Bonneville Dam and the number of salmon outfitted with transmitters in 1996, 1997, and 1998.

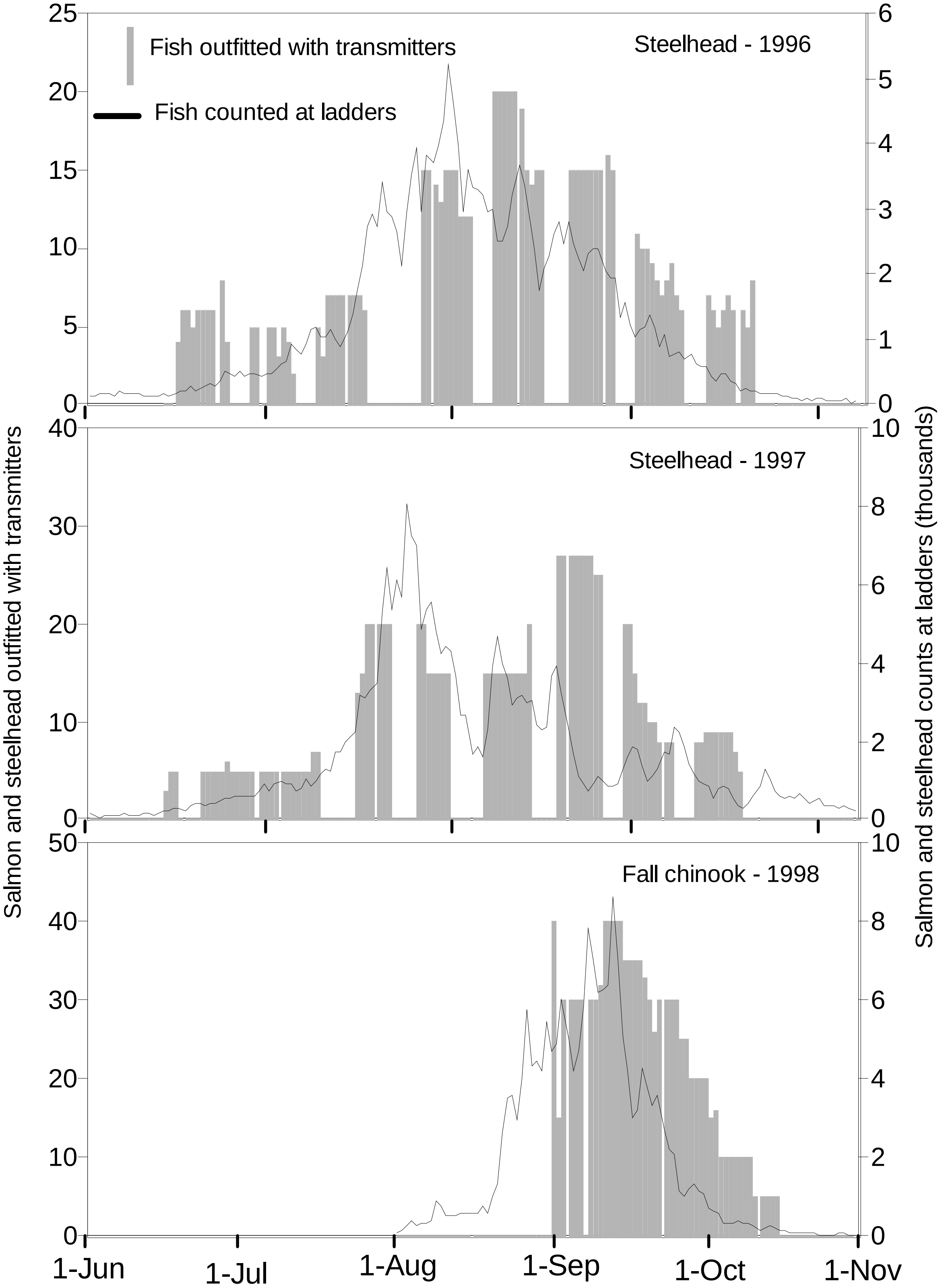

Figure 2. Daily steelhead and fall chinook salmon counts at Bonneville Dam and the number of steelhead and salmon outfitted with transmitters in 1996, 1997, and 1998.

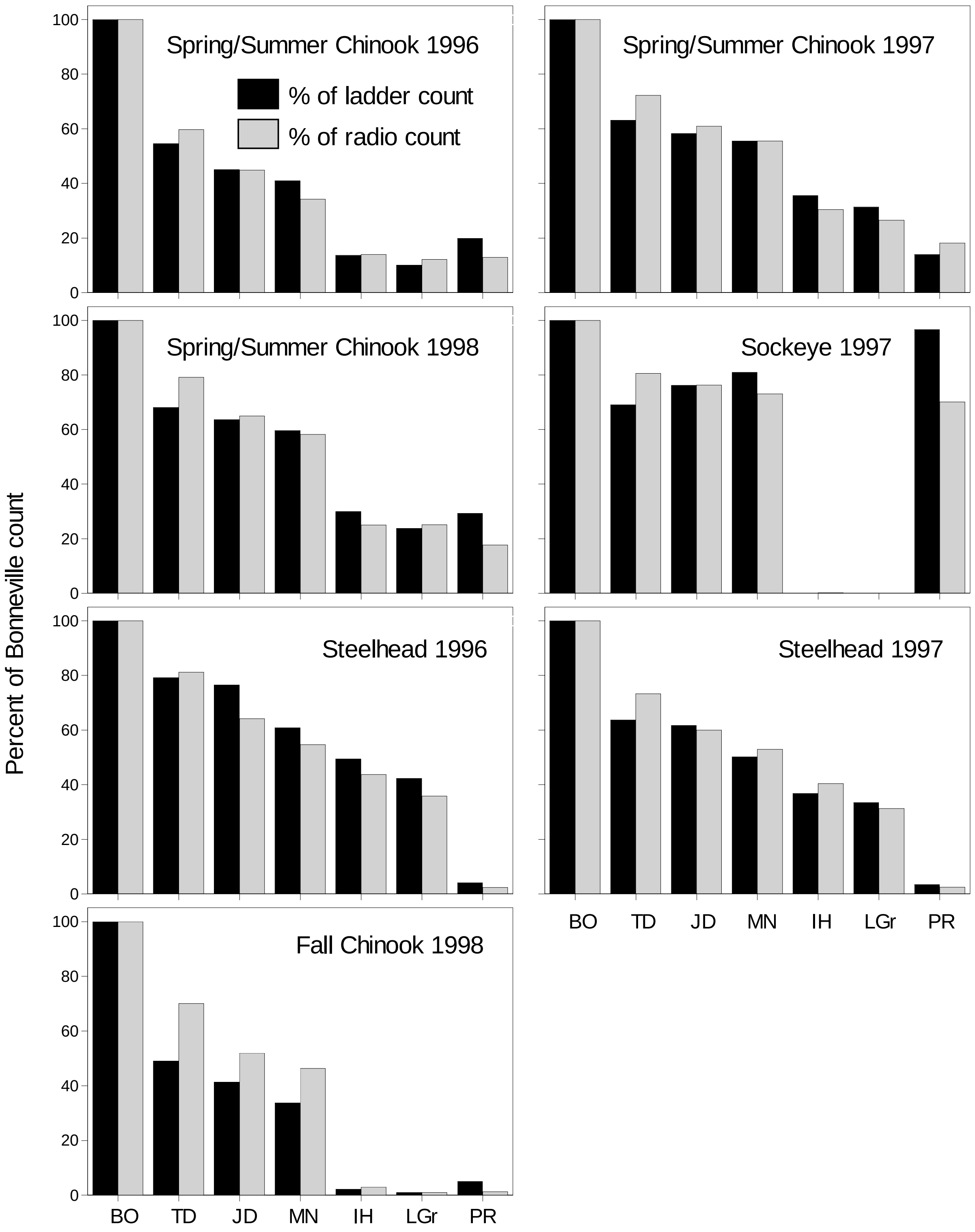

Figure 3. Percent of chinook and sockeye salmon and steelhead counted at Bonneville Dam and radio-tagged salmon and steelhead recorded at Bonneville Dam that were recorded upstream at other Columbia and Snake River dams in 1996, 1997, and 1998. Counts not adjusted for fallback and reascension or navigation lock passage.

our tagging because we stopped tagging in mid July because of high water temperatures. For a full description of tagging procedures see Bjornn et al. (2000a).

In all three years, the number of spring/summer chinook salmon tagged and released was generally proportional to the number of fish counted at the dam (Figure 1), and when tagged fish passed the dam again, the numbers were proportional, except in 1997 (Figure 4). In 1997, relatively few radio-tagged spring/summer chinook salmon passed the dam during early April when large numbers of untagged fish were passing the dam, thus the early April segment of the run may be under represented. Sockeye salmon outfitted with transmitters in 1997 and steelhead with transmitters in 1996 passed Bonneville Dam in proportion to daily counts at the dam (Figure 5). Passage of steelhead radio-tagged in 1997 under represented the run during the August peak and over represented the run during mid September (Figure 5). We did not sample from the August portion of the 1998 fall chinook salmon run, and passage of radio-tagged fish tended to undersample the run in September and oversample in October.

Overall, spring and summer chinook salmon with transmitters that passed Bonneville Dam made up 1.38% of the 1996 run, 0.79% of the 1997 run, and 1.77% of the 1998 run (Figure 6). Radio-tagged sockeye salmon made up about 1.35% of those counted at the dam in 1997. Radio-tagged steelhead made up about 0.37% of the 1996 count and 0.38% of the 1997 count Bonneville Dam, while fall chinook salmon with transmitters made up 0.49% of the total 1998 count, and about 0.68% of the count after 1 September (Figure 7).

We further evaluated our sample of radio-tagged fish throughout the runs by plotting the ratio of tagged fish to total counts for 5-d blocks for each year and species (Figure 6). The relative amount of deviation from the overall ratios for chinook salmon were calculated by standardizing the ratio for each block to the ratio for each season with a log (~base 2) scale. Ratios for spring/ summer chinook salmon were low for 5-d blocks early and late in each year, particularly early in the 1997 run, and ratios were relatively high during the count nadir at mid-season in 1996 and late in 1997 (Figure 6). For sockeye salmon, proportions for most 5-d blocks were close to the overall sampling rate. Ratios for steelhead were high in the earliest portion of the runs, low during peak counts, and higher later in September (Figure 7). Ratios for fall chinook salmon were low in early September and were higher than the overall sampling rate throughout October (Figure 7).

Environmental conditions at Bonneville Dam were different the three years of study. Flow, spill, and dissolved gas levels were lowest in 1998, highest in 1997, and intermediate in 1996 (Figures 8 and 9). Secchi disk visibility was generally lowest in 1997, highest in 1998, and intermediate in 1996, with the greater differences between and within years early in the migration season (Figure 9). Water temperatures had similar trends in all three years, but temperatures in 1998 were consistently higher than in the prior years.

In a between-years comparison of

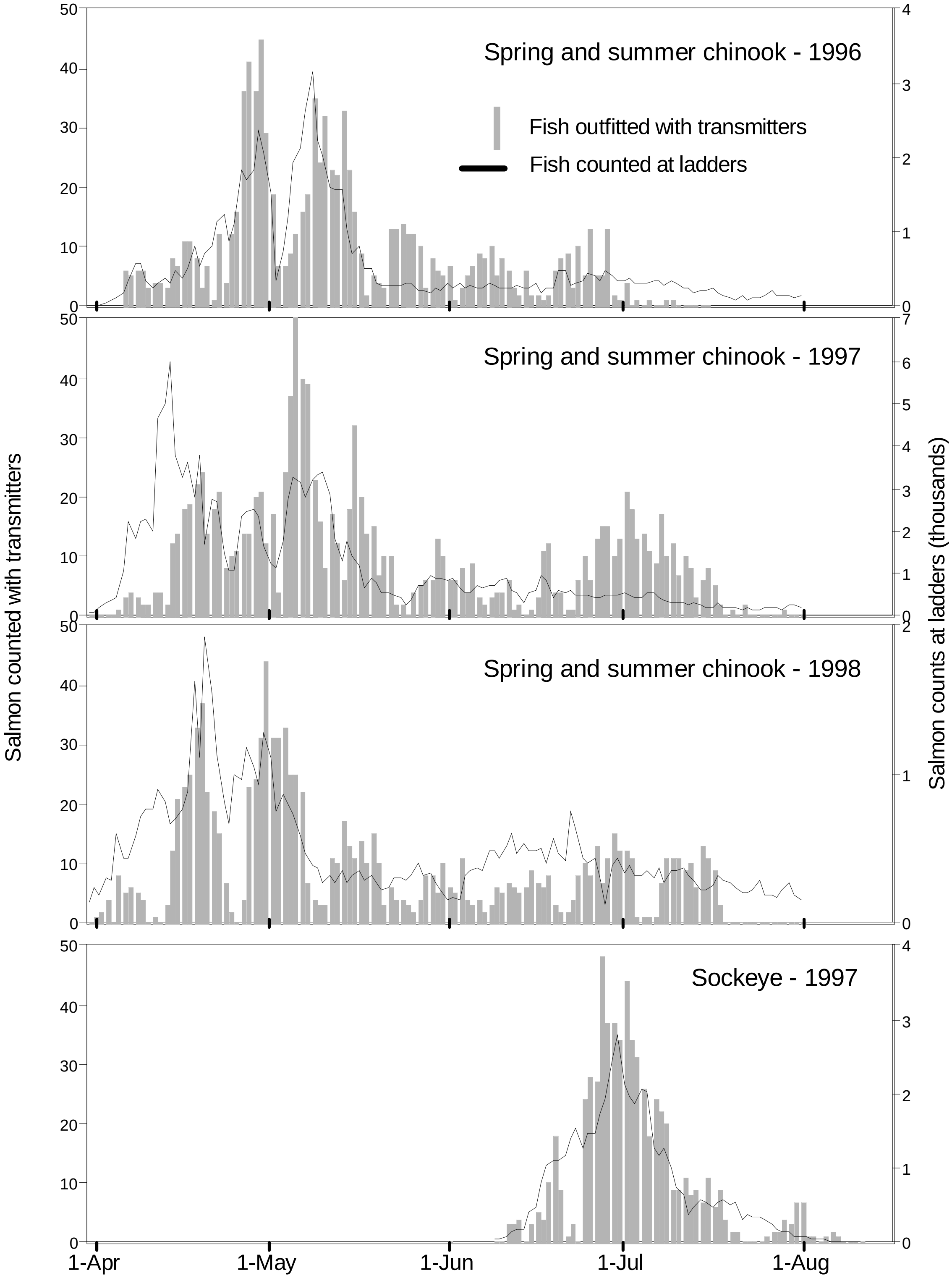

Figure 4. Daily spring and summer chinook salmon and sockeye salmon counts at Bonneville Dam and the number of salmon with transmitters that passed the dam in 1996, 1997, and 1998.

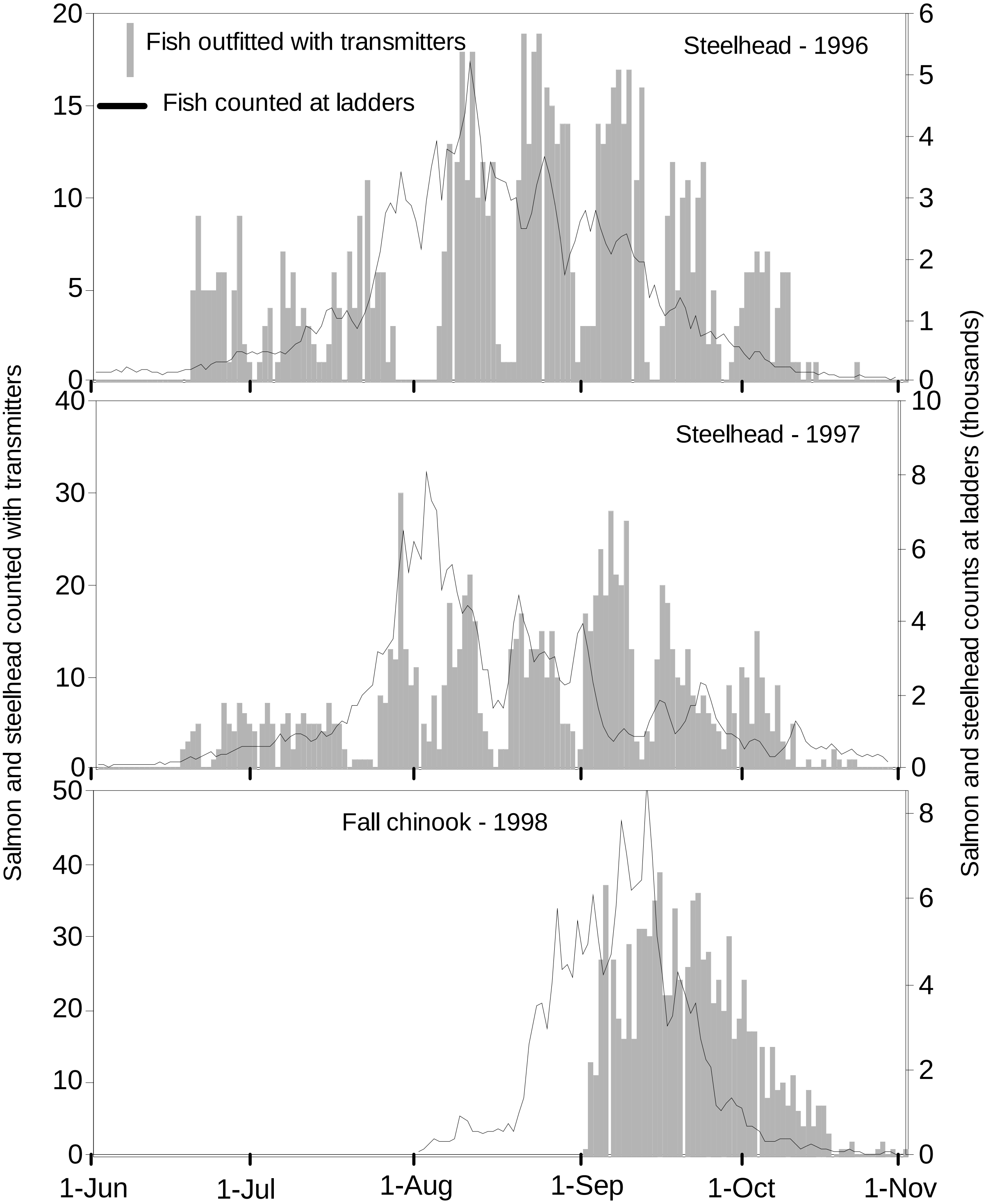

Figure 5. Daily steelhead and fall chinook salmon counts at Bonneville Dam and the number of steelhead and salmon with transmitters that passed the dam in 1996, 1997, and 1998.

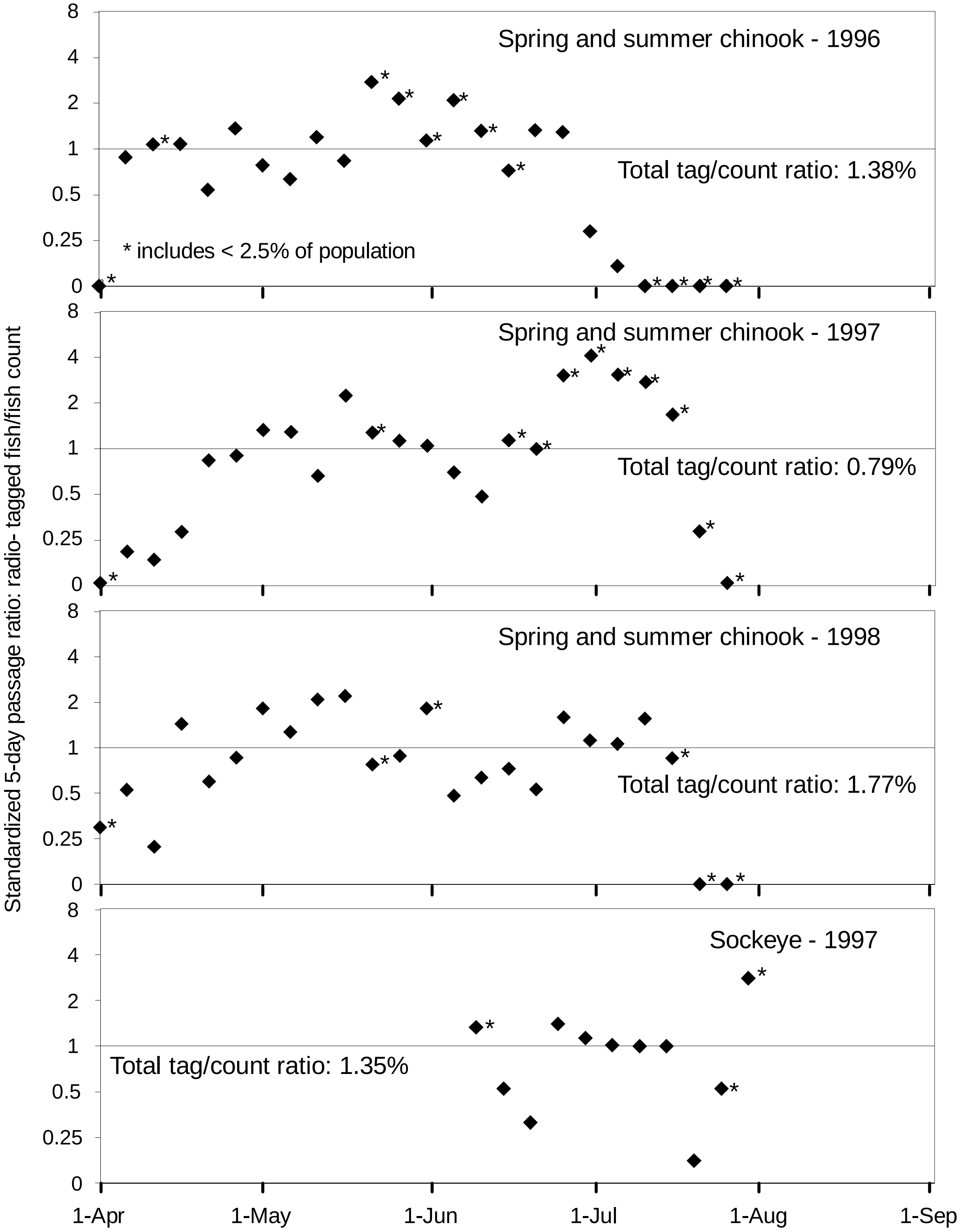

Figure 6. Standardized proportions of radio-tagged spring and summer chinook salmon and sockeye salmon passing Bonneville Dam to the total counts at the dam during 5-d blocks in 1996, 1997, and 1998. Blocks that include less than 2.5% of the total run noted with an asterisk. Log (~base 2) scale used to show relative distance from total sampling rate.

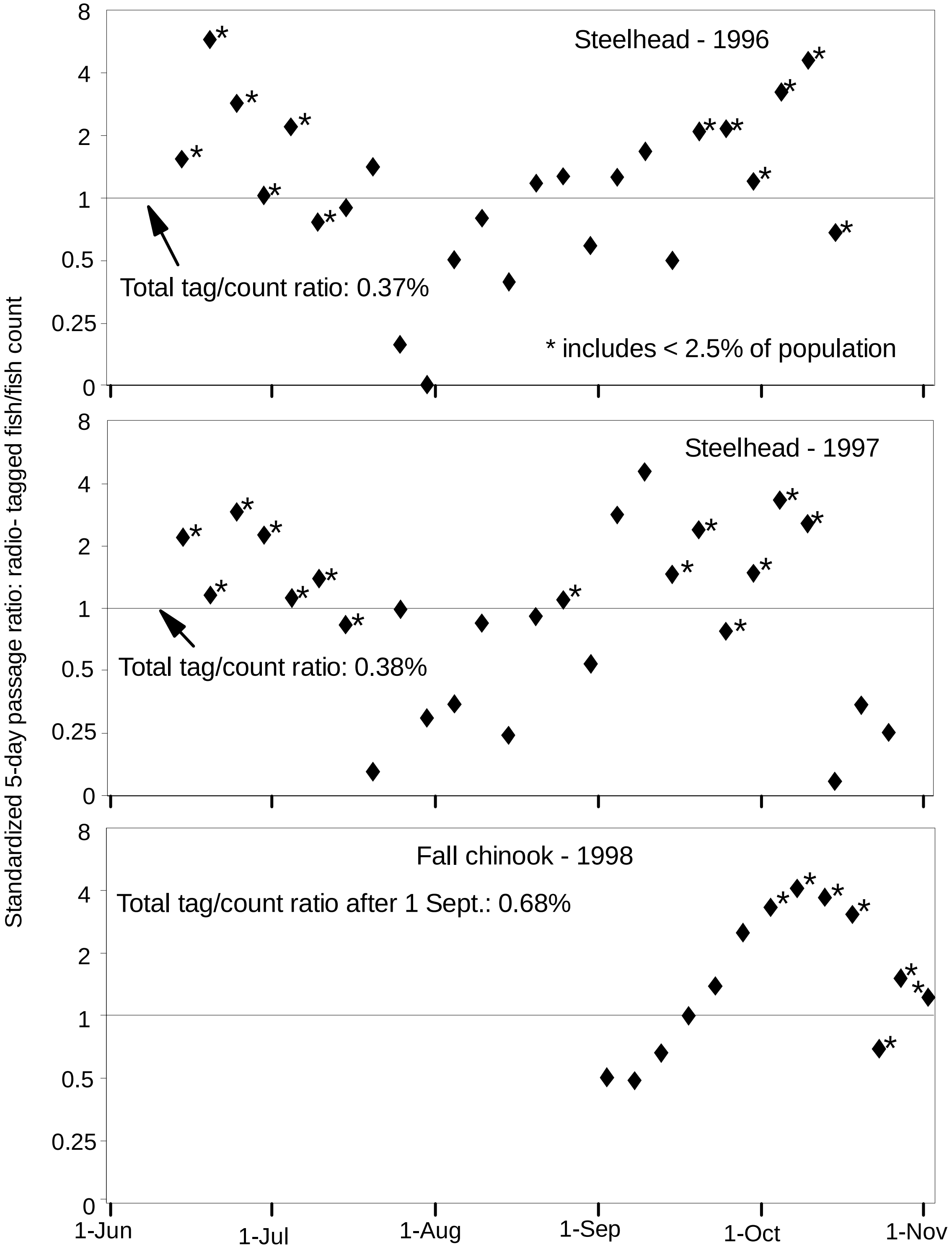

Figure 7. Standardized proportions of radio-tagged steelhead and fall chinook salmon passing Bonneville Dam to the total counts at the dam during 5-d blocks in 1996, 1997, and 1998. Blocks that include less than 2.5% of the total run noted with an asterisk. Log (~base 2) scale used to show relative distance from total sampling rate.

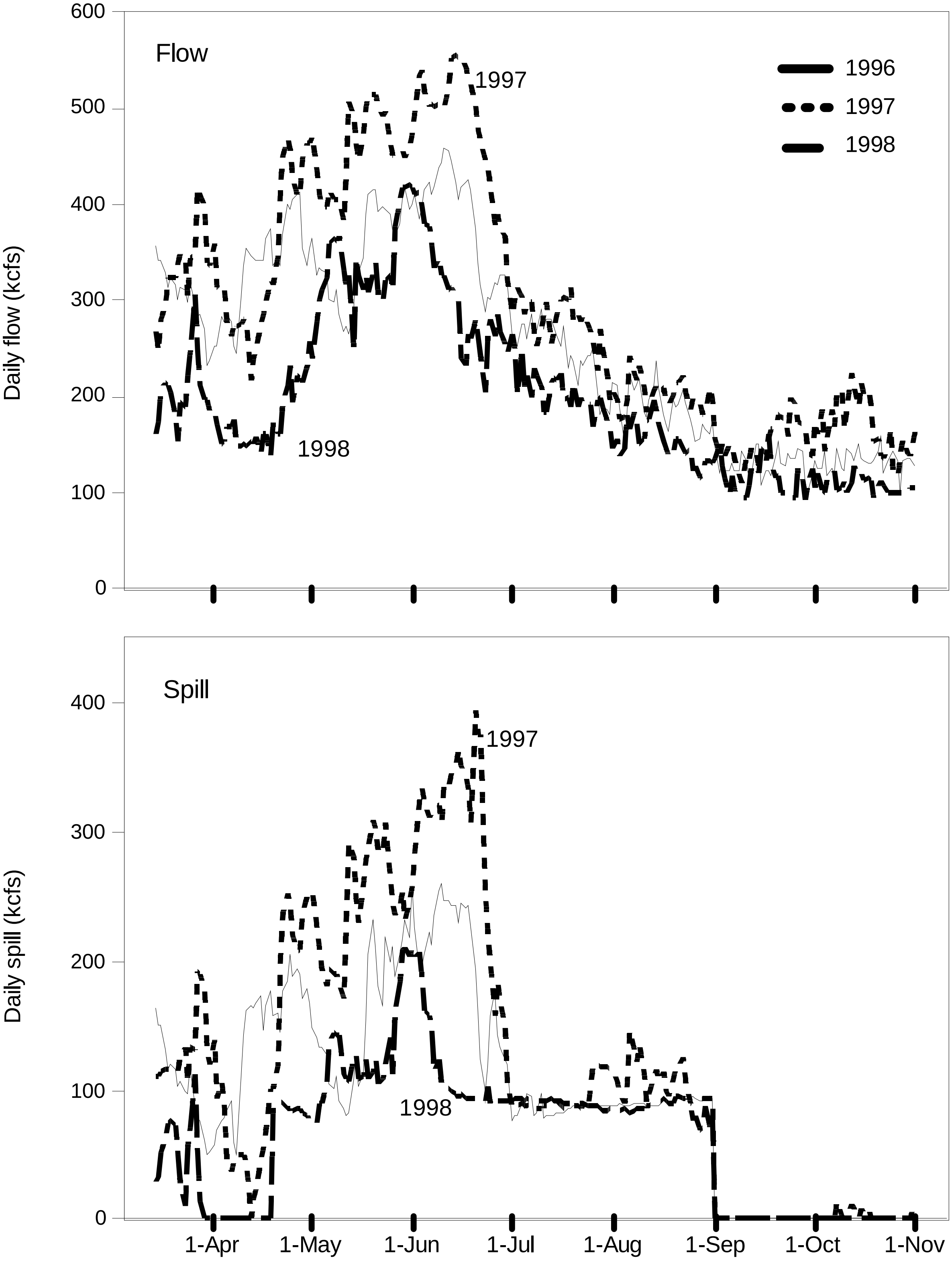

Figure 8. Daily flow and spill at Bonneville Dam in 1996, 1997, and 1998.

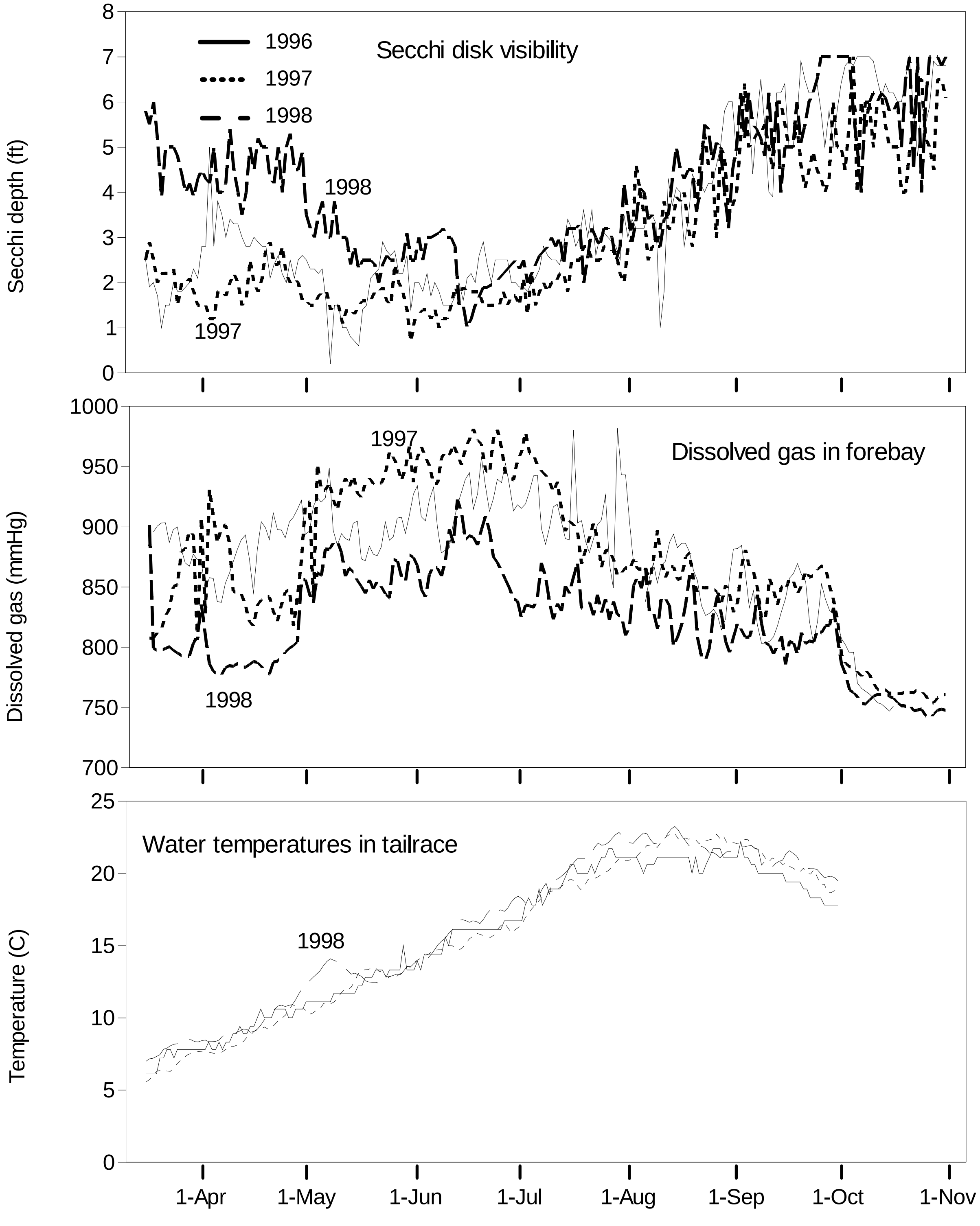

Figure 9. Daily Secchi disk visibility in the forebay, dissolved gas levels in the forebay, and water temperature in the tailrace at Bonneville Dam in 1996, 1997, and 1998.

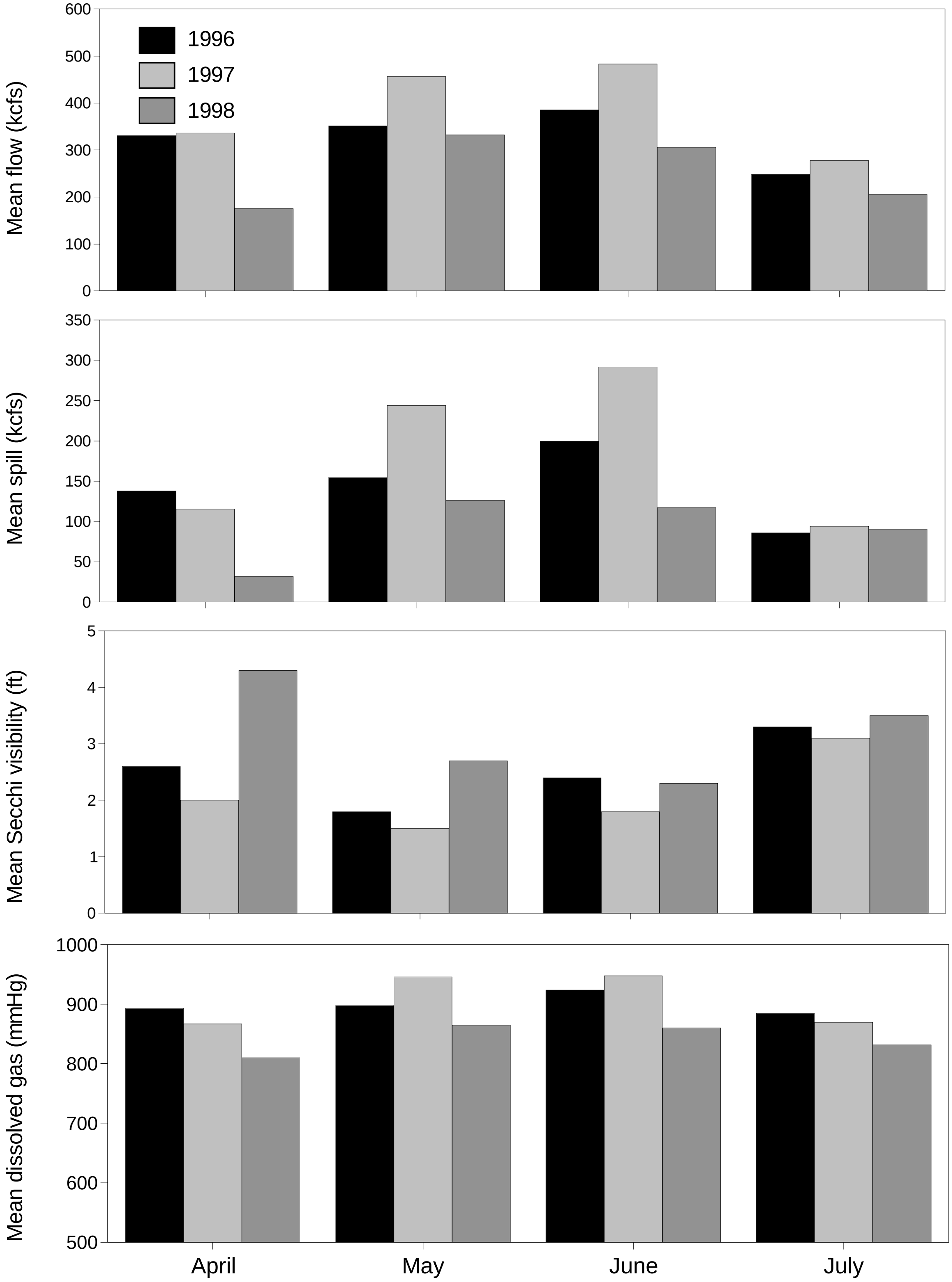

Figure 10. Monthly mean values for flow, spill, Secchi depth visibility, and dissolved gas levels in the forebay at Bonneville Dam in 1996, 1997, and 1998.

mean monthly values, 1997 had the highest mean flow for all months and the highest mean spill for the months of May, June, and July (Figure 10.) The 1998 means were the lowest for flow in all months and the lowest for spill for April, May, and June. Dissolved gas concentrations in 1998 were the lowest among years for all months, and 1998 mean Secchi disk readings were highest in all months except June (Figure 10).

Flow and spill conditions in the three years of study represented a high flow year (1997), a moderately high flow year (1996), and a near average flow year (1998) at Bonneville Dam. Timing and size of the spring and summer chinook salmon runs, however, were somewhat atypical during the three years. In 1996, the run was similar in size to the 15-year mean (1984 to 1998) at Bonneville Dam, but the peak of the run was later than average by two or more weeks (Figure 11). The 1997 chinook salmon run was larger and slightly earlier than average. Timing of the 1998 run was similar to average, but the spring chinook salmon count was below the 15-year mean. Timing of sockeye salmon passage in 1997 and steelhead passage in 1996 were similar to averages, while the 1997 steelhead run peaked earlier than usual (early August) and counts were substantially lower than average in mid September. The 1997 sockeye and 1996 steelhead run counts were slightly below average, and the 1997 steelhead count was higher than the 15-year mean. The 1998 fall chinook salmon run was similar in size and timing to the 15-year mean (Figure 11).

Methods

Data used to calculate fallback rates were obtained by monitoring the movements of adult salmon and steelhead with radio transmitters as they migrated past the dams and into tributaries. Receivers and antennas were set up at each of the dams and at the mouths of important tributaries, and fish were tracked by truck or boat. Information was also obtained from fish recaptured at hatcheries, in fisheries, and spawning areas. See Bjornn et al. (2000a) for a more complete description of tagging methods, data acquisition and processing, and other methods.

Processing and analyses of radio-telemetry data from chinook salmon, sockeye salmon, and steelhead outfitted with radio transmitters in the years 1996 to 1998 was at different levels of completion at the time that this report was prepared. All migration data were coded, checked, and assembled for all species, but the overall migration analyses had not been completed for 1997 or 1998 data. Fallback assessments are based primarily on records of fish movements at each dam, but during analyses of the overall migration histories of each fish some minor changes are likely for the 1997 and 1998 data. We do not expect those changes to substantively change the conclusions of this report.

Antenna coverage relevant to monitoring of fallback behavior of fish at Bonneville Dam varied slightly between years (Figure 12). In 1997 and 1998,receivers and antennas were monitored in the ice and trash sluiceways at both powerhouses, but not in 1996. In 1997 there was an aerial antenna on the navigation lock wall in the powerhouse I forebay, but not in 1996 or 1998. Improvements in forebay and/or ice and trash sluiceway coverage enhanced our

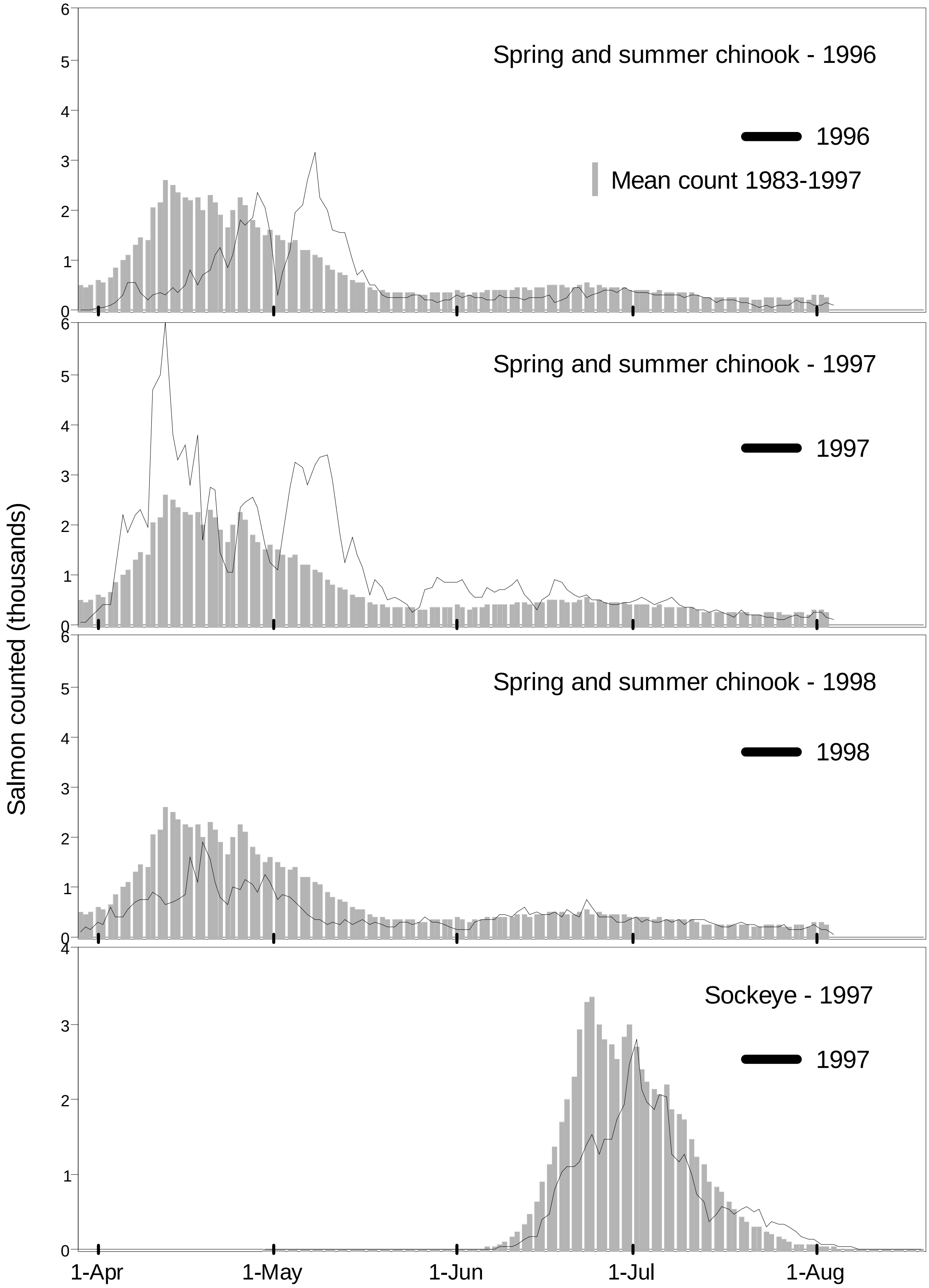

Figure 11. Daily spring and summer chinook salmon, sockeye salmon, steelhead, and fall chinook salmon counts at Bonneville Dam in 1996, 1997, and 1998, with average counts from 1984 to 1998.

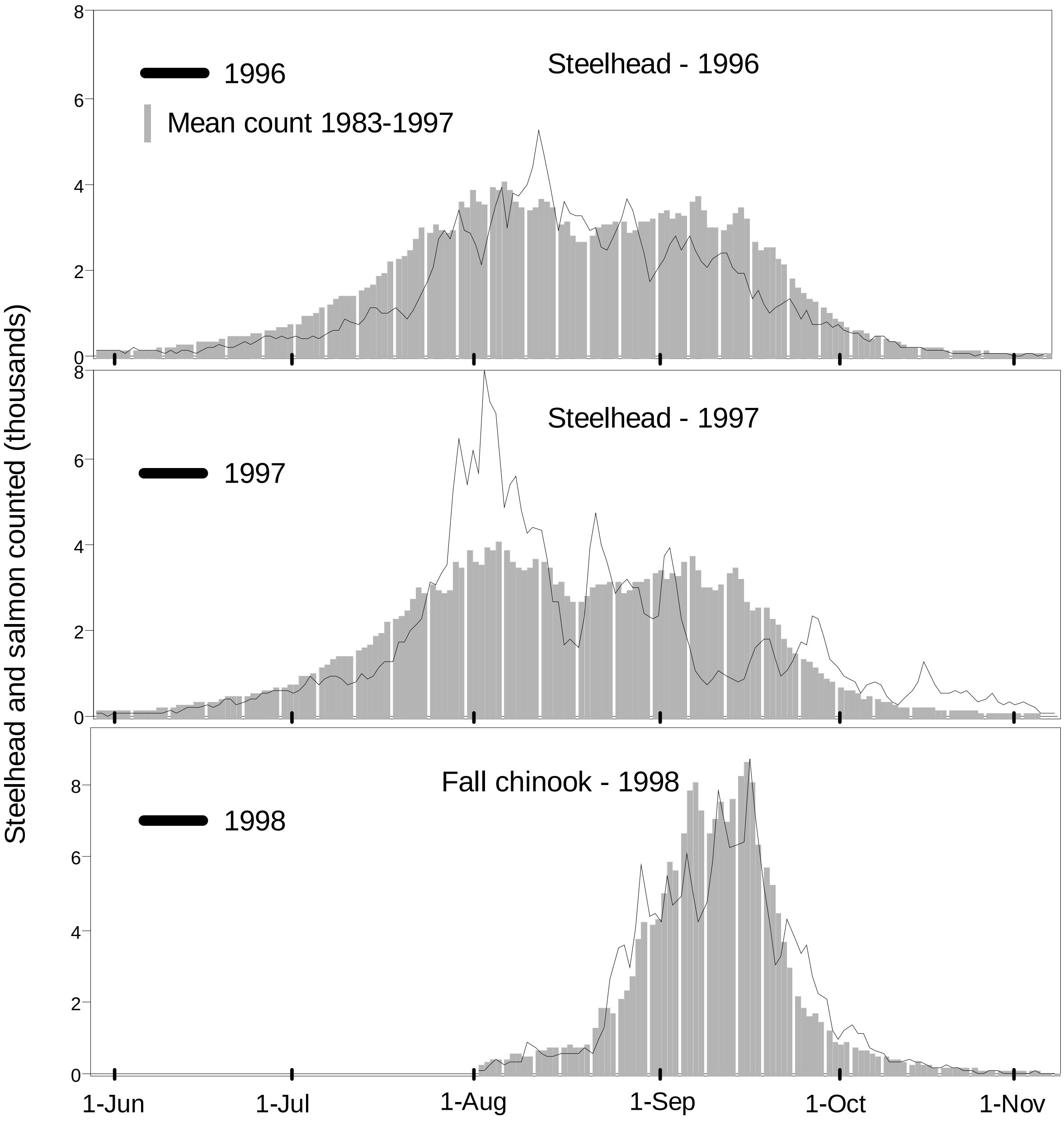

Figure 11. Cont.

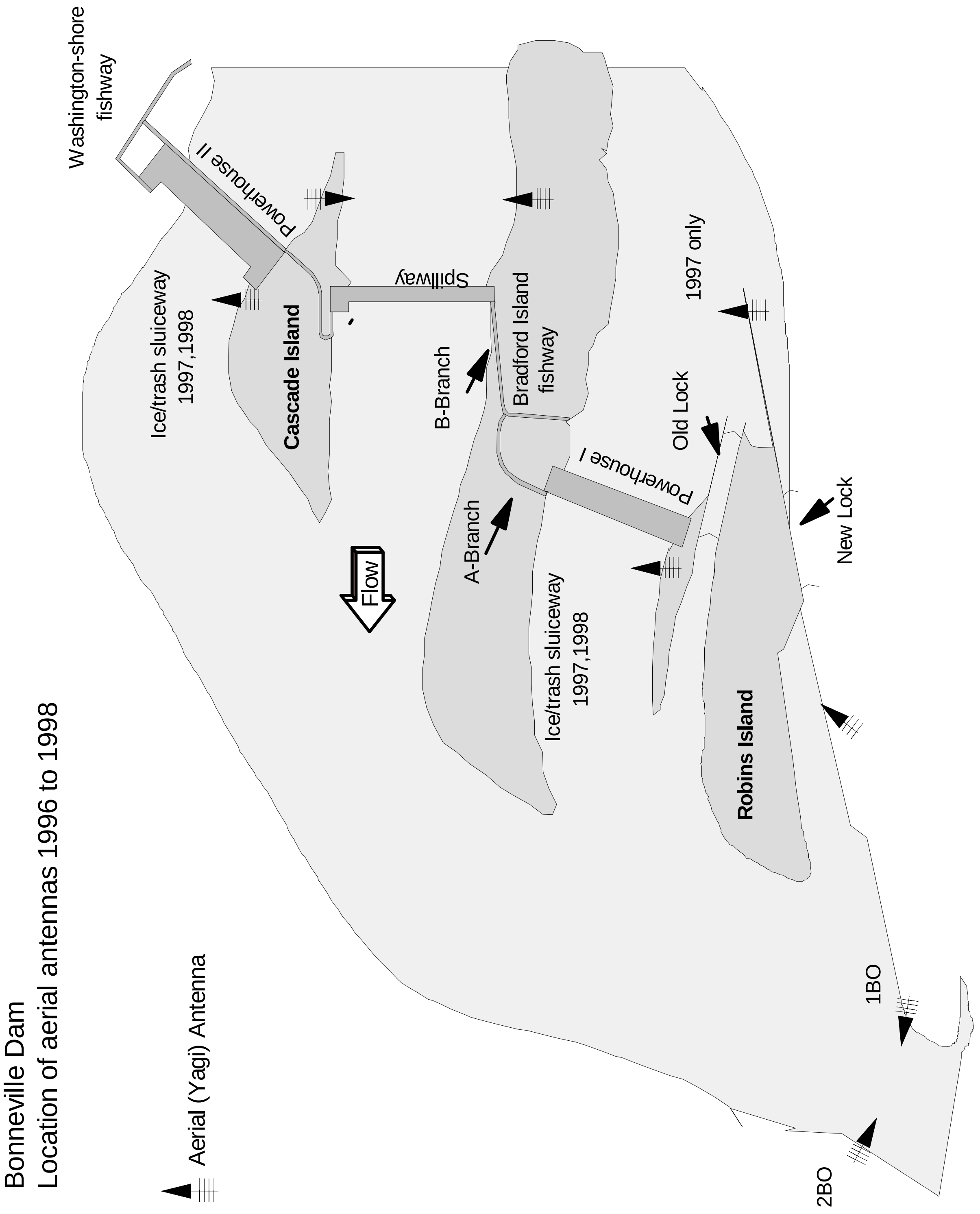

Figure 12. Location of selected antennas at Bonneville Dam in 1996, 1997, and 1998. Between-year changes in aerial Yagi coverage are noted, but small differences in underwater antenna coverage are not.

ability to identify fallback routes in 1997 and 1998. There were also some changes in receiver/antenna coverage in fishways between years, with improved coverage in later years. In 1998, the receiver and underwater antenna at the upstream end of the navigation lock did not record data consistently during much of the spring and summer chinook migration, but that was probably not a serious loss because few spring/summer chinook salmon passed or fell back over the dam via the navigation lock in 1996 or 1997. Antenna and receiver deployment upstream from Bonneville Dam also differed somewhat between years. In 1996, we had no telemetry monitoring upstream from Priest Rapids Dam, while both dams and some tributaries were monitored there in 1997 and 1998. We also monitored tributaries in the Snake River basin more in 1997 and 1998 than in 1996.

Results

Fallback Percentages and Rates for Spring/Summer Chinook Salmon

The percentages of unique spring and summer chinook salmon with transmitters that fell back over Bonneville Dam during their upstream migration based on the number of unique fish with transmitters that fell back divided by the number of unique salmon with transmitters known to have passed Bonneville Dam, regardless of route, were 13.8% in 1996, 14.6% in 1997, and 11.3% in 1998 (Table 1). We calculated a second set of percentages of fish that fell back based on fish that passed the dam only via the ladders (13.9% in 1996, 14.7% in 1997, and 11.4% in 1998), but they differed little from the first percentages (Table 1) because few spring and summer chinook salmon passed the dam via the navigation lock. Fish that fell back at Bonneville Dam after spawning in tributaries (1 in 1996, 2 in 1997 and 4 in 1998) were not included in fallback percentages nor any other fallback summaries.

We calculated standard 95% confidence intervals for annual fallback percentages assuming normally distributed errors and a normal binomial approximation; intervals for chinook salmon were +/-2.4% or less. 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. The percentages of salmon with 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 16.4% in 1996, 19.9% in 1997, and 15.9% in 1998 (Table 2). Fallback rates based only on fish that passed the dam via the ladders were 16.5% in 1996, 20.0% in 1997, and 16.0% in 1998. These latter rates excluded fish that passed the dam via the navigation lock and a small number of fish that passed the dam undetected in 1996. The differences between the two rates within a year were small because most chinook salmon passed the dam via fishways and a high percentage were recorded. The 95% confidence intervals assuming normally distributed errors

Table 1. Number of unique spring/summer chinook salmon (CK), sockeye salmon (SK), steelhead (SH), and fall chinook salmon (FCK) with transmitters that fell back (FB) at Bonneville Dam, number known to have passed the dam, number that passed the dam via the fishways at the dam, and the percentage of fish that fell back in 1996, 1997 and 1998. Confidence intervals (0.95) based on normal binomial approximation in parenthesis.

Year Species	Fish that fell back at dam	Number known to pass dam	Passed dam via fishways	FB as percent of fish known to pass dam	FB as percent of fish that passed via fishways
1996 CK	112	810	805	13.8 (11.5-16.2)	13.9 (11.5-16.3)
1997 CK	139	950	944	14.6 (12.4-16.9)	14.7 (12.5-17.0)
1998 CK	105	932	925	11.3 (9.2-13.3)	11.4 (9.3-13.4)
1996 SH	35	724	693	4.8 (3.3-6.4)	5.1 (3.4-6.7)
1997 SH	83	916	887	9.1 (7.2-10.9)	9.4 (7.4-11.3)
1997 SK	64	562	511	11.4 (8.8-14.0)	12.5 (9.7-15.4)
1998 FCK	32	913	883	3.6 (2.3-4.7)	3.6 (2.4-4.9)

Table 2. Number of fallback (FB) events by spring/summer chinook salmon (CK), sockeye salmon (SK), steelhead (SH), and fall chinook salmon (FCK) with transmitters at Bonneville Dam, the number known to have passed the dam, the number that passed dam via the fishways at the dam, and the fallback rates for 1996, 1997, and 1998. Confidence intervals (0.95) based on normal binomial approximation in parenthesis.

Year Species	Total FB events	Number known to pass dam	Passed dam via fishways	FB rate of fish known to pass dam	FB rate of fish that passed via fishways
1996 CK	133	810	805	16.4 (13.9-19.0)	16.5 (14.0-19.1)
1997 CK	189	950	944	19.9 (17.4-22.4)	20.0 (17.5-22.6)
1998 CK	148	932	925	15.9 (13.-18.2)	16.0 (13.6-18.4)
1996 SH	38	724	693	5.2 (3.6-6.9)	5.5 (3.8-7.2)
1997 SH	91	916	887	9.9 (8.0-11.9)	10.3 (8.3-12.3)
1997 SK	77	562	511	13.7 (10.9-16.5)	15.1 (12.0-18.2)
1998 FCK	38	913	883	4.2 (2.9-5.5)	4.3 (3.0-5.6)

and a normal binomial approximation for chinook salmon fallback rates were +/- 2.6%. Confidence intervals in Table 2 were based on pooled data for all radio-tagged fish in each year and did not address variability in tagged/ untagged fish ratios 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 (Figure 13) were weighted by total ladder counts at the dam during each block. We assumed 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 1996 and 1998 (Figure 14). Weighted confidence intervals were slightly wider in 1997, due mostly to a low tagged/untagged fish ratio during peak counts early in the run; the relatively small number of tagged fish created relatively high variances for those blocks. Another block in early June where 8 of 9 fish with transmitters fell back (fallback rate = 89%) added to the variance term in 1997. Despite wider confidence intervals, the weighted 1997 fallback rate was only about 2% higher than rates based on pooled data.

Fallback rates, as defined here, offered 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 not multiple reascensions after fallback nor 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 and thus fallbacks and reascensions must be used to correct dam fish counts.

Of 112 spring/summer chinook salmon that fell back at Bonneville Dam in 1996, 94 (84%) fell back once, 14 (13%) fell back twice and 4 (4%) fell back three times; 89% of the fish that fell back ultimately reascended and passed the dam. Of 139 chinook salmon that fell back in 1997, 105 (76%) fell back once, 21 (15%) fell back twice, 11 (8%) fell back 3 times, one fell back four times, and one fell back 5 times; 91% of the fish that fell back ultimately reascended and passed the dam. Of 105 chinook salmon that fell back in 1998, 75 (71%) fell back once, 21 (20%) fell back twice, 8 (8%) fell back three times, and 1 fish fell back 7 times; 81% of the fish that fell back ultimately reascended and passed the dam.

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 we could not monitor 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 in all years 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.

About half (54%) of all fallback events by chinook salmon at Bonneville Dam in 1996 occurred less than 24 h after the fish exited from the top of a fishway, and 40% occurred less than 12 h after

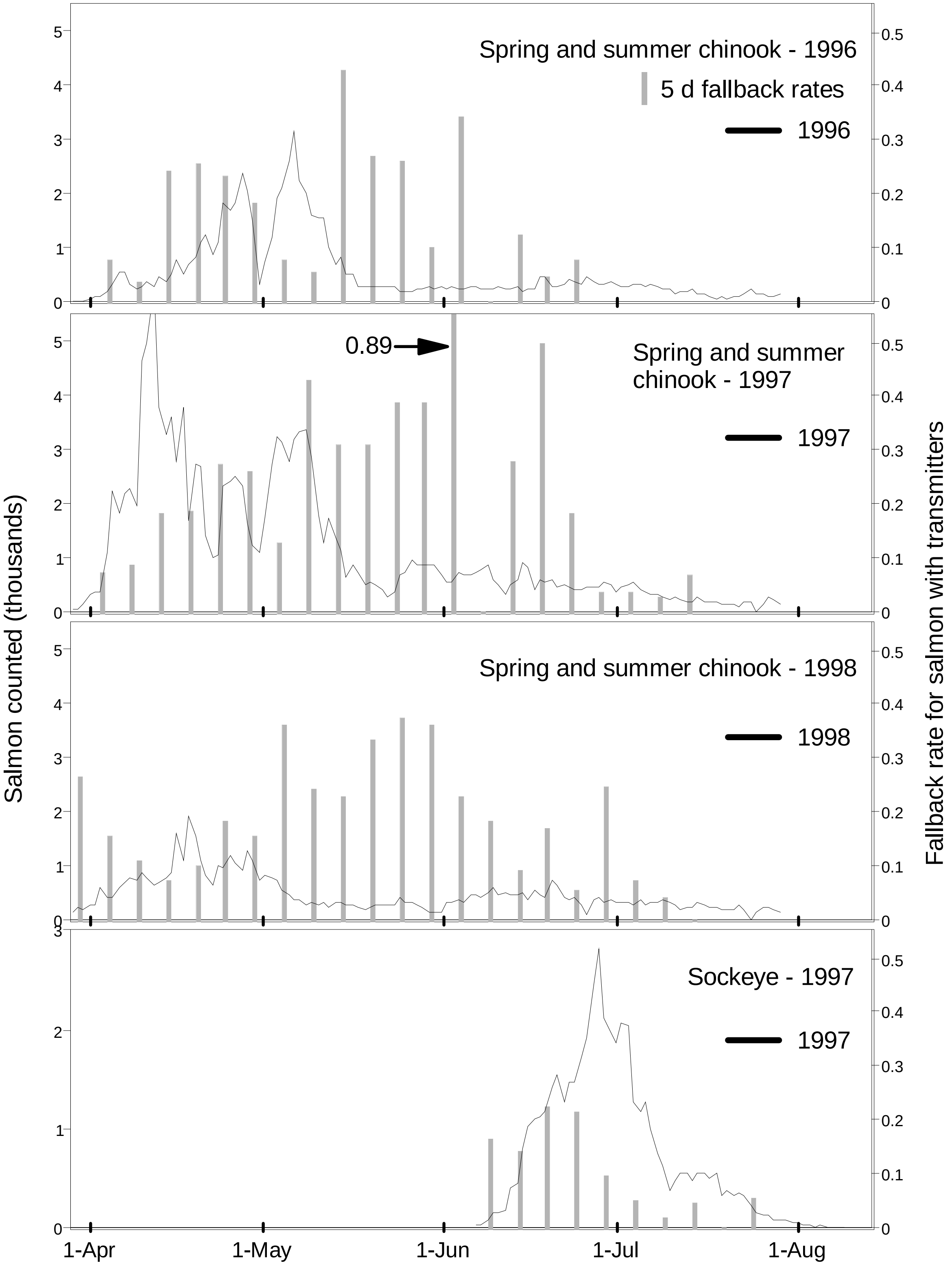

Figure 13. Fallback rates for spring/summer chinook and sockeye salmon with transmitters based on 5-d blocks, with total salmon counts at Bonneville Dam ladders in 1996, 1997, and 1998.

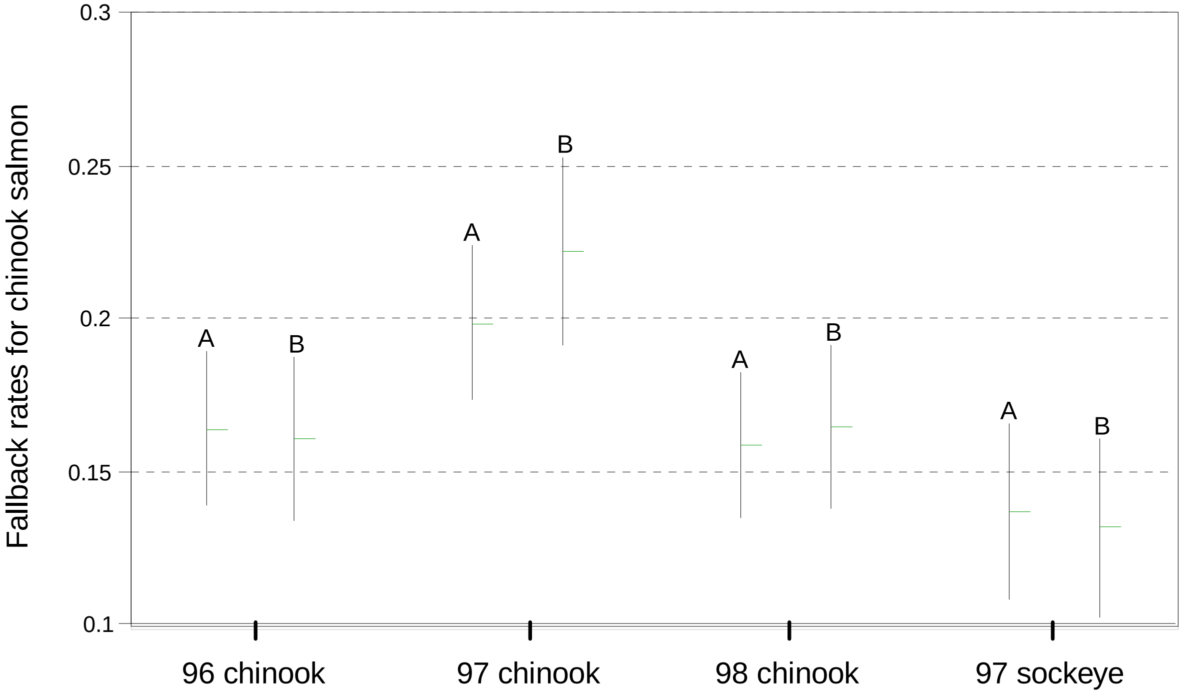

Figure 14. Fallback rates with 95% confidence intervals for radio-tagged spring/summer chinook and sockeye salmon at Bonneville Dam in 1996, 1997, and 1998. Confidence intervals calculated by (A) pooling all telemetry data, (B) weighting 5-d blocks by total counts of salmon passing ladders and computing fallback rates and standard errors for each block.

Table 3. Number of fallback (FB) events by spring/summer chinook salmon (CK), sockeye salmon (SK), steelhead (SH), and falll 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 1996, 1997, and 1998.

Year Species	Total FB events at dam	Number that FB in <24 h	Percent that FB in <24 h	Percent FB's > 24 h Recorded upriver	Percent FB's > 24 h Not recorded upriver
1996 CK	133	72	54	35	11
1997 CK	189	84	44	47	8
1998 CK	148	53	36	60	4
1996 SH	38	26	68	16	16
1997 SH	91	67	73	19	8
1997 SK	77	66	86	4	10
1998 FCK	38	4	11	71	18

passage (Table 3). In 1997, 44% of all fallback events occurred less than 24 h after passage and 37% occurred after less than 12 h. In 1998, 36% of all fallback events occurred less than 24 h after passage, and 31% occurred after less than 12 h. In 1996, 35% of chinook salmon with transmitters migrated upriver and were recorded at fixed-site receivers at tributaries or at upriver dams (fish were not monitored at the Bridge of the Gods in 1996) before they moved back down river and fell back at Bonneville Dam. The remaining 11% of fallback events in 1996 occurred more than 24 h after passing, but fish were not recorded at receivers upriver from the dam (Table 3). In 1997, 47% of chinook salmon with transmitters migrated upriver and were recorded at fixed-site receivers at tributaries, at the Bridge of the Gods, or at upriver dams before they moved back down river and fell back at Bonneville Dam. The remaining 8% of 1997 fallback events occurred more than 24 h after passing, but fish were not recorded at upriver receivers (Table 3). In 1998, 60% of chinook salmon with transmitters migrated upriver and were recorded at fixed-site receivers at tributaries, at the Bridge of the Gods, or at upriver dams before they moved back down river and fell back at Bonneville Dam. The remaining 4% of 1998 events occurred more than 24 h after passing, but fish were not recorded at upriver receivers (Table 3).

Fallback percentages were significantly (Z test $P < 0.001$) higher for spring/summer chinook salmon that passed via the Bradford Island fishway than for fish that passed via the Washington-shore fishway in all years. In 1996, 21.7% of the unique fish that were recorded at the top of the Bradford Island fishway fell back, compared to 5.3% that fell back after passing via the Washington-shore fishway (Table 4). In 1997, 22.8% of the unique fish that passed the Bradford Island fishway fell back, and 7.9% fell back after passing via the Washington-shore fishway. In 1998, 16.5% of the unique fish that passed the Bradford Island fishway fell back, and 7.7% fell back after passing the Washington-shore fishway (Table 4).

Fallback rates, the number of fallback events divided by the number of unique fish past a fishway, were also significantly (Z test $P < 0.001$) higher for chinook salmon that passed via the Bradford Island fishway in all years. In 1996, the fallback rate for chinook salmon that used the Bradford Island fishway was 25.4%, and for those that used the Washington-shore fishway, the rate was 5.5% (Table 5). In 1997, the fallback rate for salmon that used the Bradford Island fishway was 27.8%, and 10.2% for fish that used the Washington-shore fishway. In 1998, the fallback rate for salmon that used the Bradford Island fishway was 19.7%, and 9.1% for fish that used the Washington-shore fishway (Table 5).

A high percentage of the fallback events were by chinook salmon that passed over the dam via the Bradford Island fishway prior to falling back; 82% of all fallback events in 1996 and 71% of all events in 1997 and 1998 (Table 6). Of those chinook salmon that fell back within 24 h of passing Bonneville Dam, 94% to 95% of the fish had passed over the dam via the Bradford Island fishway in all three years (Table 6).

Table 4. Number of unique spring/summer chinook salmon (CK), sockeye salmon (SK), 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 .

Year Species	Unique fish at top of BI ladder	Unique fish that fell back	% past BI ladder that FB	Unique fish at top of WA ladder	Unique fish that fell back	% past WA ladder that FB
1996 CK	429	93	21.7	416	22	5.3
1997 CK	486	111	22.8	522	41	7.9
1998 CK	533	88	16.5	441	34	7.7
1996 SH	367	29	7.9	334	6	1.8
1997 SH	492	68	13.8	412	13	3.2
1997 SK	335	62	18.5	193	1	0.5
1998 FCK	410	18	4.4	478	12	2.5

* fallback percentages for BI ladder were significantly ($P < 0.01$) higher for all species

Table 5. Number of unique spring/summer chinook salmon (CK), sockeye salmon (SK), 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 1996, 1997, and 1998.

	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
1996 CK	429	109	25.4	416	23	5.5
1997 CK	486	134	27.8	522	53	10.2
1998 CK	533	105	19.7	441	40	9.1
1996 SH	367	32	8.7	334	6	1.8
1997 SH	492	74	15.0	412	14	3.4
1997 SK	335	76	22.7	193	1	0.5
1998 FCK	410	18	4.4	478	13	2.7

* fallback rates for BI ladder were significantly ($P < 0.01$) higher for all species

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), sockeye salmon (SK), steelhead (SH), and fall chinook salmon (FCK) passed each fishway in 1996, 1997, and 1998.

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
1996 CK	133	82	17	72	94.4	5.6
1997 CK	189	71	28	84	95.2	4.8
1998 CK	148	71	27	53	94.3	5.7
1996 SH	38	84	16	26	96.2	3.8
1997 SH	91	81	15	67	92.5	3.0
1997 SK	77	96	1	66	97.0	0
1998 FCK	38	47	34	4	50.0	25.0

Fallback Percentages and Rates for Sockeye Salmon

The percentage of unique sockeye salmon with transmitters that fell back over Bonneville Dam in 1997 was 11.4% of unique salmon known to have passed the dam, regardless of route (Table 1). When only fish recorded at top-of-ladder receivers and those that passed via ladders but were not detected at the uppermost antennas were used as the divisor, the 1997 fallback percentage was 12.5% and the 95% confidence interval was 9.7% to 15.4% with the same assumptions as described for spring/summer chinook salmon (Table 1).

Fallback rate, the number of fallback events divided by the number of unique sockeye salmon with transmitters known to pass Bonneville Dam was 13.7% in 1997 (Table 2). When only fish recorded at top-of-ladder receivers and those that passed via ladders but were not detected at the uppermost antennas were included, the fallback rate was 15.1% with a 95% confidence interval from 12.0% to 18.2% (Table 1). The latter rate excluded 59 sockeye salmon with transmitters that passed the dam via the navigation lock. Fallback rates for sockeye salmon that did or did not include fish that passed through the navigation lock differed more than such rates for chinook salmon because a higher percentage of sockeye salmon were recorded passing through the navigation lock. The 95% confidence intervals assuming normally distributed errors and a normal binomial approximation for sockeye salmon fallback rates were +/- 3.1%. We also calculated 95% confidence intervals for sockeye salmon using the 5-d stratified sampling method described previously for spring/summer chinook salmon (Figure 13). Because our sampling effort for sockeye salmon was generally proportional to the run, weighted fallback rates and 95% confidence intervals were similar to those for pooled data (Figure 14). (Note: a small number of passages and fallback events at the end of the sockeye salmon migration were excluded from this analysis, as we believed the radio-tagged fish were not representative of the run.)

Of 64 sockeye salmon that fell back at Bonneville Dam in 1997, 54 (84%) fell back once, 7 (11%) fell back twice, and 3 (5%) fell back three times; 95% of the fish that fell back ultimately reascended and passed the dam.

Eighty-six percent of all fallback events by sockeye salmon in 1997 occurred less than 24 h after the fish exited from the top of a fishway (Table 3), and 77% occurred less than 12 h after passage.

As with chinook salmon, sockeye salmon that passed via the Bradford Island ladder fell back at significantly (Z test $P < 0.001$) higher rates than those that passed via the Washington-shore ladder. About 18.5% of the sockeye that passed through the Bradford Island ladder fell back, compared to 0.5% that passed the dam via the Washington-shore ladder (Table 4). Fallback rates were also higher for sockeye salmon that passed over the dam via the Bradford Island ladder (22.7%) than those that used the Washington-shore ladder (0.5%) (Table 5). Of all fallback events by sockeye salmon, 96% occurred after passage via the Bradford Island fishway and 1% after passage via the fishway on the Washington shore. About 97% of the fallback events within 24 h occurred after passage via the Bradford Island fishway and no sockeye salmon fell back within 24 h after passing the Washington-shore fishway (Table 6). Percentages in Table 6 do not add up to 100% because two sockeye salmon fell back after passing over the dam via the navigation lock.

Fallback Percentages and Rates for Steelhead

The percentage of unique steelhead with transmitters that fell back over Bonneville Dam based on the number of unique steelhead known to have passed Bonneville Dam, regardless of route, was 4.8% in 1996 and 9.1% in 1997 (Table 1). Fish that fell back after likely spawning in tributaries (2 in 1996, 2 in 1997) were not included in fallback percentages nor other fallback summaries. In 1996, 32 (4.4%) steelhead with transmitters passed Bonneville Dam via the navigation lock at least once and 31 (3.4%) passed via the navigation lock in 1997. When only fish recorded at top-of-ladder receivers and those that passed the dam via ladders, but not detected at the uppermost antennas were used as the divisor, fallback percentages were 5.1% in 1996 and 9.4% in 1997 (Table 1). The 95% confidence intervals for the percentage of steelhead that fell back were +/- 1.7% in 1996 and +/- 2.0% in 1997, assuming normally distributed errors and a normal binomial approximation (Table 1). The confidence intervals in Table 1 were based on pooled data for all radio-tagged fish in each year and did not address over or under sampling or temporal differences in fallback behavior for the total run. Confidence intervals of fallback rates calculated with unweighted pooled data and weighted data for 5-d blocks (Figures 15 and 16) were similar, and exclusion of outlying blocks resulted in a wider interval in 1996 and narrower interval in 1997.

Fallback rates for steelhead, the number of fallback events divided by the number of unique steelhead with transmitters known to have passed Bonneville Dam was 5.2% in 1996 and 9.9% in 1997 (Table 2). When only fish

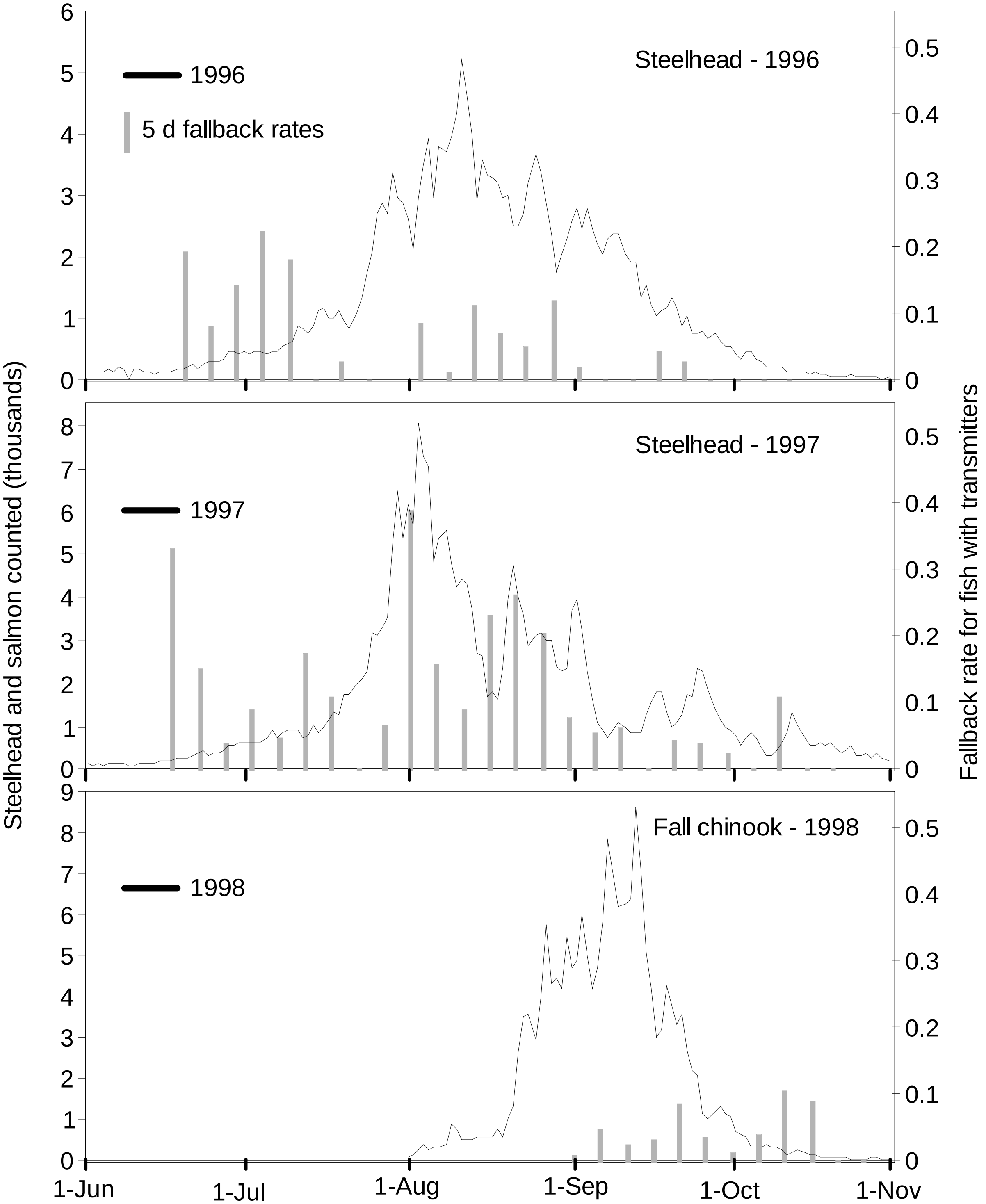

Figure 15. Fallback rates for steelhead and fall chinook salmon with transmitters based on 5-d blocks, with total counts at Bonneville Dam ladders in 1996, 1997, and 1998.

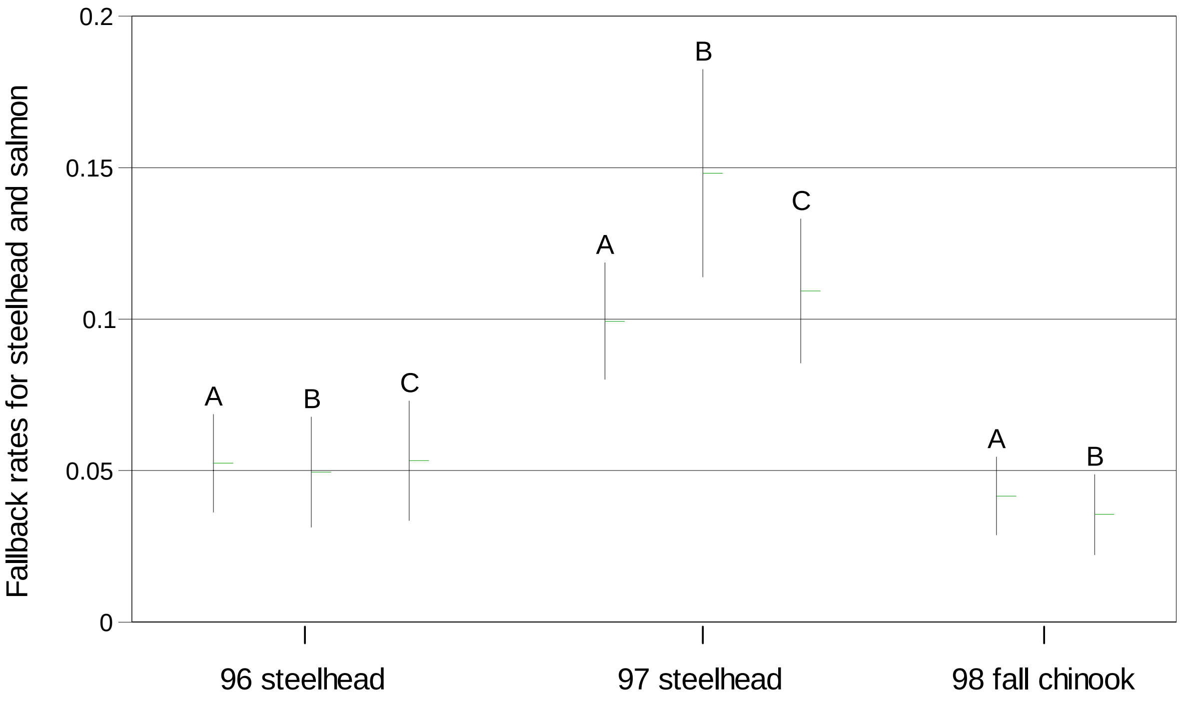

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Figure 16. Fallback rates with 95% confidence intervals for radio-tagged steelhead and fall chinook salmon at Bonneville Dam in 1996, 1997, and 1998. Confidence intervals calculated by (A) pooling all telemetry data, (B) weighting 5-d blocks by total passage counts and computing fallback rates and standard errors for each block and, (C) same as B, but excluding 1 outlying block; see text for explanation.

recorded at top-of-ladder receivers and those that passed the dam via ladders but were not detected at the uppermost antennas were included, the fallback rate was 5.5% in 1996 and 10.3% in 1997. Confidence intervals for steelhead fallback rates were similar to those for the percentages of fish that fell back; +/- 1.7% in 1996 and +/- 2.0% in 1997 (Table 2). The confidence intervals in Table 2 were based on pooled data for all radio-tagged fish in each year and did not address over or under sampling or temporal differences in fallback behavior for the total run. We also calculated 95% confidence intervals using the 5-d stratified sampling method described previously for spring/summer chinook salmon (Figure 16).

Gaps in tagging fish because of high water temperatures, combined with relatively higher rates of tagging of steelhead both early and late in the migration (see Figure 7) created relatively high variance among 5-d blocks, a larger error term, and therefore wider 95% confidence intervals. When we included all data, the weighted fallback rate for 1996 steelhead was 5.0% with a 95% confidence interval of +/- 1.8% (B in Figure 16). In late July 1996, a gap in tagging led to a block during which no radio-tagged steelhead passed the dam, but more than 14,000 untagged steelhead were counted passing via the ladders. Removal of this block, which had no error term, from calculations increased the fallback rate to 5.3% and widened confidence intervals to +/- 2.0% (C in Figure 16).

Fallback rates for steelhead were higher in 1997 than in 1996. With all 5-d blocks included, the weighted fallback rate was 14.8% (+/- 3.4%), compared to 9.9% for the rate based on pooled radio telemetry data in 1997 (Figure 16). A relatively low rate of tagging during peak steelhead counts in early August led to a block with 34,200 steelhead counted passing through the ladders, but only 23 radio-tagged steelhead passed the dam and 10 fell back. The low sampling rate (~ 0.0007) during the peak count created a relatively high variance and a large error term for the block. The high fallback rate for the block with the 23 radio-tagged fish was heavily weighted in the stratified fallback rate, and largely explains the 4.9% difference from the pooled rate. When we excluded the block from calculations, the weighted rate was 10.9% (1% higher than the pooled rate) and the 95% confidence interval was +/- 2.4% (C in Figure 16 for 1997). Wider weighted confidence intervals for steelhead than for the salmon are partially due to the relatively small proportion of steelhead radio tagged and the variability in fallback rates during the run. Nonetheless, we believe our sample was fairly representative of the run and that reported rates were reasonably good estimates of fallback by steelhead at Bonneville Dam in the two years.

Of 35 steelhead that fell back at Bonneville Dam in 1996, 32 (91%) fell back once and 3 (9%) fell back twice; 86% of the fish that fell back ultimately reascended ladders and passed the dam. In 1997, 75 (90%) steelhead fell back once, 8 (10%) fell back twice, and 77% reascended ladders and passed the dam.

Sixty-eight percent of all fallback events by steelhead in 1996 and 73% in 1997 occurred less than 24 h after fish exited from the top of a fishway (Table 3). In 1996, 16% of the steelhead that fell back were recorded at upstream tributaries or dams before they fell back at Bonneville Dam, and 16% fell back more than 24 h after passing, but were not recorded upstream prior to falling back. In 1997, 19% of the steelhead that fell back were recorded at upstream sites prior to falling back, and 8% fell back more than 24 h after passing but were not recorded upstream.

As with spring/summer chinook and sockeye salmon, fallback percentages for steelhead that passed through the Bradford Island ladder were significantly (Z test P < 0.005) higher than for steelhead that passed over the dam via the Washington-shore ladder in both 1996 and 1997. In 1996, 7.9% fell back after passing the Bradford Island ladder and 1.8% fell back after passing the Washington-shore ladder (Table 4). In 1997, the percentages were 13.8% for the Bradford Island ladder fish and 3.2% for those that used the Washington-shore ladder. Fallback rates were also significantly (P < 0.005) higher for the Bradford Island ladder: 8.7% in 1996 and 15.0% in 1997 compared to 1.8% and 3.4% at the Washington-shore ladder in those years (Table 5). Eighty-four and 81% of steelhead that fell back in 1996 and 1997 had passed through the Bradford Island ladder prior to falling back. More than 92% of steelhead that fell back within 24 h of passage in 1996 and 96% that fell back within 24 h in 1997 had passed through the Bradford Island ladder (Table 6).

Fallback Percentages and Rates for Fall Chinook Salmon

The percentage of unique fall chinook salmon with transmitters that fell back over Bonneville Dam in 1998 was 3.6% of unique salmon known to have passed the dam, regardless of route (Table 1). When only fish recorded at top-of-ladder receivers and those that passed via ladders, but were not detected at the uppermost antennas were used as the divisor, the 1998 fallback percentage was also 3.6% and the 95% confidence interval was 2.4% to 4.9% with the same assumptions as described for spring/summer chinook salmon (Table 1).

Fallback rate, the number of fallback events divided by the number of unique fall chinook salmon with transmitters known to pass Bonneville Dam was 4.2% in 1998 (Table 2). When only fish recorded at top-of-ladder receivers and those that passed via ladders but were not detected at the uppermost antennas were included, the fallback rate was 4.3% with a 95% confidence interval from 3.0% to 5.6% (Table 1). The latter rate excluded about 30 fall chinook salmon with transmitters that passed the dam via the navigation lock. The 95% confidence intervals assuming normally distributed errors and a normal binomial approximation for fall chinook salmon fallback rates were +/- 1.3%. The weighted fallback rate for fall chinook salmon using the 5-d stratified sampling method described previously was slightly lower than the pooled rate at 3.6% +/- 1.3% (Figure 16).

Of 32 fall chinook salmon that fell back at Bonneville Dam in 1998, 28 (88%) fell back once, 2 (6%) fell back twice, and 2 (6%) fell back three times; 69% of the fish that fell back ultimately reascended and passed the dam.

Eleven percent of all fallback events by fall chinook salmon in 1998 occurred less than 24 h after the fish exited from the top of a fishway, 71% occurred after fish were recorded at upstream dams or tributaries, and 18% occurred more than 24 h after passage, but fish were not recorded at upriver sites (Table 3).

In contrast to spring/summer chinook salmon, steelhead, and sockeye salmon, fall chinook salmon that passed via the Bradford Island ladder did not fall back at significantly (Z test P = 0.12) higher rates than those that passed via the Washington-shore ladder. About 4.4% of the fall chinook that passed through the Bradford Island ladder fell back, compared to 2.5% that passed the dam via the Washington-shore ladder (Table 4). Fallback rates were also higher for fall chinook salmon that passed over the dam via the Bradford Island ladder (4.4%) than those that used the Washington-shore ladder (2.7%), but differences were not significant (P = 0.18) (Table 5). Of all fallback events by fall chinook salmon, 47% occurred after passage via the Bradford Island fishway, 34% occurred after passage via the fishway on the Washington shore, and 19% occurred after passage through the navigation lock (Table 6).

Escapement Past Bonneville Dam Based on Adjusted Counts

Counts of adult salmon and steelhead that pass up the ladders at the dams are used as indices of abundance of the 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 over the dams and do or do not reascend over the dam 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 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 and Peery, 1992; Liscom et al, 1979; Monan and Liscom, 1979). At Bonneville Dam we monitored fallbacks, reascensions, and passage through the navigation lock for adult chinook salmon with transmitters and used that data to calculate adjustment factors for counts of salmon in 1996, 1997, and 1998. Adjustments were then applied to counts of fish counted in the ladders and reported in the Annual Fish Passage Reports (USACE, 1996; 1997; 1998) 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 ladders at the dam, the number of fish that fell back, the number that reascended through the ladders, and the number of fish that pass upstream through the navigation lock. Fallback and reascension through ladders creates a positive bias in the number of fish counted as they pass up the ladders, while passage through the navigation lock is unaccounted for in counts of fish passing up the ladders. Fish that pass through the lock 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 first 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 ladders (assumes that unrecorded fish passed dam via 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 ladders (includes initial and all reascensions).

The TLP_K term was the count of radio-tagged chinook salmon equivalent of the total USACE count of salmon that passed through the ladders. When adjustment factor AF was applied to the counts of salmon that passed through the ladders, the adjusted number was our best estimate of the total escapement past the dam.

Estimates of escapement derived from the adjustment factors 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 adjustments AF using pooled data for the entire time period of passage by chinook salmon with transmitters 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 potential bias, we also calculated adjustment factors using a stratified sampling method that calculated factors 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 passing ladders 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 and summer chinook salmon

Pooled adjustment factors (AF) for spring and summer chinook salmon at Bonneville Dam were 0.864 in 1996, 0.838 in 1997, and 0.869 in 1998 (Table 7). Weighted AF values and 95% confidence intervals based on all data for radio-tagged fish differed from pooled values by less than 0.015 in all years, an indication that our sampling was reasonably representative and that temporal variation in spring and summer chinook salmon fallback and reascension rates were relatively minor (Figure 17).

We calculated escapements of spring/summer chinook salmon past Bonneville Dam by multiplying fish counts reported by USACE by pooled AFs (Table 8). In 1996 the USACE adult spring and summer chinook salmon count at Bonneville Dam was 67,527 fish. After adjustment, the escapement of spring and summer chinook salmon past Bonneville Dam was estimated to be 58,343 fish, 9,184 fish (15.7%) less than the count (Table 8). The 1997 USACE adult chinook salmon count at Bonneville Dam was 141,939 fish and the adjusted escapement was 118,945 fish with a positive bias of 22,994 fish (19.3%). The 1998 USACE adult chinook salmon count was 59,775 fish and the adjusted escapement was 51,944 fish with a positive bias of 7,830 fish (15.1%) (Table 8). Standard 95% confidence intervals for the adjusted escapements were within +/- 2.2%, or approximately +/- 1,500 fish in 1996, 3,100 fish in 1997, and 1,200 fish in 1998.

Because weighted adjustment factors for spring/summer chinook salmon were not substantially different from pooled factors, weighted escapement biases were similar to pooled biases at 8,907 fish (15.2%) in 1996, 21,291 fish (17.6%) in 1997, and 8,428 fish (16.4%) in 1998 (Table 8). Biases based on pooled data were slightly higher than weighted biases in 1996 (15.7%) and 1997 (19.3%) and slightly lower in 1998 (15.1%).

Sockeye salmon

As with spring/summer chinook salmon, counts of sockeye salmon that pass up the fishways at Bonneville Dam are used as an index of escapement past the dam. Fish that fall back and reascend through ladders at Bonneville Dam create

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 and summer chinook salmon (CK), sockeye salmon (SK), steelhead (SH), and fall chinook salmon (FCK) with transmitters in 1996 to 1998.

Year-species	LP_K[a]	NLP_K	FB_{UF}	R_{UF}	TLP_K	Pooled AF_1
1996 CK	805	5	112	100	924	0.864
1997 CK	944	6	139	127	1119	0.838
1998 CK	925	7	105	85	1049	0.869
1996 SH	693	31	35	30	725	0.992
1997 SH	886	30	83	64	955	0.939
1997 SK	511	51	64	61	577	0.969
1998 FCK	883	30	32	12	894	0.999

[a] Includes fish that passed ladders unrecorded at uppermost antennas

Table 8. Reported USACE counts of spring and summer chinook salmon (CK), sockeye salmon (SK), 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 1996 to 1998 as escapement indices.

	USACE Ladder Escapement	Pooled adjustment Estimated escapement	Pooled adjustment Bias	Weighted escapement bias
1996 CK	67,527	58,343 (+/- 1,486)	9,184	8,907
1997 CK	141,939	118,945 (+/- 3,123)	22,994	21,291
1998 CK	59,775	51,944 (+/- 1,196)	7,830	8,428
1996 SH	205,213	203,571 (+/- 1,436)	1,642	13,339
1996 SH[1]				-1,436
1997 SH	258,385	242,624 (+/- 3,876)	15,761	21,446
1997 SH[1]				16,020
1997 SK	47,008	45,551 (+/- 658)	1,457	-846
1997 SK[1]				1,269
1998 FCK	189,085	188,896 (+/- 378)	189	1,135

[1] 1 outlying block removed from calculation of weighted escapement bias

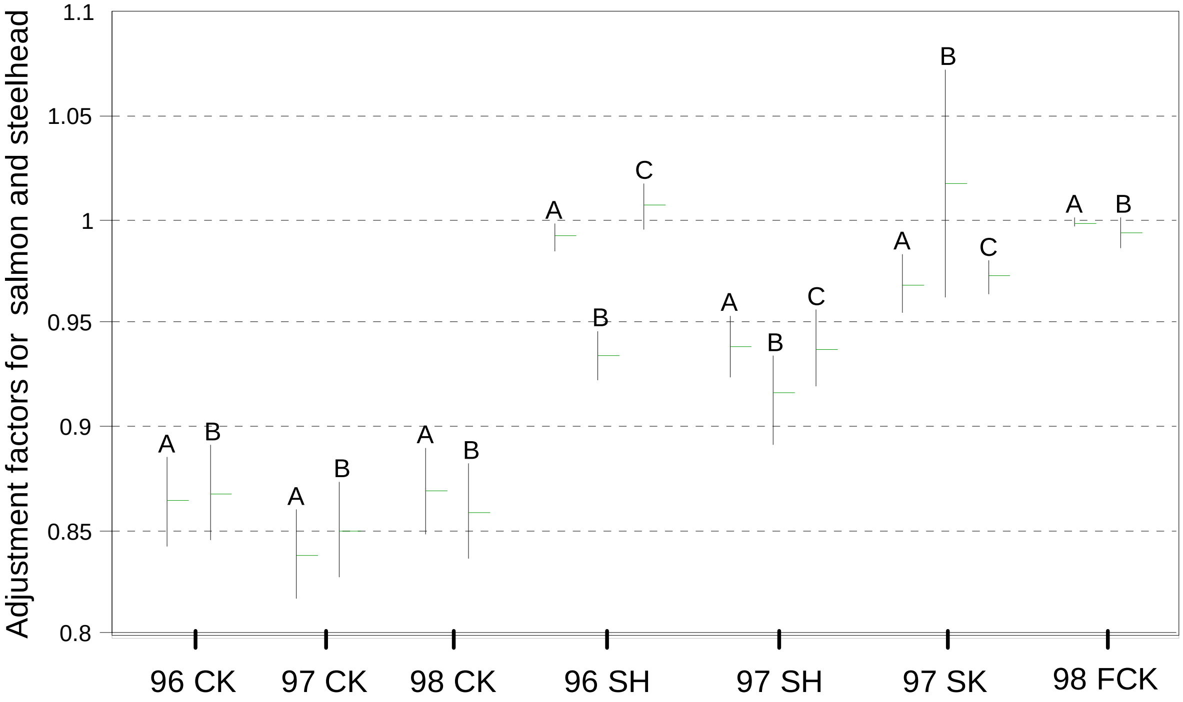

Figure 17. Escapement adjustment factors for chinook salmon, steelhead, and sockeye salmon at Bonneville Dam from 1996 to 1998. 95% confidence intervals calculated by (A) pooling all radio-telemetry data and taking standard binomial distribution, (B) weighting 5-d blocks of telemetry data by total ladder counts and computing standard errors for each block and, (C) same as B, but excluding one outlying block; see text for explanation.

a positive bias in the number of fish counted. Sockeye salmon that pass through the navigation lock are unaccounted for in counts of fish passing via ladders. Fish that pass through the lock compensate for the positive bias in fish counts due to fallback and reascension, but the amount of compensation depends on the number offallbacks and the number of fish passing through the lock. In 1997, about 9% of the radio-tagged sockeye salmon passed Bonneville Dam via the navigation lock, a higher percentage than for spring/summer chinook salmon.

We calculated pooled and weighted adjustment factors (AF) for sockeye salmon at Bonneville Dam using the same methods described above for spring/summer chinook salmon. The pooled AF was 0.969, and included all passages and fallbacks by sockeye salmon (Table 7). We calculated escapements of sockeye salmon past Bonneville Dam by multiplying fish counts reported by USACE by the pooled adjustment factor. The number of adult sockeye salmon counted in 1997 was 47,008 fish, and the adjusted escapement past the dam was 45,551 fish, a positive bias of 1,457 (3.2%) (Table 8).

The weighted AF for sockeye salmon was 1.018, when all radio-tagged fish were included, and resulted in a negative bias of 846 fish (1.8%) (Table 8). We believe the adjustment was distorted by one 5-d block early in the migration when four radio-tagged sockeye salmon passed the dam via the fishways and another 8 passed via the navigation lock for a block adjustment factor of 3.0; weighting the block by the total ladder count raised the AF to more than 1.0, with a wide 95% confidence interval of +/- 0.054 (Figure 17). When we removed the block (~2% of all passages by radio-tagged fish), the AF was 0.973 that resulted in an estimated positive bias in the counts of 1,269 fish (Table 8). The 95% confidence interval was less than +/- 0.01 without the block (Figure 17). We believe the latter was a more accurate weighted escapement adjustment.

Steelhead

As with spring/summer chinook and sockeye salmon, counts of steelhead that pass up the fishways at Bonneville Dam are used as an index of escapement past the dam. Steelhead that fall back and reascend through ladders at Bonneville Dam creates a positive bias in the number of fish counted. Steelhead that passed through the navigation lock are unaccounted for in the counts of fish passing via ladders. Fish that pass through the lock 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. Between 3.4% and 4.5% of the radio-tagged steelhead passed Bonneville Dam via the navigation lock in 1996 and 1997, a higher percentage than for spring/summer chinook salmon, but lower than for sockeye salmon. We calculated pooled and weighted adjustment factors (AF) for steelhead at Bonneville Dam using the same methods described above for spring/summer chinook salmon.

For steelhead tagged in 1996, the pooled AF was 0.992, and for those tagged in 1997 the pooled AF was 0.939 (Table 7). We calculated escapements of steelhead past Bonneville Dam by multiplying fish counts reported by USACE by the pooled AF. The count of adult steelhead in 1996 was 205,213 fish, and the adjusted escapement count was 203,571 fish with a positive bias of 1,642 (0.8%); the 1997 adult count was 258,385, and the adjusted count was 242,624 fish with a positive bias of 15,761 fish (6.5%) (Table 8). The 95% confidence intervals for pooled adjustments were +/- 1,400 steelhead in 1996 and +/- 3,900 fish in 1997 (Table 8).

The weighted AF for steelhead in 1996 was 0.935 when we included all 5-d blocks, including the block with no radio-tagged fish; the bias was about 13,300 fish, but as discussed above, we believe this weighted AF was not the most accurate. After we removed the 5-d block with no radio-tagged fish, the AF was 1.007 with a negative bias of about 1,400 fish, an indication that escapement through the navigation lock more than compensated for the positive escapement bias caused by fallback and reascension via ladders (Table 8). The weighted AF in 1997, with all data included was 0.917, with a positive bias of 21,446 fish (9.1%). We believe the weighted AF for 1997 was distorted by one 5-d block in early August when relatively few radio-tagged steelhead passed the dam coincident with peak ladder counts including about 13% of the 1997 run. This block had the lowest AF in 1997, but was the most heavily weighted. When we removed the block from calculations, the weighted AF was 0.938, with a positive bias of 16,020 fish (6.6%). We believe the latter estimate was a more accurate estimate of the steelhead count adjustment for fish tagged in 1997 (Figure 17).

Fall chinook salmon

As with other species, counts of fall chinook salmon that pass up the fishways at Bonneville Dam are used as an index of escapement past the dam. Fish that fall back and reascend through ladders at Bonneville Dam create a positive bias in the number of fish counted. Fall chinook salmon that pass through the navigation lock are unaccounted for in counts of fish passing via ladders. Fish that pass through the lock 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. In 1998, about 4% of the radio-tagged fall chinook salmon passed Bonneville Dam via the navigation lock.

We calculated pooled and weighted adjustment factors (AF) for fall chinook salmon at Bonneville Dam using the same methods described above for other species. The pooled AF was 0.999, and included all passages and fallbacks by fall chinook salmon (Table 7). We calculated escapements of fall chinook salmon past Bonneville Dam by multiplying fish counts reported by USACE by the pooled adjustment factor. The number of adult fall chinook salmon counted in 1998 was 189,085 fish, and the adjusted escapement past the dam was 188,896 fish, a positive bias of 189 (0.1%) (Table 8).

The weighted AF for fall chinook salmon was 0.994, when all radio-tagged fish were included, and resulted in a positive bias of 1,135 fish (0.6%) (Table 8). Confidence intervals were +/- 0.007 (Figure 17).

Fallback Routes by Radio-Tagged Salmon and Steelhead

Antenna and receiver configurations at Bonneville Dam in all years did not permit us to monitor the exact location and time of fallback events, but we could determine the probable route of fallback (spillway, powerhouses, navigation lock, or ice and trash sluiceways) and approximate time of fallback, particularly in 1997 and 1998 when antenna coverage was most complete. We had antennas in the bottom of ice and trash sluiceways and navigation lock in 1997 and 1998, and in the forebay of the spillway in all years; we did not have antenna coverage that would record fish passing through the turbine penstocks. We identified routes of fallback primarily with records from forebay antennas and the first telemetry records in the tailrace or at fishways after the fallback event. Locations of first record in the tailrace after fallback were not definitive evidence of fallback routes, but together with telemetry records from the forebay they were evidence of the fallback route. Many salmon and steelhead that fell back were recorded first at one or both of the receivers (1BO and 2 BO) in the tailrace downstream from Robins Island (Figure 12) after falling back and we believe most of those fish fell back over the spillway, although some may have fallen back via unmonitored routes through the powerhouses. Many fish were first recorded after fallback at antennas in the fishways adjacent to the spillway, an indication that they fell back over the spillway. Small numbers of fish were first recorded after fallback at the navigation lock and the bottom of the ice and trash sluiceways.

Spring and summer chinook salmon

In the three years, for all fallback events, 41% to 51% of all fallback events by spring/summer chinook salmon were first recorded in the tailrace at the 1BO or 2BO sites (Figure 18). About 25% of the fallback fish were first recorded at antennas at the entrances to or in the B Branch and Cascade Island fishways adjacent to the spillway in 1996 and 1997, and 14% were first recorded there in 1998. Less than 15% of the fallback fish were first recorded at antennas at the navigation lock after falling back in all years (Figure 18). Less than 15% of all fallback fish were first recorded at fishway antennas at either powerhouse in all years, an indication that relatively few fish fell back through the powerhouses. In 1997 and 1998, antennas were installed at the downstream end of ice and trash sluiceways at both powerhouses. Eight percent of all fallback fish were first recorded in the Powerhouse I ice and trash sluiceway in 1997 and 7% were first recorded there in 1998. Five percent were first recorded in the Powerhouse II ice and trash sluiceway in 1997 and 12% were first recorded there in 1998 (Figure 18).

The numbers presented in the preceding paragraph include all fallback events, regardless of the time between exit from the top of the ladders and when the fish fell back. For fallback events that occurred within 24 h of the exit from the top of a fishway, a higher percentage of the fish were first recorded at antennas at the entrances or in the B-Branch and Cascade Island fishways than for all fallback events (Figure 18). In the three years, 38% to 49% of fish that fell back within 24 h of passing over the dam were first recorded at one of the two fishways adjacent to the spillway. A smaller percentage of the fish that fell back within 24 h of passing the dam were recorded at the 1BO and 2BO tailrace sites than for all fallback events. None of the 24-h fallback fish were recorded passing through the ice and trash sluiceway at powerhouse I, and only 2% in 1997 and 6% in 1998 at powerhouse II.

Records of fish at the two receivers in the forebay of the spillway added resolution to fallback routes by providing information on location of the fish prior to the fallback event. We believe the most meaningful spillway forebay records occurred closest in time to the first record for each fish in the tailrace after a fallback. In all years and with all forebay-fallback time gaps (1, 3, and 12 h), the highest percentages (44% to 63%) of first records on the downstream side of the dam were at the 1BO and 2BO tailrace receivers (Figure 19). In 1996 and 1997, more than 20% of the fallback fish were first recorded at the entrances or in the B-Branch and Cascade Island fishways, versus about 13% in 1998 for all forebay-fallback time gaps. Similar percentages (8% to 13%) of fish recorded in the tailrace within 12 h after they were recorded in the spillway forebay were first recorded at the navigation lock in all three years. In 1998, more than 20% of the salmon that had 1 h and 3 h forebay-downstream site time gaps, were recorded as they passed through the lower end of the ice and trash sluiceway of powerhouse II, a much higher percentage than in 1997. In all measurements in all years, a higher percentage of fallback salmon were first recorded at the entrance or in the B-Branch fishway than at the Cascades Island fishway, as might be expected since most of the fish that fell back had migrated around Bradford

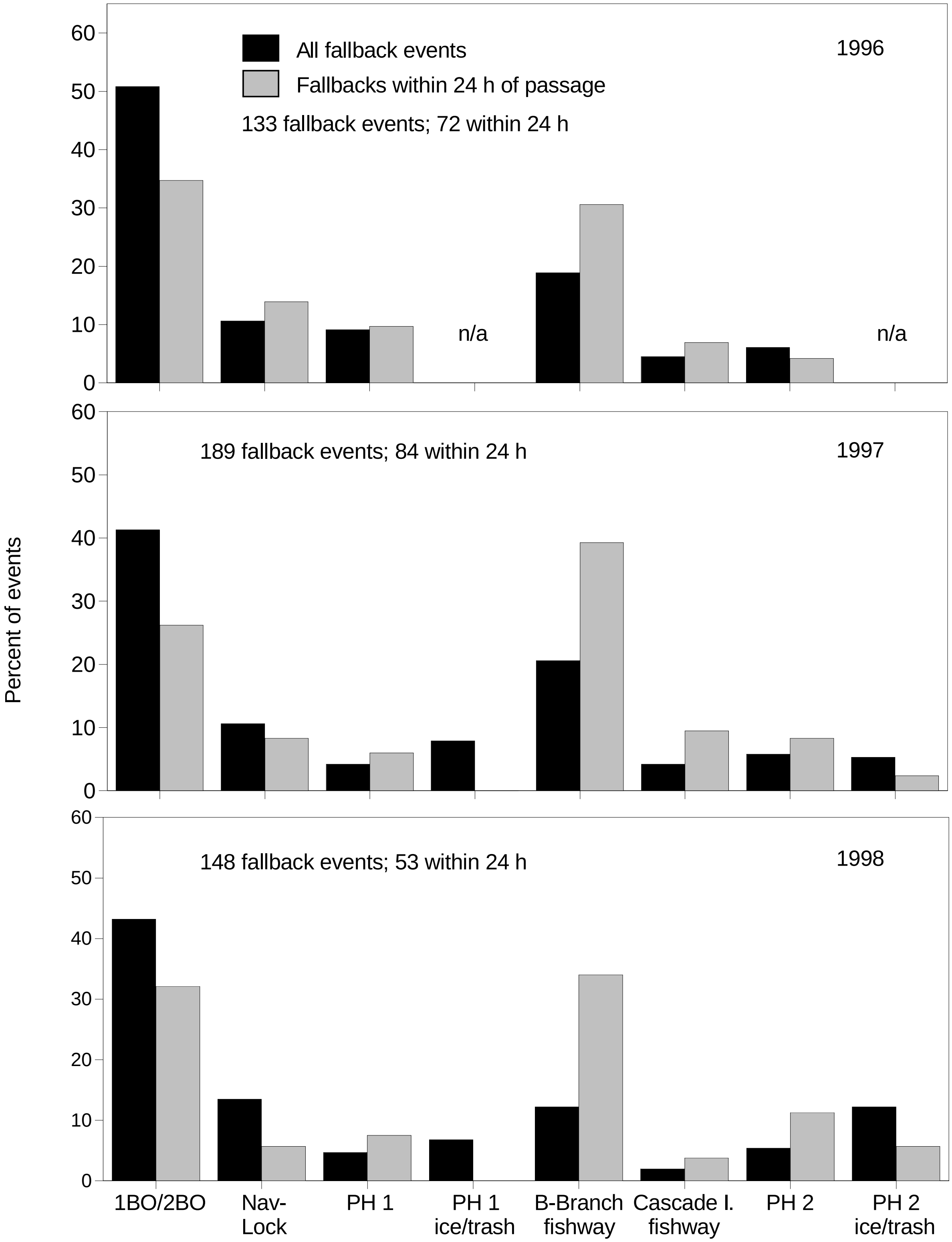

Figure 18. Location of first telemetry records of spring/summer chinook salmon downstream from the dam after all fallback events, and after fallback events that occurred within 24 h of passage at Bonneville Dam in 1996, 1997, and 1998.

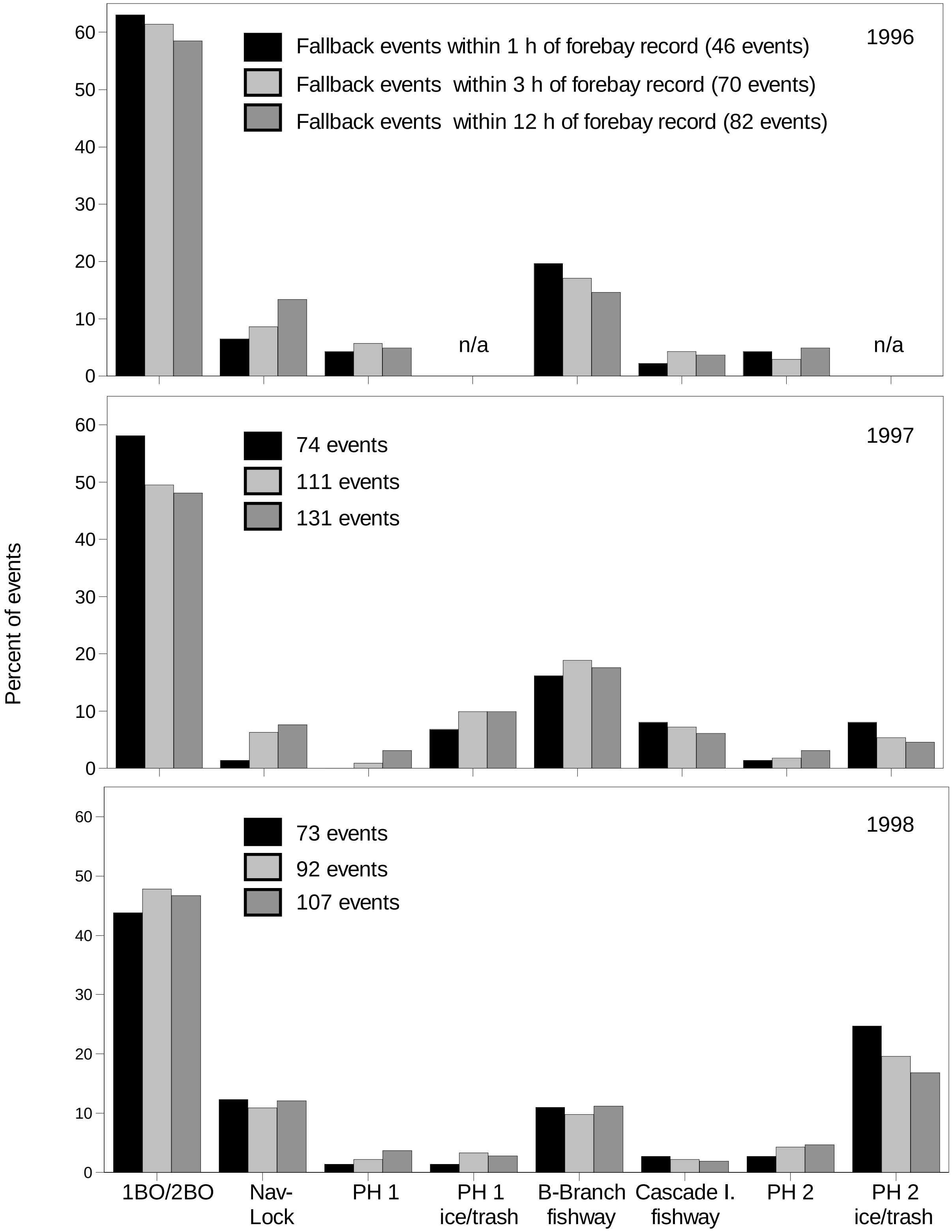

Figure 19. Location of first telemetry records downstream from the dam after all spring/summer chinook salmon fallback events that occurred within 1 h, 3 h, and 12 h after the last telemetry record in the forebay of the spillway at Bonneville Dam in 1996, 1997, and 1998.

Island into the spillway after passing the dam.

Sockeye salmon

As with spring/summer chinook salmon, we believe most sockeye salmon with transmitters that fell back over Bonneville Dam in 1997 fell back over the spillway. Forty-five percent of the sockeye salmon after all fallback events, and 52% of those that fell back within 24 h of passing a ladder, were recorded first in the tailrace, at antennas at the entrance, or in the B-Branch fishway adjacent to the spillway (Figure 20). Only 1-2% of the fallback sockeye salmon were recorded first at Cascade Island fishway on the north side of the spillway. About 12% of the sockeye salmon were first recorded at the 1BO and 2BO tailrace sites, and 12% were first recorded at antennas at the navigation lock. Between 12% and 14% of all fallback sockeye salmon were first recorded at fishway antennas at Powerhouses I, and a similar percentage at Powerhouse II, for all events, and for those that fell back within 24 h of passage. Antennas were installed at the bottom of the ice and trash sluiceways at both powerhouses in 1997; 1 fish was first recorded in a sluiceway as it fell back over the dam.

Sockeye salmon recorded at the two receivers in the spillway forebay added resolution to fallback routes by providing location information prior to the fallback event. For all forebay-tailrace time gaps (1, 3, and 12 hr), the highest percentage (53% to 73%) of first downriver records were at antennas of the B-branch fishway adjacent to the south side of the spillway (Figure 20, part B). Seven to 17% of the sockeye salmon that fell back in less than 12 hr were first recorded in the tailrace at the 1BO and 2BO sites in the tailrace, and less than 10% were first recorded in the navigation lock channel. About 20% of the fallback sockeye salmon were first recorded at one of the powerhouses, and none were first recorded at ice and trash sluiceways (Figure 20).

Steelhead

Approximately 80% of all fallback events by steelhead outfitted with transmitters in 1996 and 1997 at Bonneville Dam occurred on days when there was spill. Of the events that occurred within 24 h of passage over the dam, 97% of the fallbacks were on days when spill occurred in 1997, and 100% occurred on days with spill in 1996. Based on spill conditions, telemetry records in the forebay, and telemetry records at and downstream from Bonneville Dam following fallback, we believe most steelhead with transmitters that fell back over Bonneville Dam fell back over the spillway.

For steelhead, the location of first telemetry records in the tailrace after fallbacks were more evenly distributed throughout the tailrace sites than for spring/summer chinook or sockeye salmon. For all fallback events in 1996 and 1997, 24% and 38% of the steelhead were first recorded at the 1BO and 2BO sites in the tailrace downstream from the dam. For fallback events within 24 h of passing over the dam, 15% and 34% of the fish were first recorded at the two tailrace sites (Figures 21 and 22). In 1997, more (21% of all and 27% of those within 24 h) of the steelhead that fell back were first recorded at or in the B-Branch fishway than the Cascade Island fishway (4% and 6%), but in 1996 about equal numbers of fish were first recorded at both

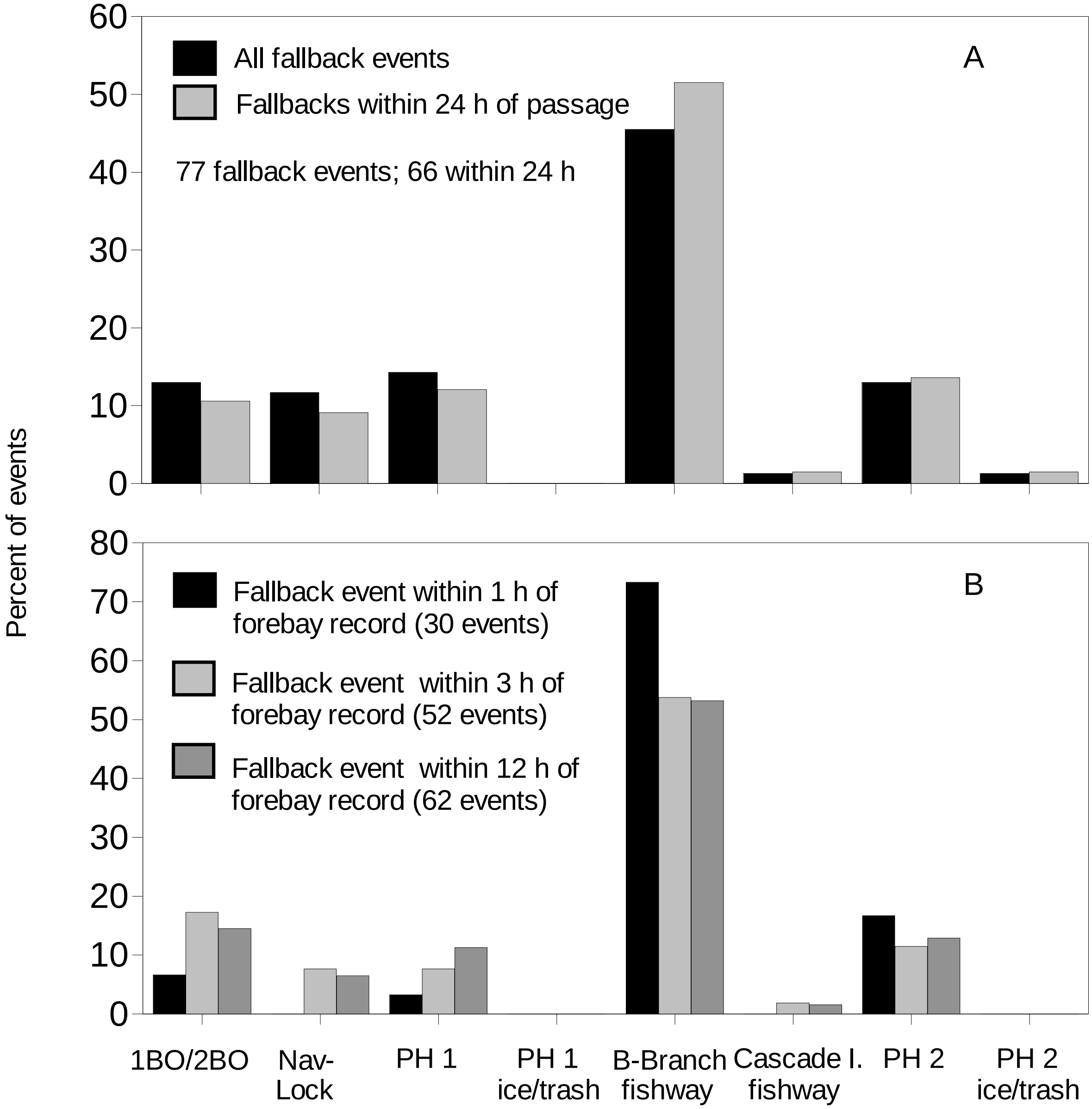

Figure 20. Location of first telemetry records of sockeye salmon downstream from the dam after all fallback events and after fallback events that occurred within 24 h of their passage at Bonneville Dam in 1997 (A). Location of first telemetry record by sockeye salmon downstream from the dam after fallbacks that occurred within 1 h, 3 h, and 12 h of the last record at receivers in the forebay of the spillway in 1997 (B).

fishways (part A, Figures 21 and 22). In the two years, 13% to 15% of the steelhead that fell back were first recorded at antennas at the navigation lock, and 5% to 13% of all fallback steelhead were first recorded at fishway antennas at Powerhouses I and II. Antennas were installed at the bottom of the ice and trash sluiceways at both powerhouses in 1997; 1 fish was first recorded in a sluiceway as it fell back over the dam.

Steelhead recorded at the two receivers in the spillway forebay added resolution to likely fallback routes. For 1997 steelhead with 1, 3, and 12 h time

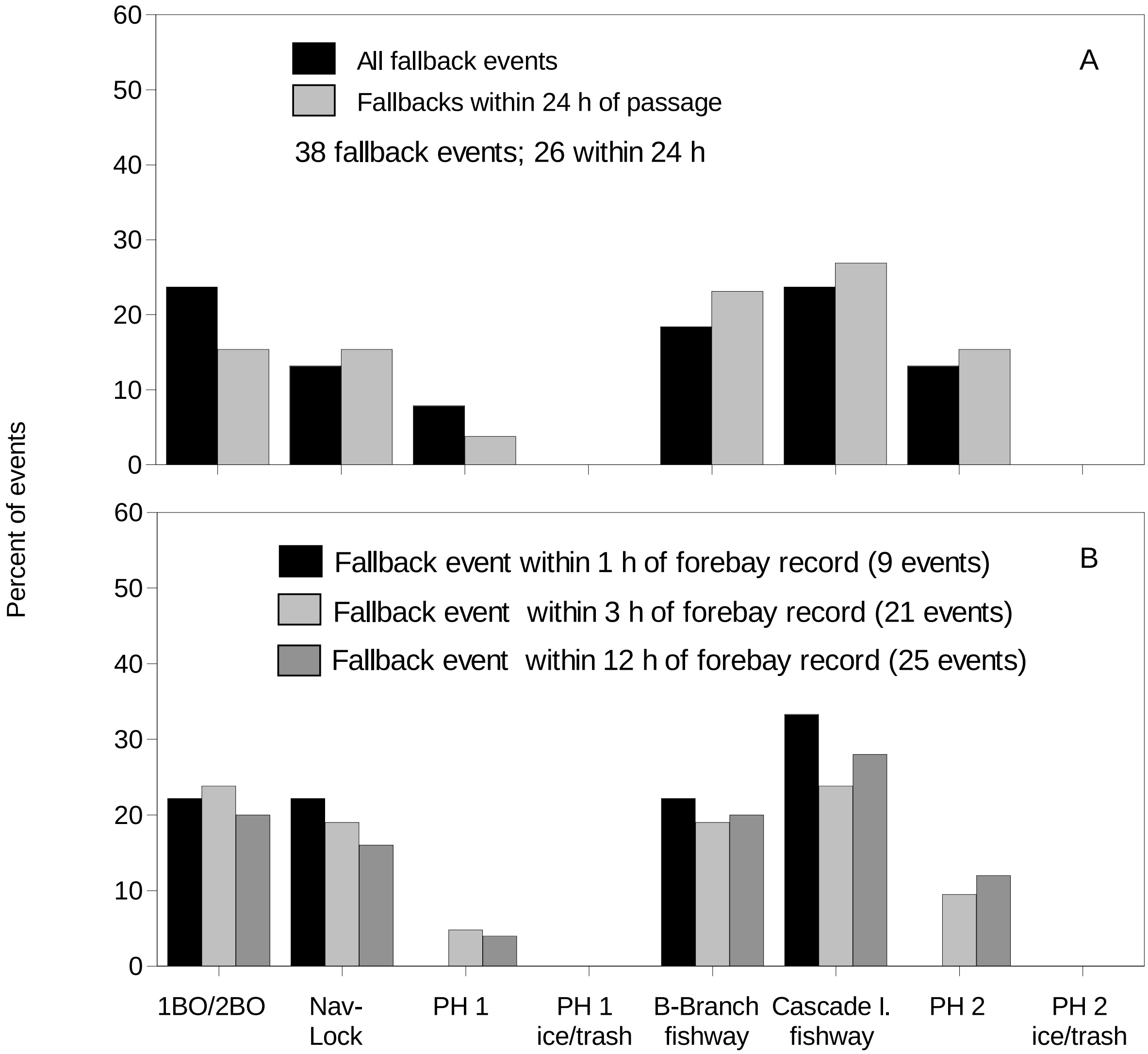

Figure 21. Location of first telemetry records of steelhead downstream from the dam after all fallback events and after fallback events that occurred within 24 h of their passage at Bonneville Dam in 1996 (A). Location of first telemetry record by steelhead downstream from the dam after fallbacks that occurred within 1 h, 3 h, and 12 h of the last record at receivers in the forebay of the spillway in 1996 (B).

gaps between the last forebay records and the first records in the tailrace, the highest percentage (36% to 40%) of fish were first recorded at the 1BO and 2BO sites downriver from the dam, followed by 23% to 30% of the fish first recorded in the B-branch fishway adjacent to the south side of the spillway. Less than 20% of the fallback steelhead in 1997 were first recorded in the navigation lock. For the 25 steelhead that had records in both the spillway forebay and at sites downstream from the dam in 1996, the highest percentage of fish (24% to 33%) were first recorded at the Cascades the highest percentage of fish (24 Island fishway, followed by 20% to 24% at the two downriver sites, 19% to 22% at the B-branch fishway, and 16% to 22% at the navigation lock (Figures 21 and 22). Relatively low percentages of fallback steelhead were first recorded at one of the

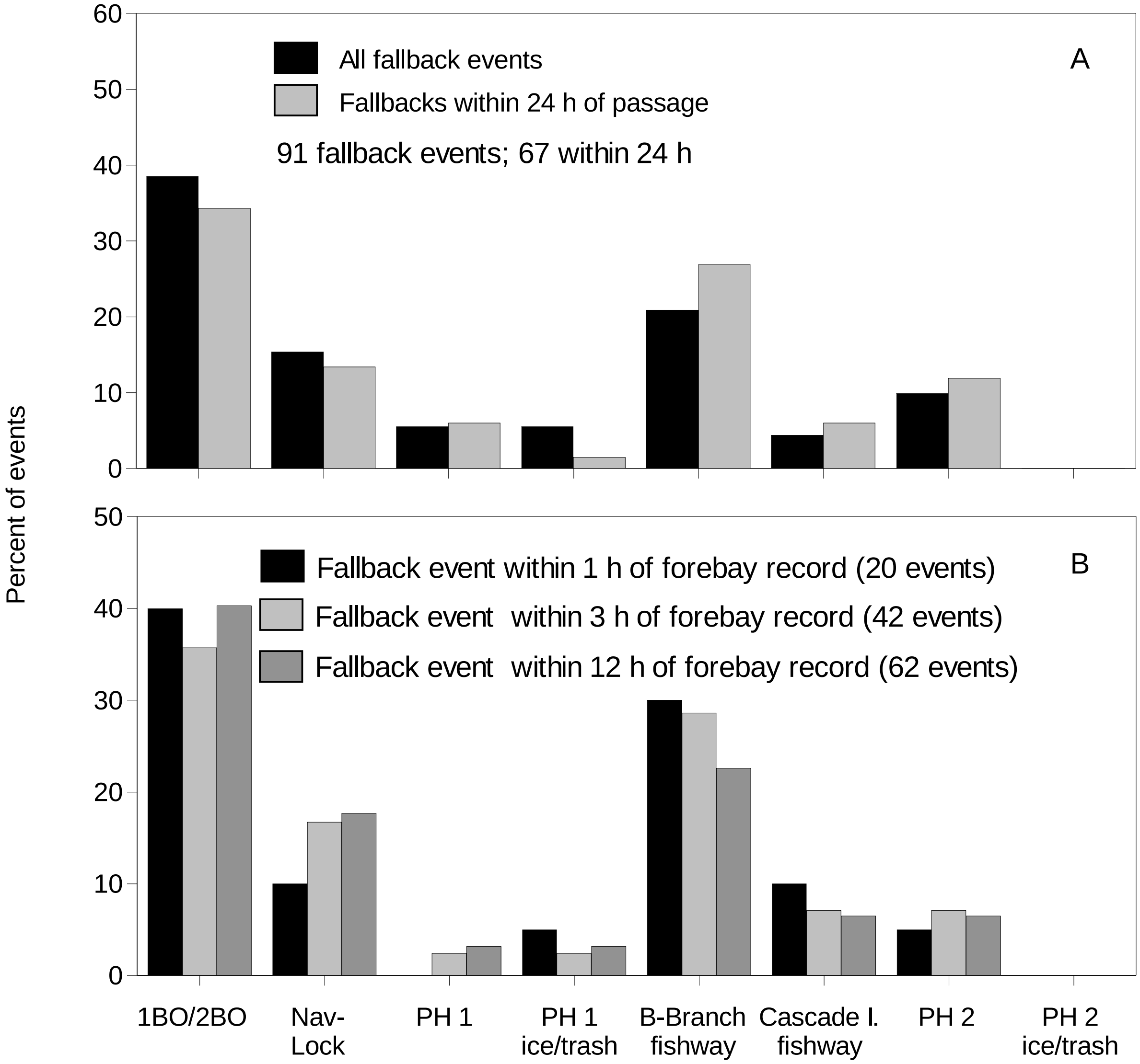

Figure 22. Location of first telemetry records of steelhead downstream from the dam after all fallback events and after fallback events that occurred within 24 h of their passage at Bonneville Dam in 1997 (A). Location of first telemetry record by steelhead downstream from the dam after fallbacks that occurred within 1 h, 3 h, and 12 h of the last record at receivers in the forebay of the spillway in 1997 (B).

powerhouses or at ice and trash sluiceways in both 1996 and 1997.

Fall chinook salmon

Unlike spring/summer chinook salmon, sockeye salmon, and steelhead, all radio-tagged fall chinook salmon passed Bonneville Dam during the period of no-spill that began on 1 September, 1998. We believe most fall chinook salmon withtransmitters that fell back over Bonneville Dam in 1998 fell back via the navigation lock. For all fallbacks, about 60% of fall chinook salmon were recorded first at antennas in the navigation lock. Another 37% were first recorded at the tailrace receivers (Figure 23). One fish

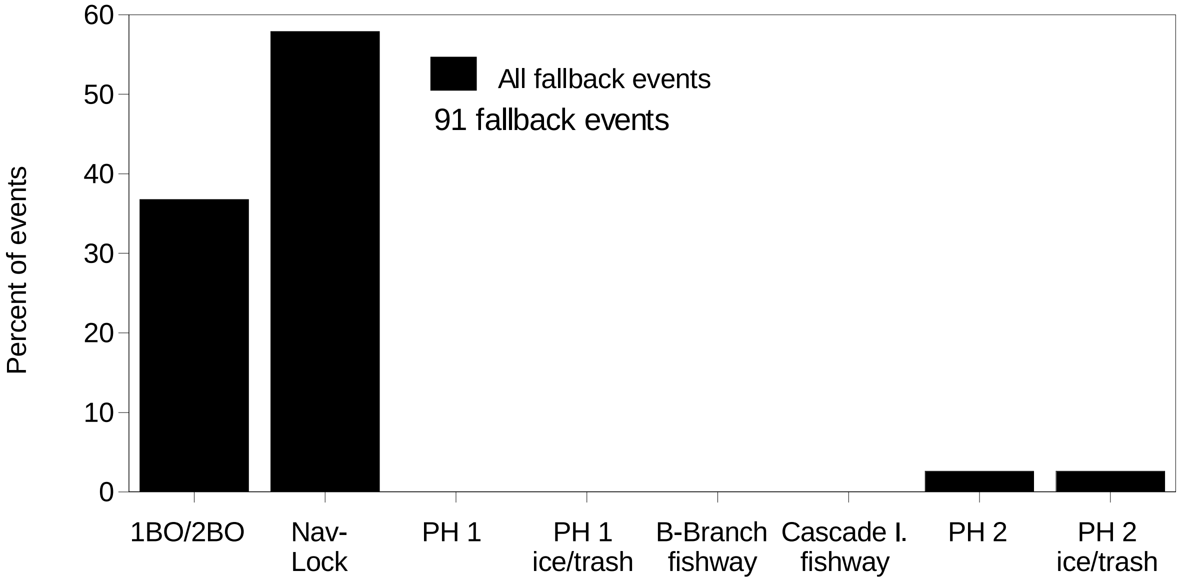

Figure 23. Location of first telemetry records of fall chinook salmon downstream from the dam after all fallback events at Bonneville Dam in 1998.

(3%) was recorded falling back through an ice and trash sluiceway, and 1 (3%) was first recorded at a fishway antenna at Powerhouse II. All four fish that fell back within 24 h of passing the dam were first recorded in the navigation lock.

Thirteen fall chinook salmon were recorded at the spillway forebay receivers within 12 h prior to falling back. Sixty-two percent of those fish were subsequently recorded in the navigation lock, 31% were recorded at tailrace receivers, and 1 (8%) was recorded in an ice and trash sluiceway.

Effects of Environmental Factors on Spring/Summer Chinook Salmon Fallbacks

Flow, spill, turbidity, and dissolved gas levels at Bonneville Dam varied within and between years during the spring and summer chinook salmon migrations from 1996 to 1998 (Figures 8, 9, and 10). In previous studies, fallback rates have increased with increased flow and spill at Columbia and Snake River dams, but methods and results from earlier studies usually involved small numbers of marked fish (see Bjornn and Peery 1992). We examined relationships between flow, spill, and fallback behavior of spring/summer chinook salmon for each year (1996-1998) using a variety of methods. We also considered the impact of turbidity, dissolved gas levels, and temperature on fallbacks and used multiple regression models to explore the combined effect of several environmental factors.

We used a variety of linear and logistic regression models to test univariate relationships between fallbacks by chinook salmon and environmental conditions at Bonneville Dam. The variety of methods were an attempt to accommodate shortcomings in experimental design: first, the tagging schedule at Bonneville Dam (10 d with tagging, 4 d without tagging) created minor problems with

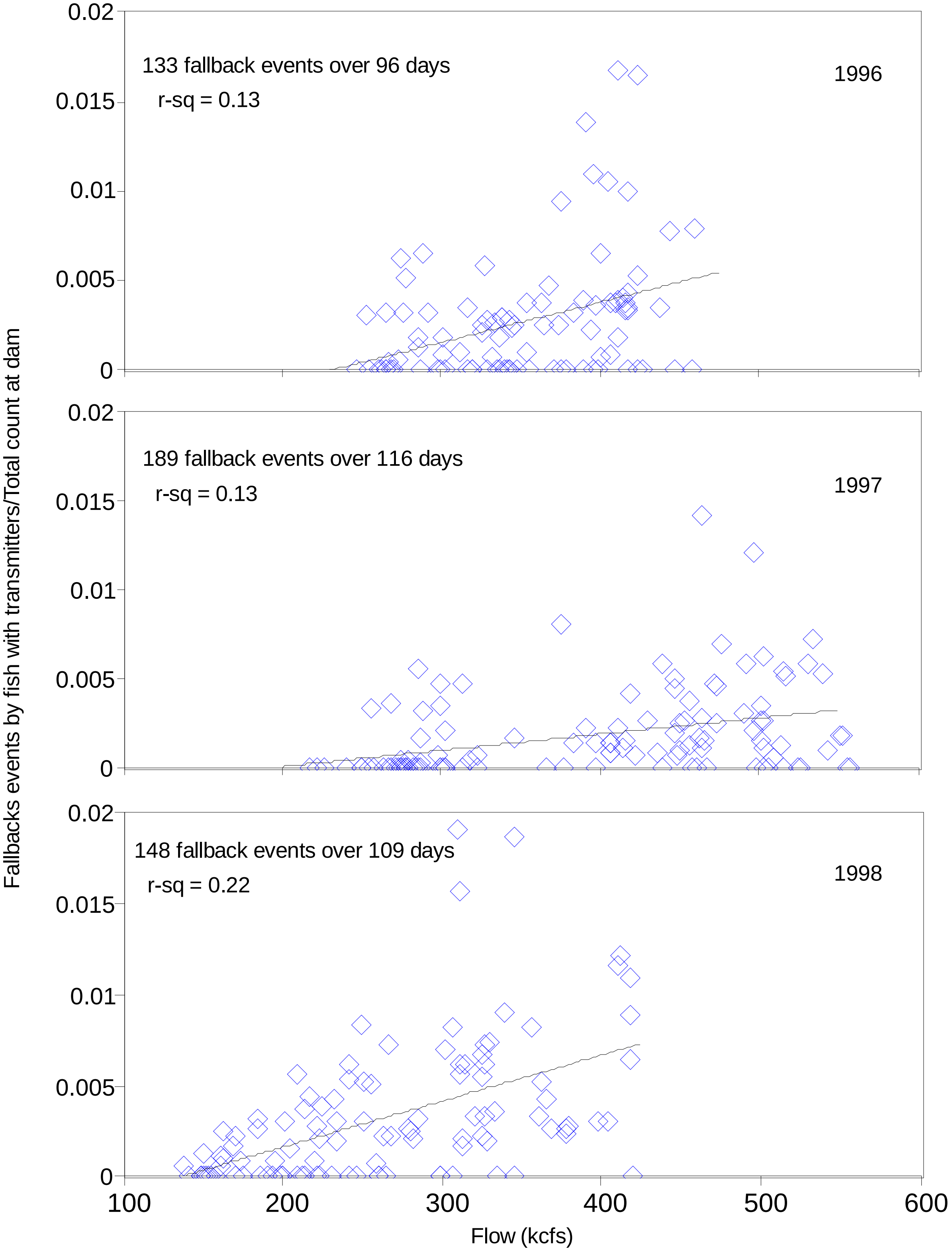

Figure 24. Relation of the ratio (fb_n/c_n) of spring/summer chinook salmon with transmitters that fell back (fb_n) divided by the number counted (c_n) each day at Bonneville Dam versus daily flow in 1996, 1997, and 1998.

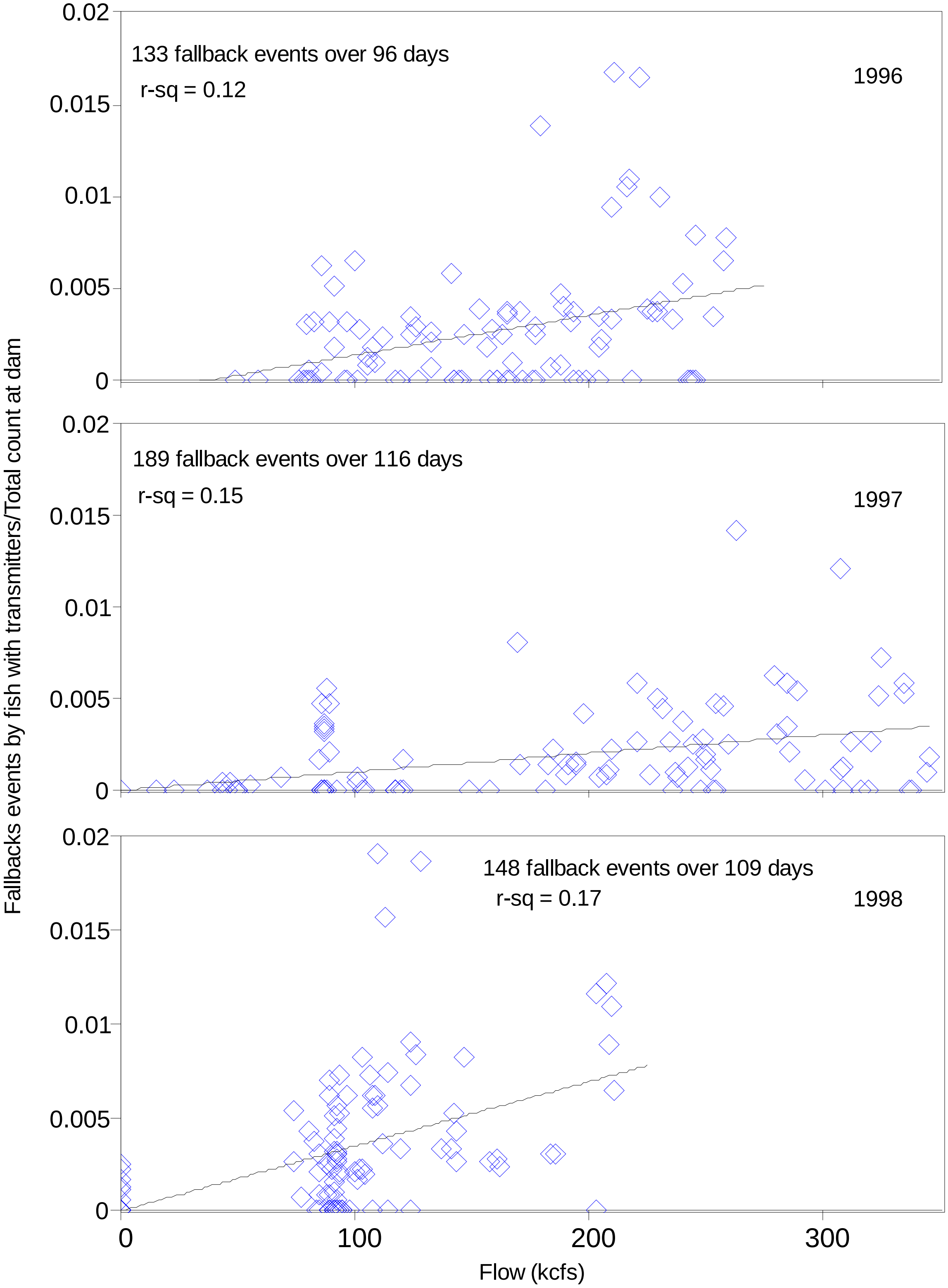

Figure 25. Relation of the ratio (fb_n/c_n) of spring/summer chinook salmon with transmitters that fell back (fb_n) divided by the number counted (c_n) each day at Bonneville Dam versus daily spill in 1996, 1997, and 1998.

proportionality of radio-tagged fish to the overall run; second, independent of the tagging schedule, daily passage and fallback rates by salmon with transmitters varied throughout the migration; and third, environmental variables varied continuously, making discreet comparisons of fallback rates at specific environmental conditions difficult. To address these concerns we analyzed fallback rates with moving average techniques, multi-day blocks, blocks based on flow, spill, and Secchi disk visibility, blocks based on passage of a minimum number of fish with transmitters, t-Tests and logistic regressions of binary (fallback/no fallback) data sets.

One of the preliminary comparisons we made was that of daily fallback events by salmon with transmitters divided by the total count of salmon passing through the fishways. If radio-tagged chinook salmon were representative of the overall run, then such a ratio might be a measure of the proportion of fish that fell back each day that could be related to environmental variables. Fallback proportions increased with flow and spill each year (Figures 24 and 25), but flow and spill did not account for a very high proportion of the variability of that measure of a fallback rate in any of the three years ($r^2 = 0.12$ to 0.22). We included about 98% of all fallback events in this analysis, although, many fish had migrated upriver to tributary sites or other dams before they returned to Bonneville Dam and fell back. The < 2% that we excluded fell back weeks after the last radio-tagged fish had passed the dam. When we limited the analysis to fallbacks that occurred within 24 h of exit from the top of a fishway, trends were similar.

We also calculated daily fallback/daily passage ratios for radio-tagged fish only. With this method, fallback ratios on individual days ranged widely (up to 1.0), particularly on days when few radio-tagged fish passed the dam and one or more fell back. Because of the high variability of the fallback ratio we have not presented the relation with flow and spill.

Fallback ratios for 5-d moving average

To moderate the ratio variability problem on individual days, we calculated daily fallback ratios using the moving average number of fallback events over 5 days and the number of chinook salmon with transmitters recorded at the tops of fishways over the same 5 days (moving average ratio). Fallback events that occurred more than 24 h after a fish exited from the top of a fishway were not included in the analysis because many 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 at Bonneville Dam. Correlations between moving average ratios and environmental variables at the dam (flow, spill, turbidity, dissolved gas) were strong in some cases. However, r^2 values reported for moving average ratios should only be viewed as indicative of general trends, as autocorrelation and variance errors are often created by moving average techniques.

In 1996, 72 spring/summer chinook salmon with transmitters fell back within 24 h of passage at Bonneville Dam. Using only these fallback events, the highest ratios of 5-day mean fallback events to 5-day mean passage occurred during mid-April and again from mid-May to early June (Figure 26). A fallback ratio nadir occurred during the first two weeks in May that may have been partly caused by 4 d of

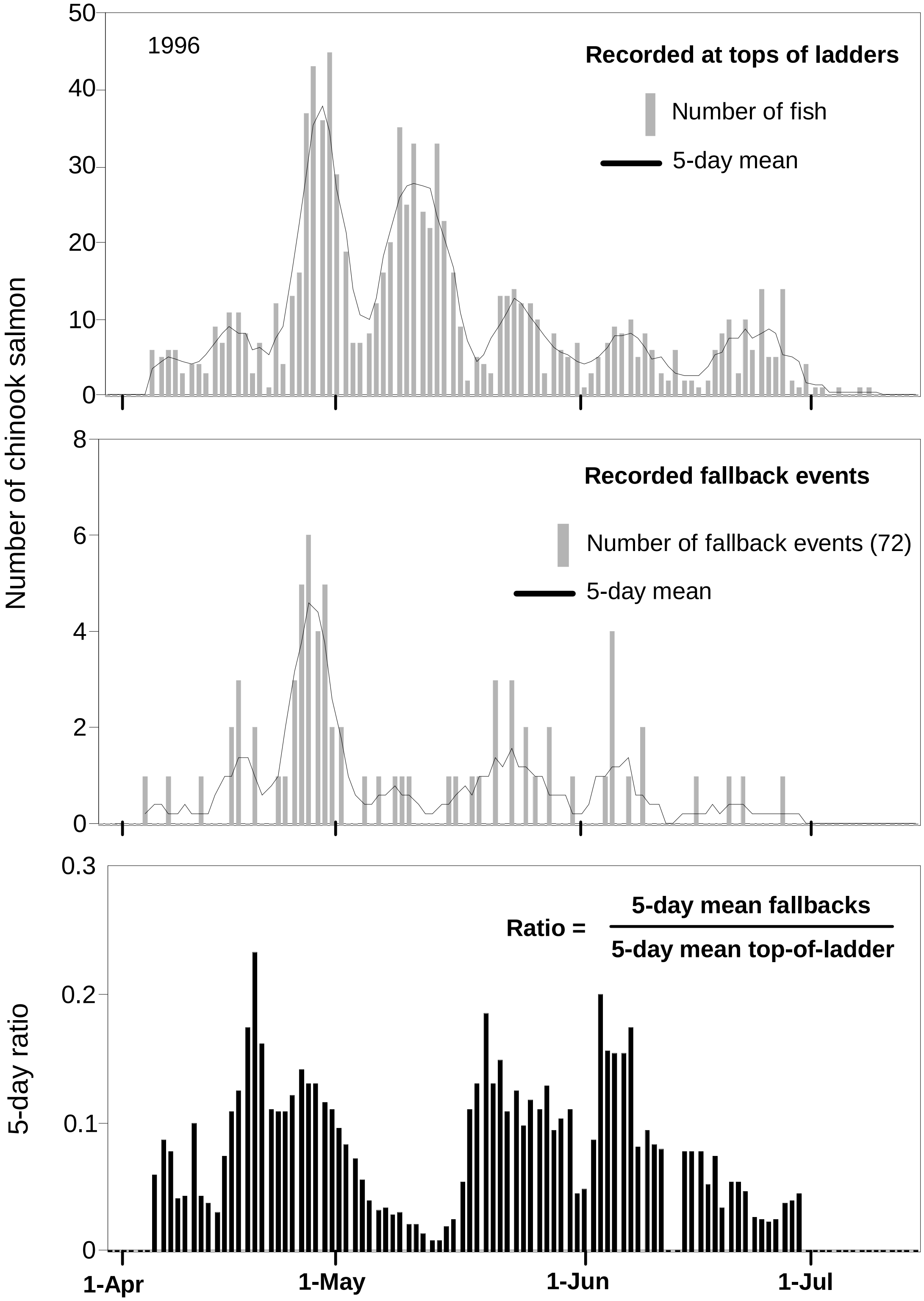

Figure 26. Daily number and 5-d moving average of recorded passages at tops of the fishways at Bonneville Dam, daily number and 5-d moving average fallbacks within 24 h of passage, and the daily 5-d moving average fallback ratios for spring/summer chinook salmon with transmitters in 1996.

no tagging in early May (Figure 1). The 5-day fallback ratios based on only salmon with transmitters were positively correlated with daily flow, spill, and dissolved gas, and negatively correlated with Secchi disk visibility between 5 April and 15 July, the period when all radio-tagged spring and summer chinook salmon passed Bonneville Dam in 1996. A higher proportion of the variability in the 5-day fallback ratios was accounted for by flow and spill (r^2 ~ 0.40 and 0.35, Figure 27) than the regressions in Figures 24 and 25. Secchi disk visibility, and dissolved gas levels in the forebay were weakly correlated with the 5-day fallback ratios in 1996, r^2 values were ~ 0.13 and 0.06 (Figure 27).

In 1997, 84 spring/summer chinook salmon with transmitters fell back within 24 h of passage at Bonneville Dam. Fish with transmitters began to pass the dam, and began falling back, in early April (Figure 28). Nadirs for the continuous fallback ratio occurred in early and late May in 1997 and again in late summer; the highest ratio values were in mid-May and mid-June. Fallback ratios were positively correlated with daily flow, spill, and dissolved gas, and negatively correlated with Secchi disk visibility between 6 April and 30 July, the period when more than 99% of all radio-tagged spring and summer chinook salmon passed Bonneville Dam in 1997 (Figure 29). The r^2 values for regressions of flow and spill with the moving average fallback ratio at Bonneville Dam were ~ 0.33 and 0.30, slightly lower than in 1996. Secchi disk visibility and dissolved gas concentrations in the forebay were more strongly correlated with the fallback ratios for chinook salmon in 1997 than in 1996, r^2 values were ~ 0.19 and 0.19 (Figure 29).

In 1998, 53 chinook salmon with transmitters fell back within 24 h of passage at Bonneville Dam. Fish with transmitters began to pass the dam in the first week of April, but the first fallbacks within 24 h of passage did not occur until mid-April (Figure 30). Nadirs for the continuous fallback ratio occurred in mid-May and in July, and they were partly caused by the 4-day periods of no tagging; the highest ratio values were in early and late May when flows were high. Ratio values were positively correlated with daily flow, spill, and dissolved gas, and negatively correlated with Secchi disk visibility between 2 April and 19 July, the period when more than 99% of all radio-tagged spring and summer chinook salmon passed Bonneville Dam in 1998. A relatively high proportion of the variability in the 5-day moving average fallback rate in 1998 was explained by flow and spill; the r^2 values were ~ 0.49 and 0.46. There was no spill for almost two weeks in early April, and no fallbacks occurred within 24 h of passage during that period. Secchi disk visibility, and dissolved gas levels in the forebay were more highly correlated with the 5-day fallback ratios (r^2 values were ~ 0.34 and 0.40) in 1998 than in the two previous years (Figure 31).

Fallback ratios for consecutive 5-d blocks

In a third approach to analysis of environmental factors and fallbacks, we again used passage of chinook salmon with transmitters and fallbacks within 24 h of passing Bonneville Dam, but grouped data in consecutive 5-day blocks and calculated fallback ratios and mean values for the independent variables for each block. With this method, each fallback event affected only the ratio for the block

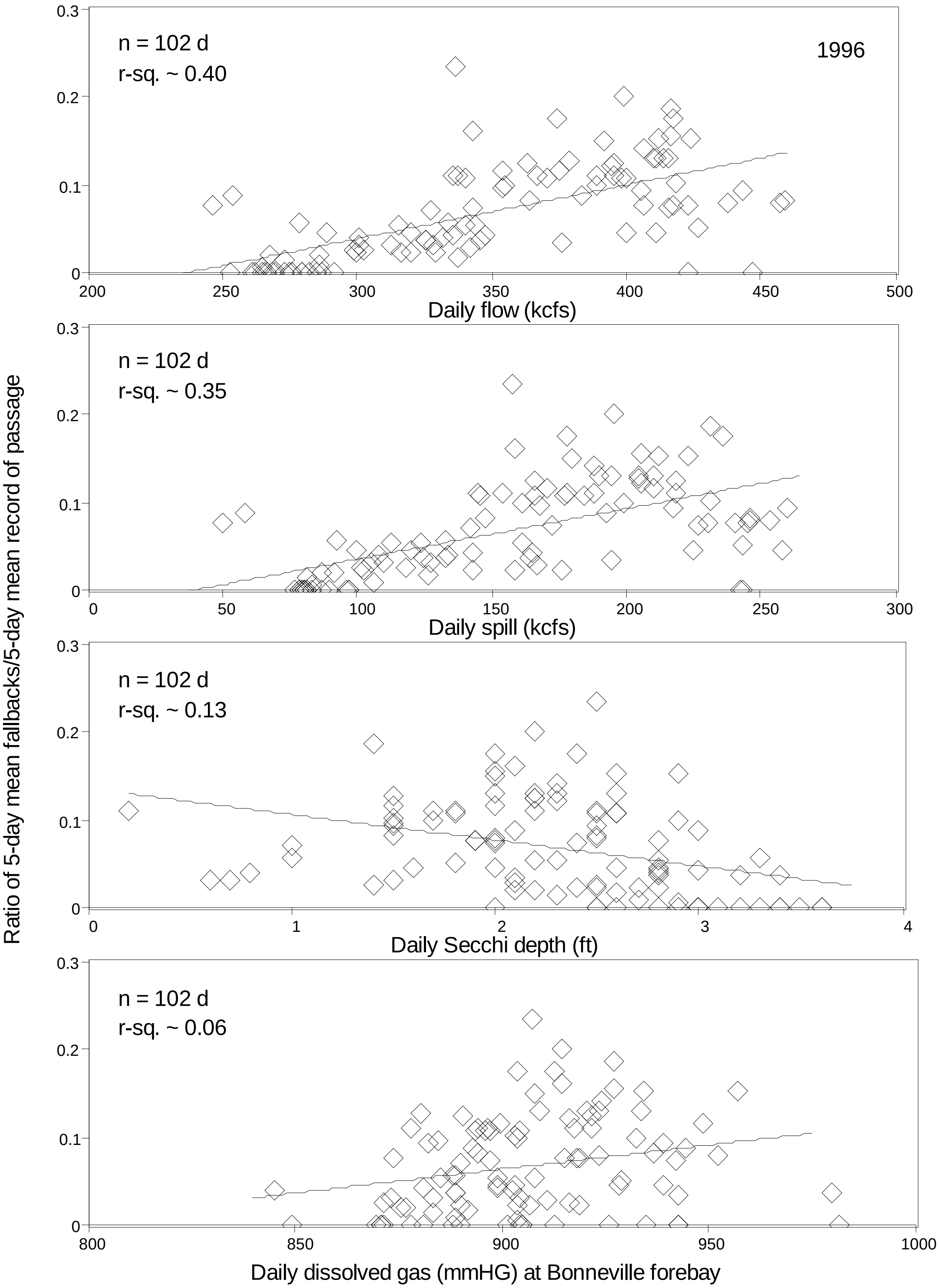

Figure 27. Regressions of daily mean flow, spill, Secchi disk visibility, and dissolved gas levels in the forebay with 5-d moving average fallback ratios for spring/summer chinook salmon with transmitters at Bonneville Dam in 1996. ApprIximate r-sq values.

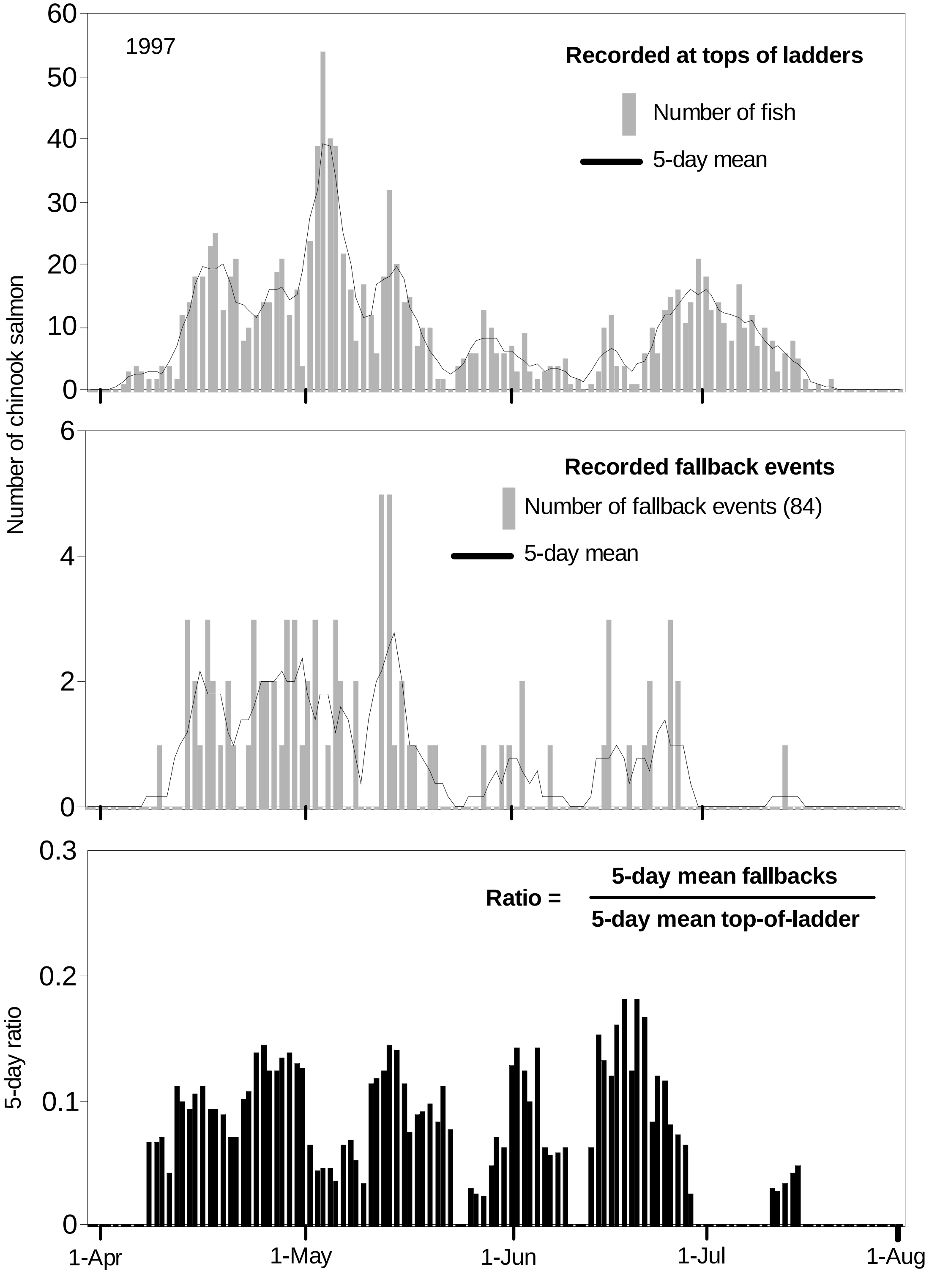

Figure 28. Daily number and 5-d moving average of recorded passages at tops of the fishways at Bonneville Dam, daily number and 5-d moving average fallbacks within 24 h of passage, and the daily 5-d moving average fallback ratios for spring/summer chinook salmon with transmitters in 1997.

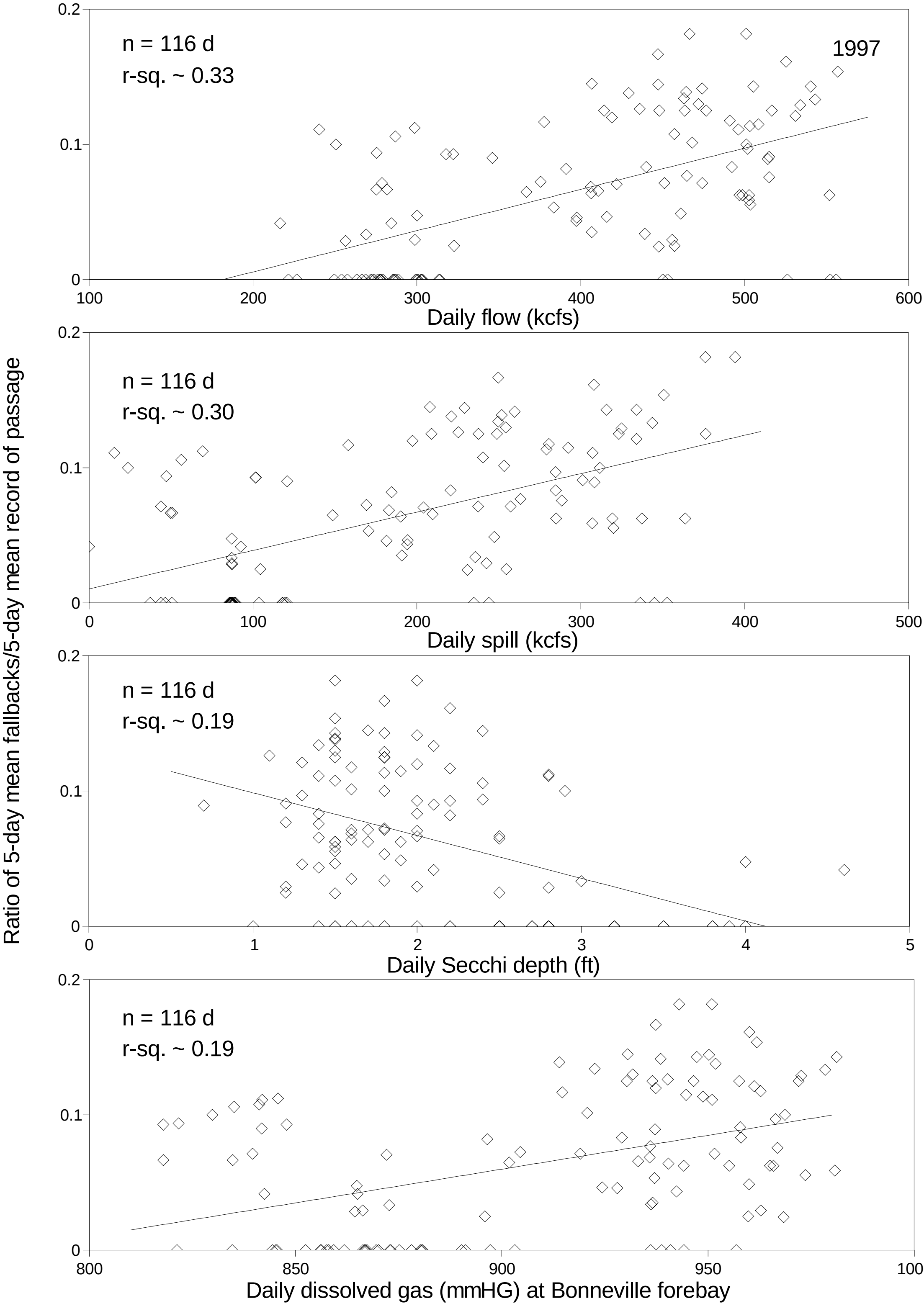

Figure 29. Regressions of daily mean flow, spill, Secchi disk visibility, and dissolved gas levels in the forebay with 5-d moving average fallback ratios for spring/summer chinook salmon with transmitters at Bonneville Dam in 1997. Approximate r-sq values.

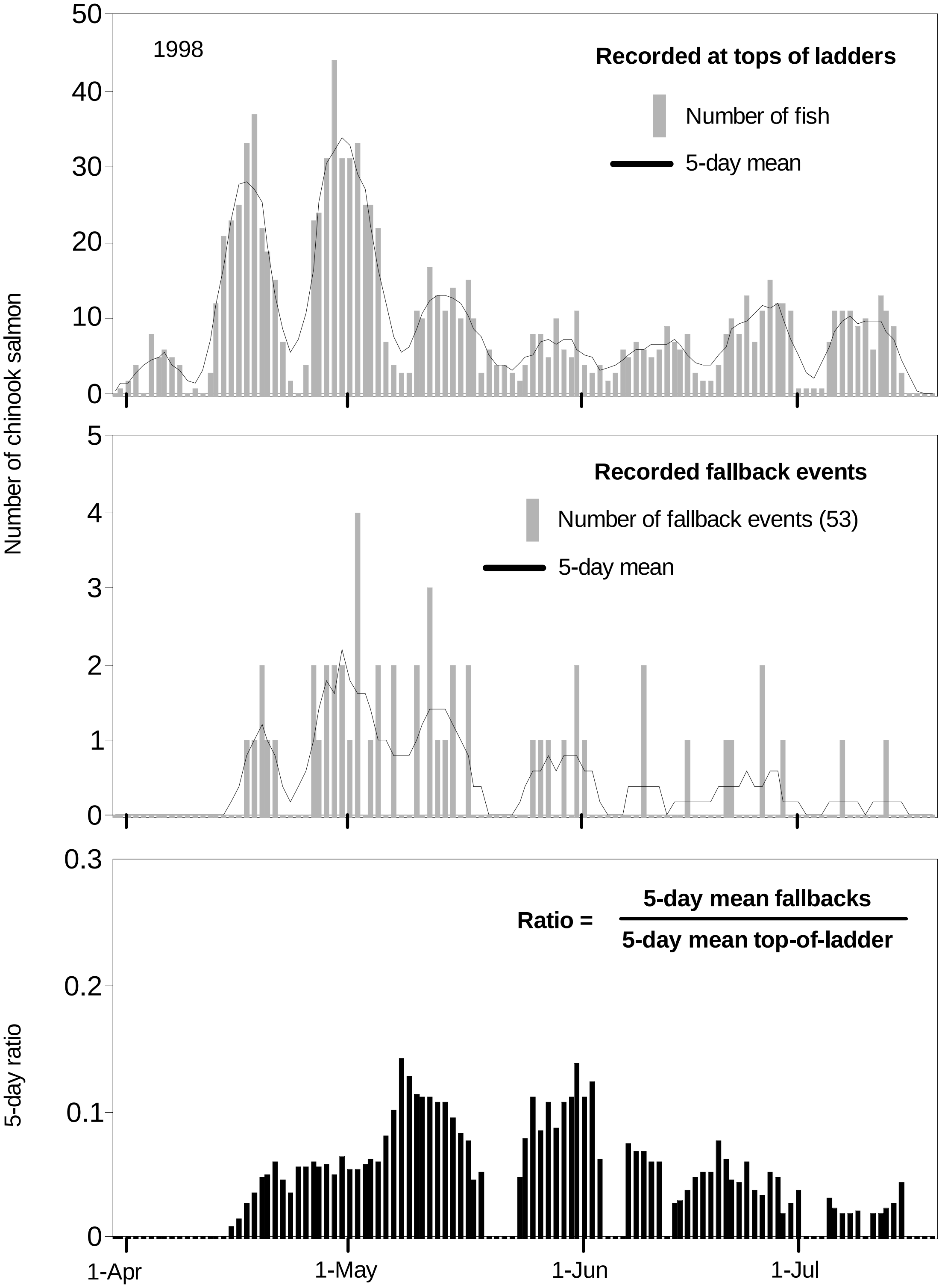

Figure 30. Daily number and 5-d moving average of recorded passages at tops of the fishways at Bonneville Dam, daily number and 5-d moving average fallbacks within 24 h of passage, and the daily 5-d moving average fallback ratios for spring/summer chinook salmon with transmitters in 1998.

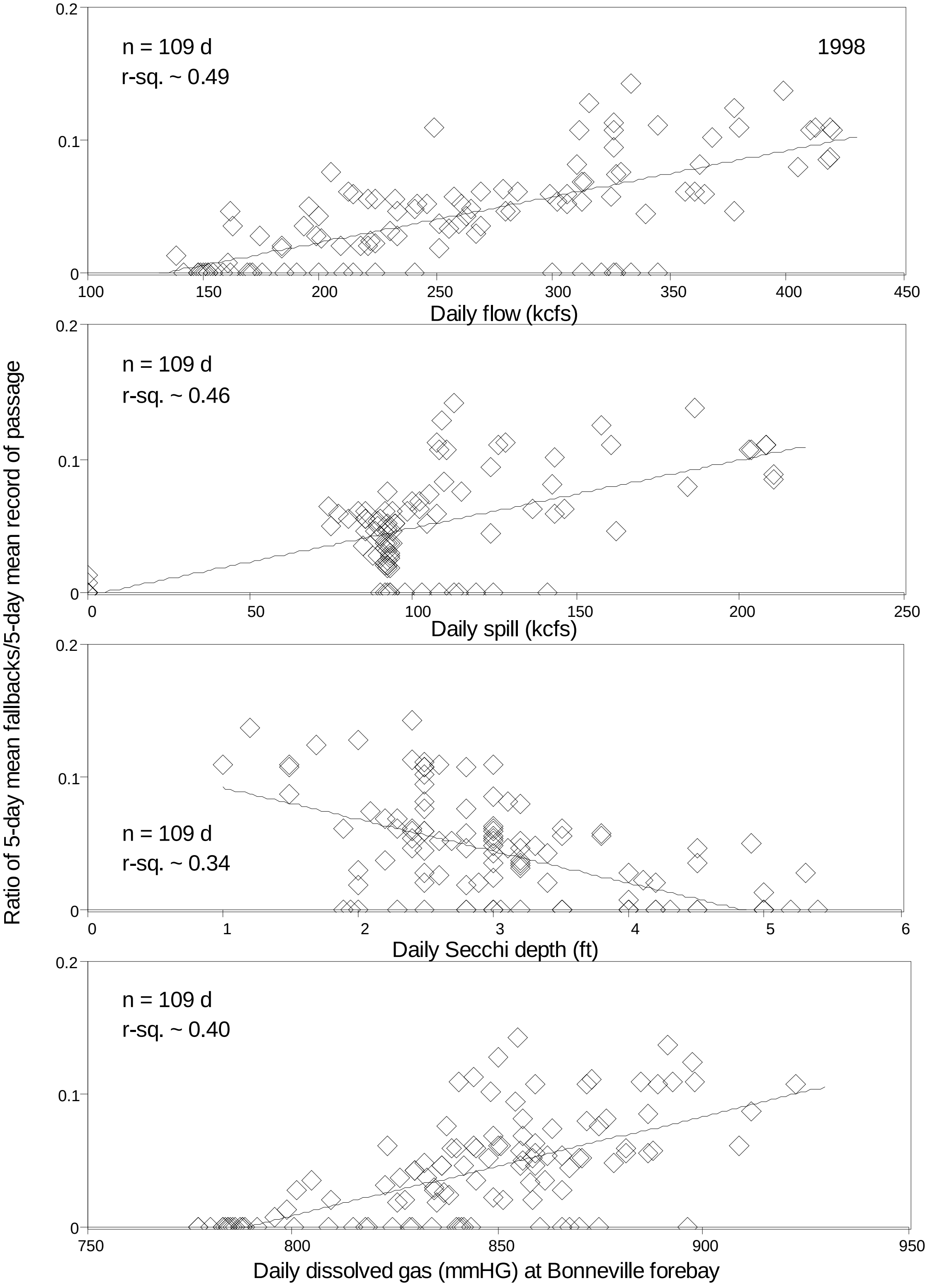

Figure 31. Regressions of daily mean flow, spill, Secchi disk visibility, and dissolved gas levels in the forebay with 5-d moving average fallback ratios for spring/summer chinook salmon with transmitters at Bonneville Dam in 1998. Approximate r-sq values.

in which it occurred. In the 5-d moving average method, each fallback event affected 5 daily fallback ratios, and the relative contribution of each event may have been magnified. Because fish passage was not uniform over the chinook salmon migration, consecutive 5-day blocks had unequal numbers of fish per block. In addition, fallback ratios and mean values for independent variables changed with the blocking sequence start date. To account for this variability, we ran analyses on the five possible block sequences over the date range that radio-tagged chinook salmon passed Bonneville Dam for each year. Sequences started on consecutive days, and each had 18 or 19 blocks (5-d periods). For ease of comparison with results from other methods, we present only data for 5-d blocks starting on the first day that radio-tagged salmon began passing the dam. We believe the selected block was representative.

For each year and environmental variable, we ran standard regressions as well as regressions weighted for the number of fish in each block and logistic regressions that used maximum likelihood methods to account for variability in both the number of fallback events and the number of fish in each block. In all three years, we found positive correlations with mean flow, spill, and dissolved gas levels and fallback ratios for spring/summer chinook salmon; ratios were negatively correlated with mean Secchi disk depth and water temperature.

In 1996, all unweighted and weighted linear models and logistic models using spill and flow with fallback ratios based on 5-d blocks were significant at $P < 0.05$. The r^2 values for the unweighted linear regressions were 0.23 for spill and 0.27 for flowweighted r^2 values were 0.46 for spill and 0.48 for flow (Figure 32). No linear or logistic models were significant for Secchi depth visibility or temperature. The weighted linear model and the logistic model were significant ($P < 0.05$) for dissolved gas levels, while the unweighted linear model was not.

Linear and logistic regression models for 1997 data were significant at $P < 0.05$ for flow and spill. The unweighted r^2 values were 0.33 for spill and 0.30 for flow; weighted values were 0.28 for flow and 0.29 for spill (Figure 33). The unweighted and logistic models were significant at $P < 0.05$ for Secchi depth visibility, with fallback ratios increasing with increasing turbidity; the r^2 value for the unweighted model was 0..22. The weighted Secchi depth model was not significant. Only the unweighted model for dissolved gas was significant at $P < 0.05$ ($r^2 = 0.21$). With water temperature, the logistic model was significant, but the linear models were not.

In 1998, all linear and logistic models for flow, spill, dissolved gas, and Secchi depth visibility were significant at $P < 0.005$, and no models were significant for water temperature. The r^2 values for flow and spill were between 0.46 and 0.52, and were between 0.34 and 0.39 for Secchi depth and dissolved gas (Figure 34). Fallback ratios increased with flow, spill, and dissolved gas, and decreased with increasing Secchi depth visibility.

Fallback ratios for variable-day bins

In a fourth approach, we grouped passage by chinook salmon at Bonneville Dam during consecutive days until at least 25 fish with transmitters had passed the dam (bins with a minimum of 20 fish had

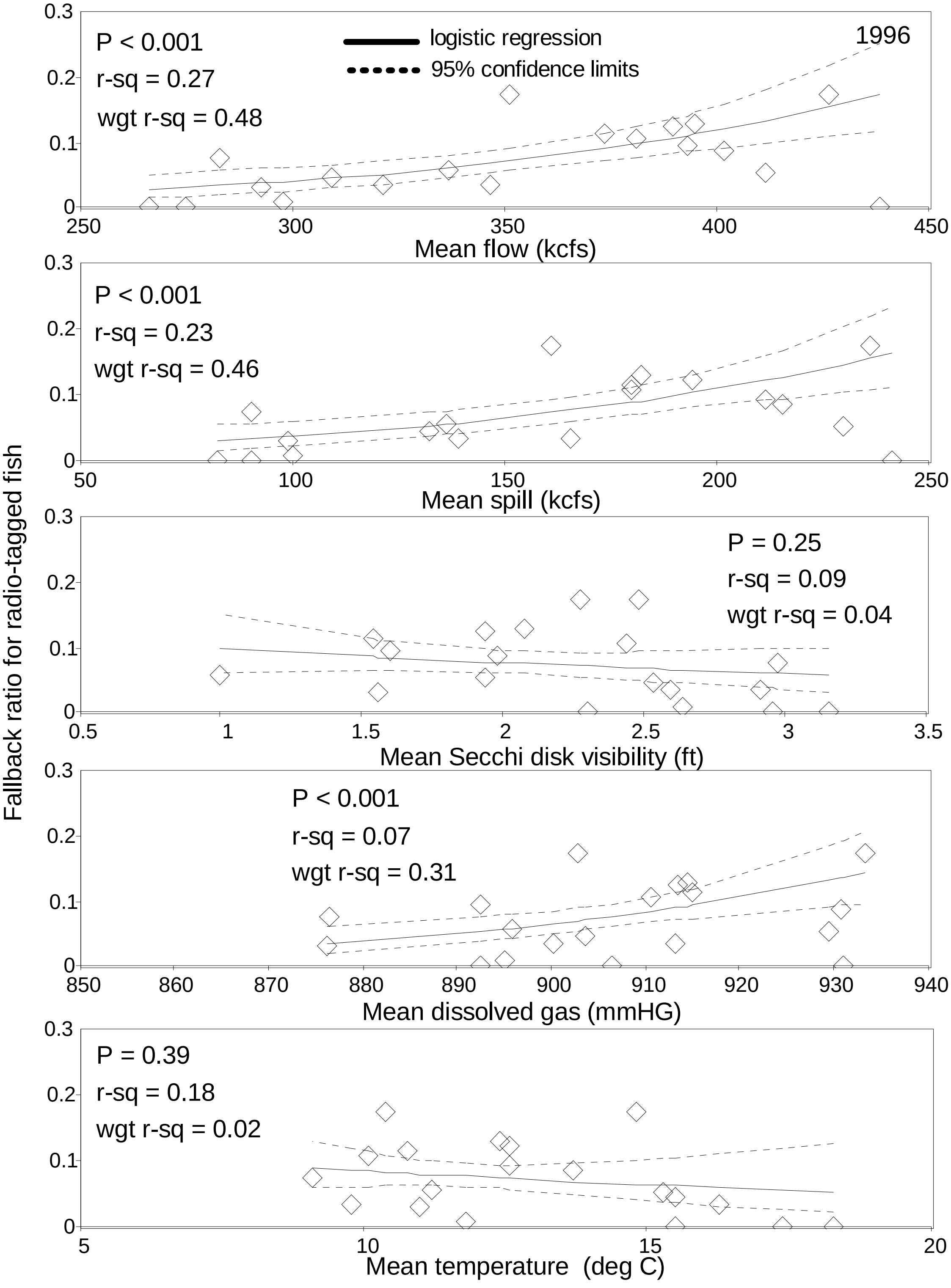

Figure 32. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring/summer chinook salmon fallbacks within 24 h at Bonneville Dam in 1996; includes r-sq values for weighted and unweighted linear regression models. All models based on consecutive 5-d blocks.

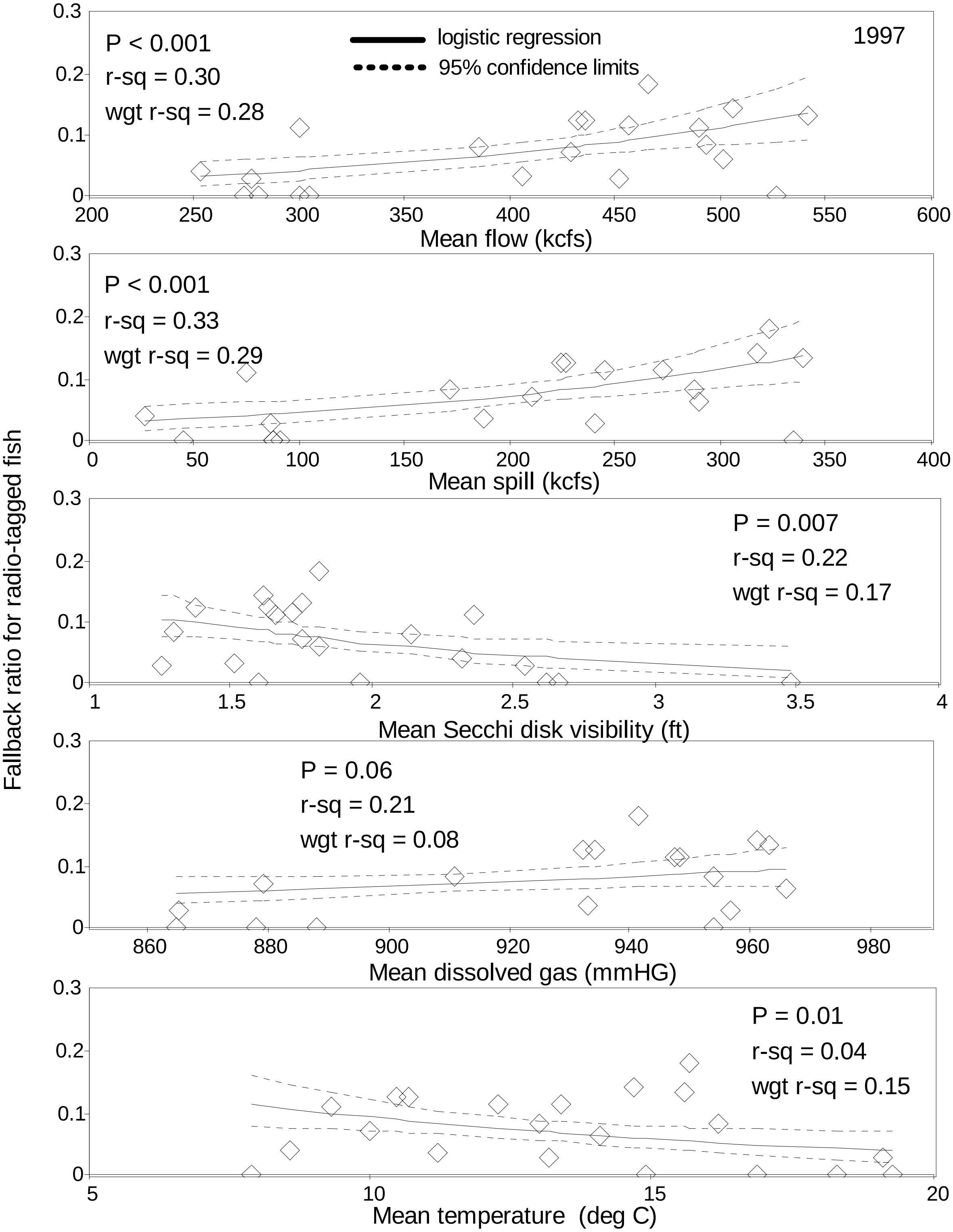

Figure 33. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring/summer chinook salmon fallbacks within 24 h at Bonneville Dam in 1997; includes r-sq values for weighted and unweighted linear regression models. All models based on consecutive 5-d blocks.

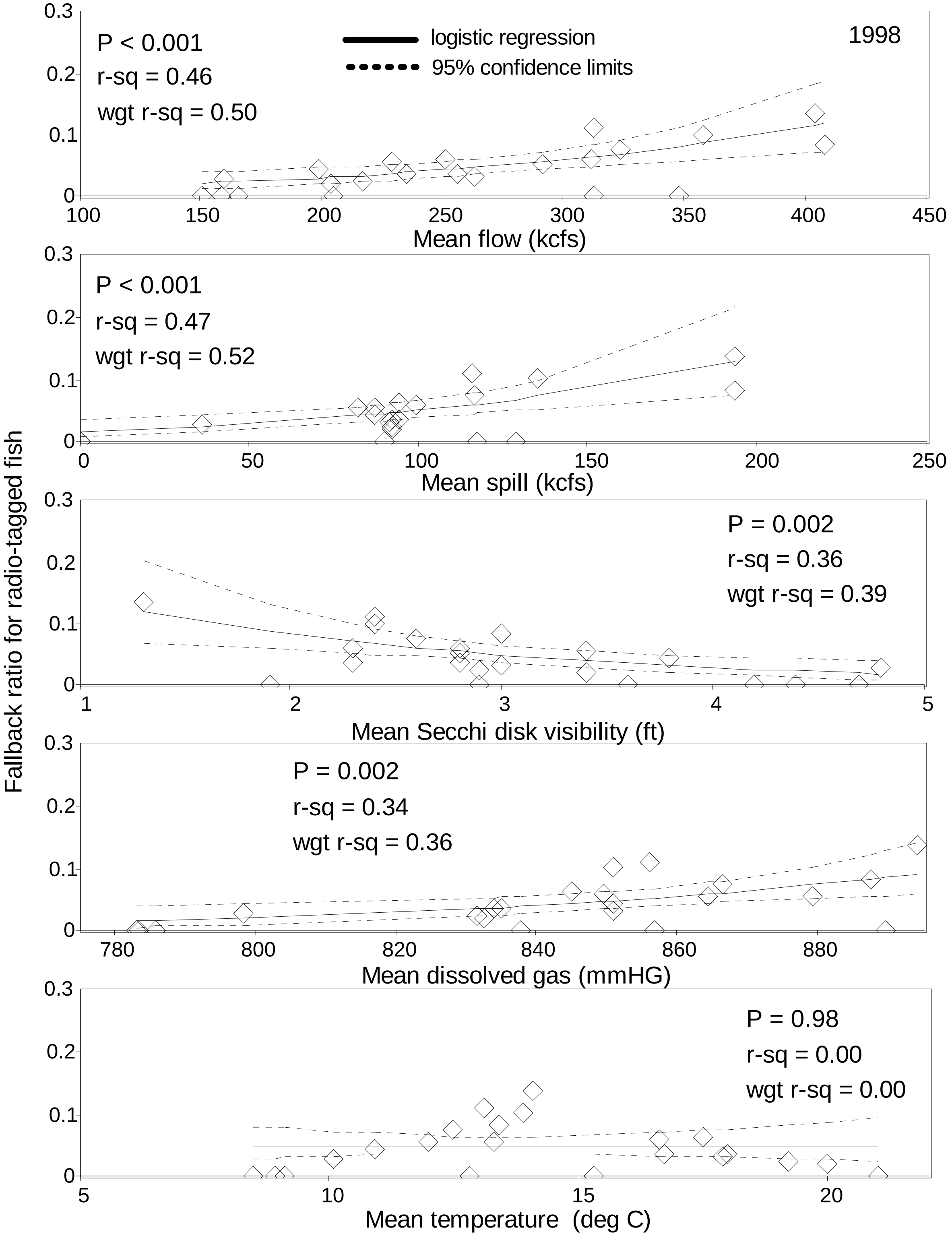

Figure 34. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring/summer chinook salmon fallbacks within 24 h at Bonneville Dam in 1998; includes r-sq values for weighted and unweighted linear regression models. All models based on consecutive 5-d blocks.

substantially higher variance). The 25-fish minimum produced 27 to 35 bins, with an average of approximately 31 fish/bin (standard deviation ~ 7 fish) for the three years. We then calculated mean flow, spill, Secchi disk visibility, dissolved gas level, water temperature, and a fallback ratio for each bin, and tested logistic and weighted and unweighted linear regression models for each year. Because there was relatively low variability in the number of fish/bin, weighting had limited impact on results. As with any grouping method, however, some variability and sensitivity was lost among independent variables by taking mean bin values.

We created 27 bins for the 1996 data set, with a mean of 3.5 d/bin (median 3.0 d/bin) (Figure 35). All linear and logistic models had significant positive relationships between fallback ratios and flow, spill, and dissolved gas at $P < 0.005$. Weighted and unweighted linear models had r^2 values between 0.35 and 0.51 for flow and spill, and were 0.28 and 0.31 for dissolved gas (Figure 36). Correlations were negative for Secchi visibility and water temperature, but no models were significant and r^2 values were less than 0.05. Logistic regressions using maximum likelihood methods produced similar trends.

We created 35 bins with a mean of 3.1 d/bin (median 2 d/bin) for 1997 spring/summer chinook salmon data (Figure 35). All linear and logistic models were significant for flow and spill ($P < 0.005$). Correlations for flow and spill were positive, with r^2 values for weighted and unweighted linear models were between 0.24 and 0.28 (Figure 37); with logistic models, the probability of falling back increased with increasing flow or spill. The weighted model and the logistic model for Secchi depth were significant at $P < 0.10$, with fallback ratios increasing with turbidity. No models with dissolved gas levels were significant at $P < 0.10$. Water temperature was negatively correlated with fallback ratio, with an unweighted r^2 value of 0.17 and a weighted value of 0.14. Both models, as well as the logistic model, were significant at $P < 0.05$.

We created 23 bins with a mean of 3.1 d/bin (median 2.5 d/bin) for 1998 spring/summer chinook salmon data (Figure 35). All linear and logistic models for flow, spill, and dissolved gas were significant at $P < 0.005$, with positive correlations and r^2 values between 0.31 and 0.35 flow, spill and dissolved gas (Figure 38). Models for Secchi depth were also significant ($P < 0.01$), with fallback ratios increasing with increasing turbidity. No models were significant for water temperature and fallback ratios.

Fallback ratios for groups based on environmental conditions

In a fifth approach, we grouped fish by daily flow and spill conditions for each year and calculated fallback ratios for each group. Only fallbacks within 24 h of passage were used, and as with the 5-d blocking method, groups based on flow or spill had unequal numbers of fish. With this method, fish from different portions of the run were pooled together, raising statistical concerns when applying results to the run at large. We believe, however, that it was a viable method for comparing fallback rates for radio-tagged fish at specific spill and flow conditions given the lack of uniformly distributed conditions during the chinook salmon migrations.

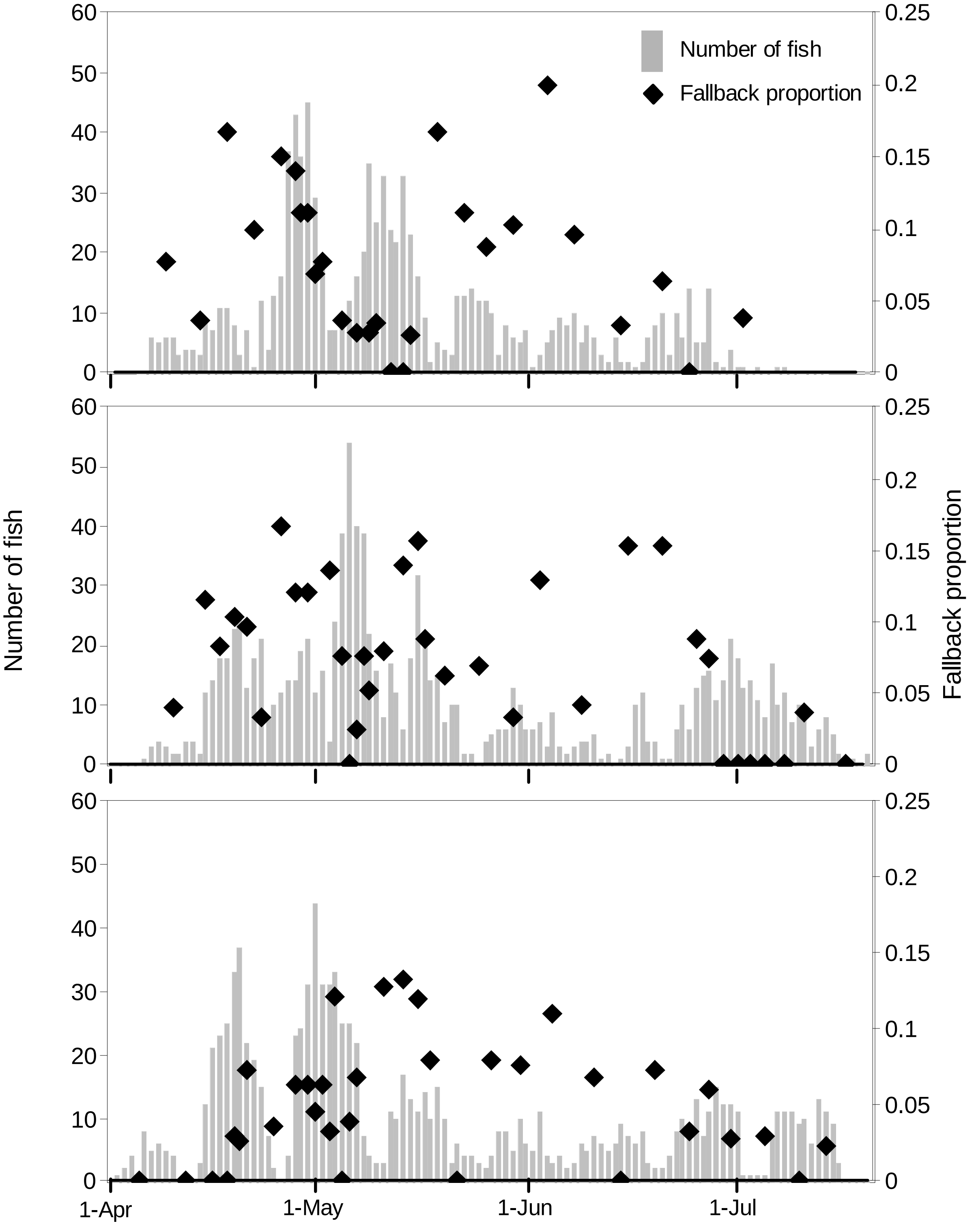

Figure 35. Daily number of radio-tagged spring/summer chinook salmon that passed Bonneville Dam, and the proportion of salmon in consecutive bins of at least 25 fish that fell back within 24 h of passage in 1996, 1997, and 1998.

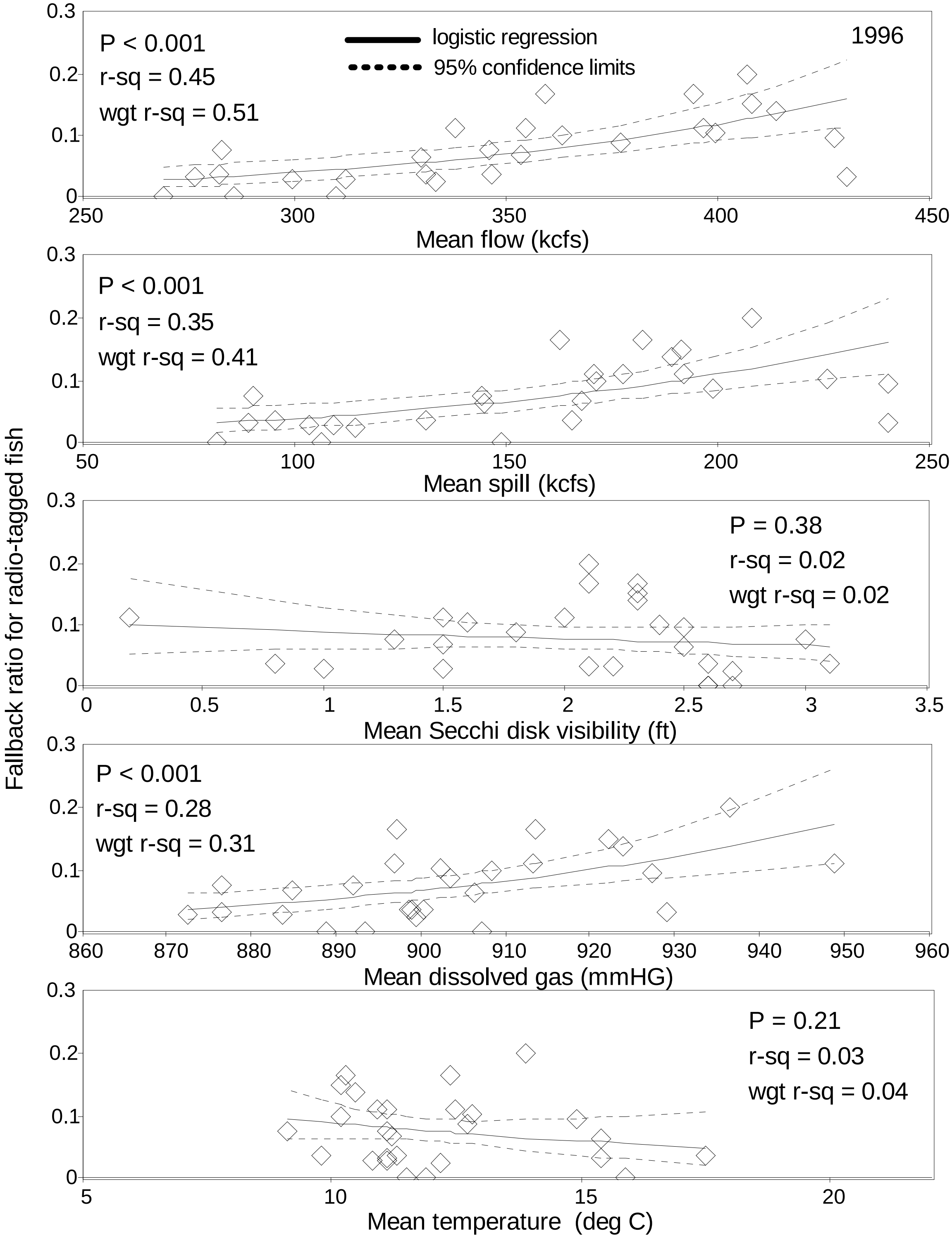

Figure 36. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring/summer chinook salmon fallbacks within 24 h at Bonneville Dam in 1996; includes r-sq values for weighted and unweighted linear regression models. All models based on variable-width time bins that included at least 25 fish.

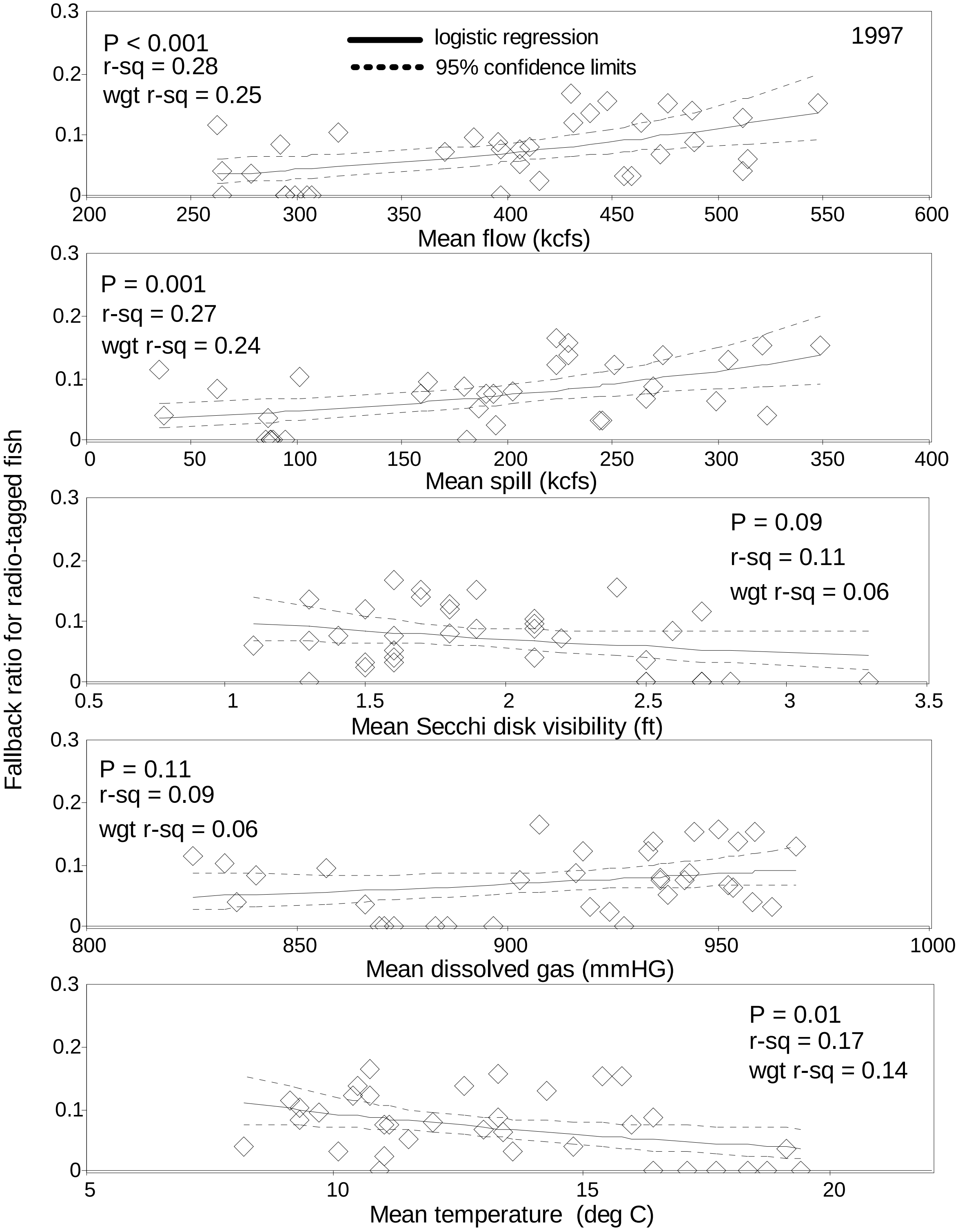

Figure 37. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring/summer chinook salmon fallbacks within 24 h at Bonneville Dam in 1997; includes r-sq values for weighted and unweighted linear regression models. All models based on variable-width time bins that included at least 25 fish.

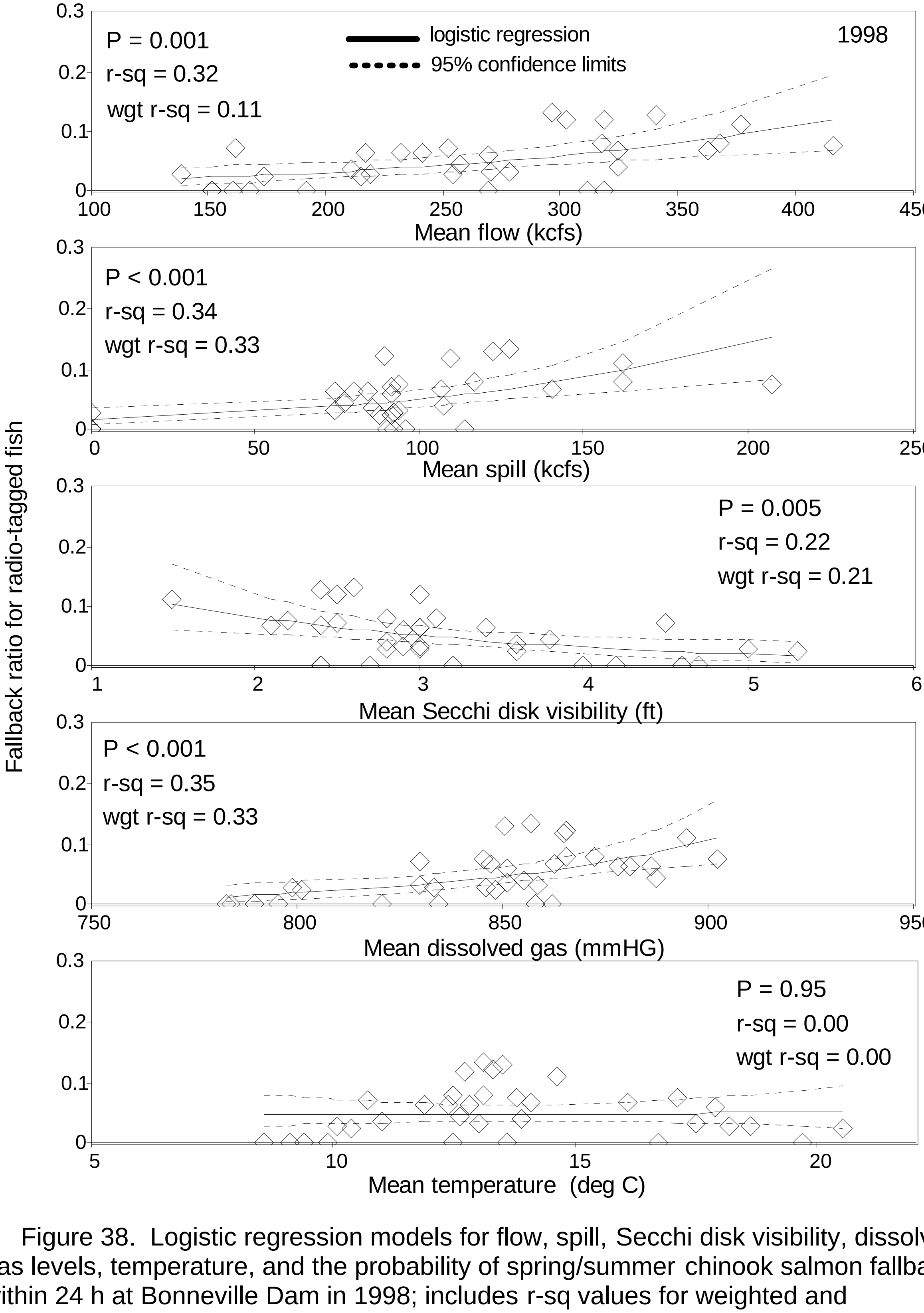

Figure 38. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of spring/summer chinook salmon fallbacks within 24 h at Bonneville Dam in 1998; includes r-sq values for weighted and unweighted linear regression models. All models based on variable-width time bins that included at least 25 fish.

In 1996, flow at Bonneville Dam during the passage of radio-tagged spring and summer chinook salmon ranged from approximately 240 kcfs to 460 kcfs. We grouped chinook salmon based on mean daily flow increments of 10 kcfs. The 22 groups had a mean of 42 chinook salmon per group (median of 41). For the 193 passages of the dam during flows less than 300 kcfs, four radio-tagged chinook salmon fell back for an aggregate fallback ratio of 0.021 (Table 9).

Fifty-two percent of the 928 passages of chinook salmon at Bonneville Dam in 1996 occurred at flows less than 350 kcfs, for which the aggregated fallback ratio was 0.041. Fallback ratios did not exceed 0.10 for any groups with flow less than 350 kcfs. Of all passages by radio- tagged chinook salmon at Bonneville Dam, 443 (48%) occurred at flows greater than 350 kcfs. In 7 of 11 blocks with flow greater than 350 kcfs, fallback ratios exceeded 0.10 (Table 9). The aggregated fallback ratio for all passage when flows were 350 kcfs or more was 0.117, 2.9 times the ratio for passage when flows were less than 350 kcfs. Weighted and unweighted linear models and logistic models were significant ($P < 0.01$), with $r^2 = 0.30$ for the unweighted model and 0.55 for the weighted model.

In 1997, flow at Bonneville Dam during the passage of radio-tagged spring and summer chinook salmon ranged from about 210 kcfs to more than 550 kcfs. We grouped chinook salmon based on mean daily flow increments of 10 kcfs. The 30 groups with fish had a mean of 38 chinook salmon per group (median of 33). Fifty-two percent of 1,126 passages of salmon at Bonneville Dam occurred at flows less than 410 kcfs, for which the aggregated fallback ratio was 0.053. Of all passages by radio-tagged chinook at Bonneville Dam, 541 (48%) occurred at flows greater than 410 kcfs. In 8 of 14 blocks with flow greater than 410 kcfs, fallback ratios were 0.10 or greater (Table 9). The aggregated fallback ratio for all passages when flows exceeded 410 kcfs or more was 0.098, 1.8 times the ratio for passage when flows were less than 350 kcfs. The weighted linear model and logistic model were significant ($P < 0.005$), with higher fallback ratios at higher flow. The r^2 value was 0.27 for the weighted model. An unweighted linear model was not significant ($r^2 = 0.13$; $P = 0.053$).

In 1998, flow at Bonneville Dam during the passage of radio-tagged spring and summer chinook salmon ranged from approximately 130 kcfs to 420 kcfs. We grouped chinook salmon based on mean daily flow increments of 10 kcfs. The 28 groups had a mean of 38 chinook salmon per group (median of 35). Of 276 passages of salmon at the dam during flows less than 200 kcfs, 6 (2.2%) radio-tagged chinook salmon fell back (Table 9). Fifty percent of 1,060 passages of Bonneville Dam occurred at flows less than 250 kcfs, for which the aggregated fallback ratio was 0.036 (3.6%). Fallback ratios did not exceed 0.10 (10%) for any groups with flow less than 250 kcfs. Of all passages by radio-tagged chinook salmon at Bonneville Dam, 533 (50%) occurred at flows greater than 250 kcfs. In 6 of 16 blocks with flow greater than 350 kcfs, fallback ratios were 0.10 or greater (Table 9). The aggregated fallback ratio for all passage when flows were 250 kcfs or more was 0.064 (6.4%), about double the ratio for passage when flows were less than 250 kcfs. All models were significant ($P < 0.01$) for flow and fallback ratio in 1998. The r^2 values were 0.25 for the unweighted linear model and 0.34 for the weighted model.

Table 9. Recorded passages (past dam), fallbacks within 24 h of dam passage (24 h FB), and fallback ratios (FB/ recorded passages) by flow increments for spring/summer chinook salmon at Bonneville Dam in 1996, 1997, and 1998.

	1996			1997			1998		
Flow	Past dam	24 h FB	FB ratio	Past dam	24 h FB	FB ratio	Past dam	24 h FB	FB ratio
130-139							34	1	0.03
140-149							31	0	0.00
150-159							19	0	0.00
160-169							102	3	0.03
170-179							45	1	0.02
180-189							20	0	0.00
190-199							25	1	0.04
200-209							21	1	0.05
210-219				4	0	0.00	48	2	0.04
220-229				--	--	--	61	3	0.05
230-239				--	--	--	50	2	0.04
240-249	6	0	0.00	2	0	0.00	71	5	0.07
250-259	6	0	0.00	27	0	0.00	71	2	0.03
260-269	62	1	0.02	19	1	0.05	59	5	0.08
270-279	31	1	0.03	35	4	0.11	39	1	0.03
280-289	68	3	0.03	72	2	0.03	9	0	0.00
290-299	20	0	0.00	51	1	0.02	13	0	0.00
300-309	42	2	0.05	39	0	0.00	60	6	0.10
310-319	43	1	0.02	39	2	0.05	63	6	0.10
320-329	57	2	0.04	37	3	0.08	85	2	0.02
330-339	90	6	0.07	--	--	--	9	0	0.00
340-349	60	5	0.08	13	1	0.08	19	1	0.05
350-359	69	6	0.09	--	--	--	2	0	0.00
360-369	40	5	0.13	11	0	0.00	36	4	0.11
370-379	43	5	0.12	29	2	0.07	11	0	0.00
380-389	17	0	0.00	8	2	0.25	--	--	--
390-399	63	7	0.11	108	6	0.06	4	1	0.25
400-409	37	7	0.19	91	7	0.08	8	1	0.13
410-419	132	15	0.11	84	5	0.06	45	5	0.11
420-429	18	5	0.28	30	5	0.17			
430-439	5	0	0.00	31	3	0.10			
440-449	10	2	0.20	70	9	0.13			
450-459	9	0	0.00	52	2	0.04			
460-469				70	9	0.13			
470-479				43	5	0.12			
480-489				--	--	--			
490-499				21	2	0.10			
500-509				56	4	0.07			
510-519				41	4	0.10			
520-529				5	0	0.00			
530-539				19	4	0.21			
540-549				13	1	0.08			
>550				6	0	0.00			

* lines indicate midpoint of passage counts for radio-tagged chinook salmon.

In the three years, fallback ratios for groups based on spill increased with increasing spill. Linear models were highly significant ($P < 0.005$) for 1996 and 1998 data, and less so ($P < 0.05$) for 1997 data; logistic models for all years were significant at $P < 0.005$. Unweighted linear models had r^2 values of 0.53, 0.13, and 0.34 in 1996, 1997, and 1998; weighted r^2 values were 0.54, 0.19, and 0.63, respectively.

In 1996, spill at Bonneville Dam during the passage of radio-tagged spring and summer chinook salmon ranged from about 50 kcfs to 260 kcfs. Using 10-kcfs increments, we formed 22 groups with a mean of 44 fish per group (median of 29). As with flow at Bonneville Dam, we observed an increase in fallback ratios with increased spill (Table 10). For 99 passages by chinook salmon when spill was less than 90 kcfs, only one fallback event was recorded and the aggregated fallback ratio was 0.011. For 423 (46%) passages that occurred at spills of less than 160 kcfs the aggregated fallback ratio was 0.036. The remaining 505 passages (54%) occurred at spills greater than 160 kcfs and the aggregated fallback ratio was 0.113. For 158 passages that occurred at spills greater than 200 kcfs the fallback ratio was 0.127.

In 1997, spill at Bonneville Dam during the passage of radio-tagged spring and summer chinook salmon ranged from 0 to about 400 kcfs. Using 10-kcfs increments, 31 groups were formed with a mean of 36 fish per group (median of 18). As with flow at Bonneville Dam, we observed an increase in fallback ratios with increased spill (Table 10). For 263 passages by chinook salmon when spill was less than 100 kcfs, 8 fallback events were recorded and the aggregated fallback ratio was 0.030. For 617 (55% of total) passages that occurred at spills less than 200 kcfs the aggregated fallback ratio was 0.049. The remaining 509 passages (45%) occurred at spills greater than 200 kcfs and the aggregated fallback ratio was 0.106.

In 1998, spill at Bonneville Dam during the passage of radio-tagged spring and summer chinook salmon ranged from 0 to 220 kcfs. Using 10-kcfs increments, 14 groups were formed that had a mean of 76 fish per group (median of 35). As with flow at Bonneville Dam, we observed an increase in fallback ratios with increased spill (Table 10). Only one fallback event was recorded for 153 passages by chinook salmon when spill was less than 10 kcfs, and the aggregated fallback ratio was 0.007. For 472 (45%) passages that occurred at spill of less than 90 kcfs the aggregated fallback ratio was 0.036. The remaining 588 (55%) passages occurred at spills greater than 90 kcfs and the aggregated fallback ratio was 0.061. For 68 passages that occurred at spills greater than 150 kcfs the fallback ratio was 0.103.

We did not analyze relationships between turbidity, dissolved gas levels, or temperature and fallback ratios using the grouping method.

T-Tests and logistic regressions of binary data (fallback vs. no fallback)

For each year, we also created a binary data set that included every passage of Bonneville Dam by spring/summer chinook salmon with transmitters. Fish that fell back within 24 h of passage received a 1 and fish that did not fall back within 24 h received a 0.

Table 10. Recorded passages (past dam), fallbacks within 24 h of dam passage (24 h FB), and fallback ratios (FB/recorded passages) by spill volume for spring and summer chinook salmon at Bonneville Dam in 1996, 1997, and 1998.

	1996			1997			1998		
Spill	Past dam	24 h FB	FB ratio	Past dam	24 h FB	FB ratio	Past dam	24 h FB	FB ratio
0-9				4	0	0.00	153	1	0.01
10-19				2	0	0.00	--	--	--
20-29				12	0	0.00	--	--	--
30-39				3	0	0.00	--	--	--
40-49	6	0	0.00	25	4	0.16	--	--	--
50-59	5	0	0.00	23	2	0.09	--	--	--
60-69	--	--	--	18	1	0.06	--	--	--
70-79	6	0	0.00	--	--	--	106	5	0.05
80-89	82	1	0.01	168	1	0.01	213	11	0.05
90-99	31	2	0.06	8	0	0.00	284	10	0.04
100-109	136	5	0.04	62	5	0.08	110	9	0.08
110-119	15	1	0.07	--	--	--	36	2	0.06
120-129	41	0	0.00	13	1	0.08	49	4	0.08
130-139	29	2	0.07	--	--	--	22	2	0.09
140-149	46	2	0.04	11	0	0.00	19	2	0.11
150-159	26	2	0.08	13	0	0.00	4	0	0.00
160-169	83	6	0.07	16	2	0.13	7	0	0.00
170-179	113	12	0.11	8	2	0.25	--	--	--
180-189	86	14	0.16	85	3	0.04	12	2	0.17
190-199	65	5	0.08	146	9	0.06	--	--	--
200-209	28	3	0.11	70	8	0.11	34	3	0.09
210-219	50	7	0.14	--	--	--	11	2	0.18
220-229	16	4	0.25	58	11	0.19			
230-239	22	2	0.09	75	4	0.05			
240-249	22	1	0.05	75	8	0.11			
250-259	20	3	0.15	68	7	0.10			
260-269				--	--	--			
270-279				14	2	0.14			
280-289				39	4	0.10			
290-299				12	0	0.00			
300-309				27	1	0.04			
310-319				8	0	0.00			
320-329				20	4	0.20			
330-339				21	3	0.14			
340-349				12	1	0.08			
>350				10	1	0.10			

* lines indicate midpoint of passage counts for radio-tagged chinook salmon.

We then tested whether fish that fell back passed the dam under significantly different environmental conditions than those that did not fall back, using both standard t-tests to show general comparisons (data pooled for all passages) and logistic regression to show fallback probabilities and confidence intervals.

In 1996, there were 928 known passages up over the dam by 810 chinook salmon at Bonneville Dam. Following passage, 72 fish fell back within 24 h of passing and 856 did not. Mean flows and spills were significantly higher ($P < 0.001$) when salmon fell back at the dam than when fish passed the dam that did not fall back (Table 11). Mean flow when fish

Table 11. Number of chinook salmon (CK), sockeye salmon (SK), and steelhead (SH) that either did or did not fall back within 24 h of passing Bonneville Dam and mean daily flow, spill, Secchi dish visibility, dissolved gas level, and water temperature on the date of the passages in 1996, 1997, and 1998.

Year Species	Number	%	Mean total flow	Mean total spill	Mean Secchi depth	Mean dissolved gas	Mean water temp
1996 CK (928 passages)							
FB in 24 h	72	7.8	376**	180**	2.0	911**	11.7
did not FB	856	92.2	347**	154**	2.0	903**	12.0
1997 CK (1,126 passages)							
FB in 24 h	84	7.5	424**	213**	1.8*	921	12.2*
did not FB	1,042	92.5	397**	185**	1.9*	913	13.0*
1998 CK (1,047 passages)							
FB in 24 h	53	5.0	286**	112**	3.0*	860**	13.7
did not FB	1,007	95.0	253**	87**	3.3*	846**	13.7
1997 SK (636 passages)							
FB in 24 h	66	10.4	351	150	2.5	900	17.0
did not FB	570	89.6	343	142	2.5	895	17.3
1997 SK (623 passages through 30 July)							
FB in 24 h	61	9.8	364	154	2.3*	904*	16.7**
did not FB	562	90.2	346	143	2.5*	896*	17.2**
1996 SH (743 passages; 688 used for temperature)							
FB in 24 h	26	3.5	243**	110**	4.6**	n/a	19.3*
did not FB	717	96.5	184**	58**	5.5**	n/a	20.0*
1997 SH (985 passages)							
FB in 24 h	67	6.8	224*	110**	4.5	857**	21.3**
did not FB	918	93.2	202*	59**	4.6	820**	20.5**

* P < 0.05; ** P < 0.005 using standard t-test

fell back was 376 kcfs; for fish that did not fall back, mean flow was 347 kcfs when they passed the dam. Mean spill when fish fell back was 180 kcfs; for fish that did not fall back, mean spill was 154 kcfs. Mean Secchi disk depth visibility and water temperature were not significantly different between the two groups. Mean dissolved gas levels were significantly higher (P < 0.005) when fish fell back (911 mmHg) than when fish passed the dam that did not fall back (903 mmHg) (Table 11).

In 1997, there were 1,126 known passages over the dam by 950 spring/summer chinook salmon at Bonneville Dam. Following passage, 84 fell back within 24 h and 1,042 did not. Mean flows and spills were significantly higher (P < 0.003) at the time the fallback salmon passed the dam than when fish passed the dam that did not fall back (Table 11). Mean flow when fish fell back was 424 kcfs; for fish that did not fall back, mean flow was 397 kcfs when they passed the dam. Mean spill when fish fell back was 213 kcfs; for fish that did not fall back, mean spill was 185 kcfs. Differences in mean Secchi disk depth visibility were about 0.1 ft, a difference that was significant at $P < 0.05$. Dissolved gas levels were not significantly different for the two groups of fish (Table 11). Mean water temperature was about 1° C higher for fish that did not fall back, a difference that was significant at $P < 0.05$.

In 1998, there were 1,060 known passages via the fishways by 932 chinook salmon at Bonneville Dam. Following passage, 53 fell back within 24 h and 1,007 did not. Mean flows and spills were significantly higher ($P < 0.002$) at the time when salmon fell back at the dam than when fish passed the dam that did not fall back (Table 11). Mean flow when fish fell back was 286 kcfs; for fish that did not fall back, mean flow was 253 kcfs. Mean spill when fish fell back was 112 kcfs; for fish that did not fall back, mean spill was 87 kcfs. Mean Secchi disk depth visibility was significantly lower ($P < 0.01$) when fish fell back (3.0 ft) than when fish that did not fall back passed the dam (3.3 ft). Mean dissolved gas levels were significantly higher ($P < 0.005$) when fish fell back (860 mmHg) than when fish that did not fall back passed the dam (846 mmHg) (Table 11). We found no significant differences in water temperatures for the two groups.

Logistic regression models that used the full binary data sets produced similar significant results. The probability of falling back within 5 d of passage increased significantly with flow and spill ($P < 0.005$) in all years. Logistic models were significant at $P = 0.05$ for water temperature in 1997, (fallback ratios decreased as temperature increased), for Secchi disk visibility in 1997 and 1998, (fallback ratios increased with turbidity), and for dissolved gas in 1996 and 1998 (fallback ratios increased with dissolved gas levels).

Effects of Environmental Factors on Sockeye Salmon Fallbacks - 1997

The first comparison we made for sockeye salmon was that of daily fallback events by fish with transmitters divided by the total count of sockeye salmon passing through the fishways. If radio-tagged sockeye salmon were representative of the overall run, then such a ratio would be a measure of the proportion of fish that fell back each day and could be related to environmental variables. There was no significant increase in the fallback proportion when flow and spill increased ($r^2 < 0.06$, Figure 39). We included all fallback events in this analysis, although a few fish may have migrated upriver to tributary sites or other dams before they returned to Bonneville Dam and fell back. When we limited the analysis to fallbacks that occurred within 24 h of exit from the top of a fishway, trends were similar but r^2 values were slightly lower.

We also calculated daily fallback/daily passage ratios for only radio-tagged sockeye salmon. With this method, fallback ratios on individual days ranged widely (up to 1.0), particularly on days when few radio-tagged fish passed the dam but one or more fell back. To moderate the ratio variability problem, we calculated daily fallback ratios using the moving 5-d moving average number of fallback events and the moving average number of sockeye salmon with transmitters recorded at the tops of fishways over the same 5 d. We did

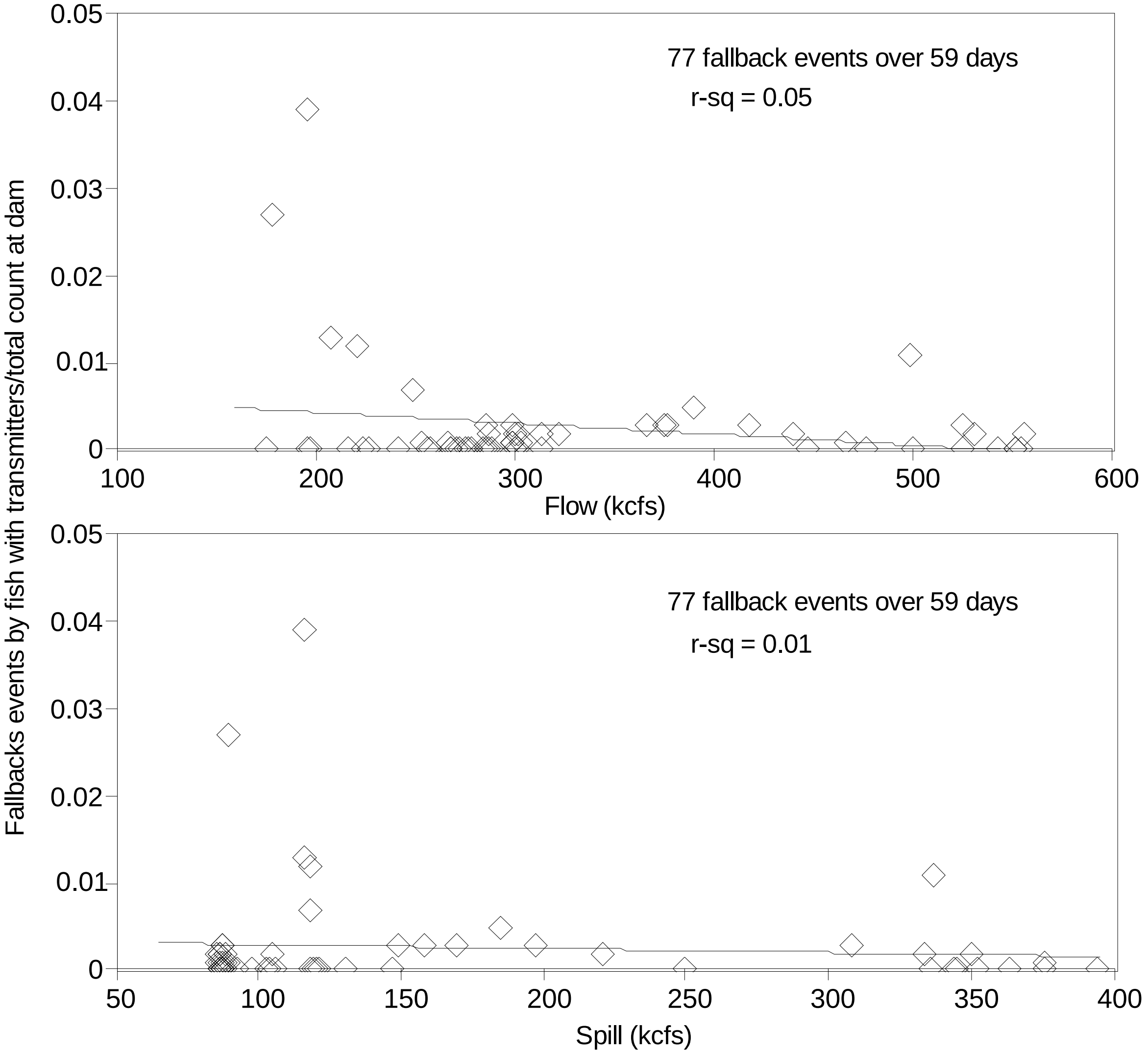

Figure 39. Regressions of ratio (fb_n/c_n) of sockeye salmon with transmitters that fell back (fb_n) to the number counted (c_n) passing through the fishways at Bonneville Dam versus daily flow and spill in 1997.

not include fallback events that occurred more than 24 h after a fish exited from the top of a fishway in the analysis because some fish had migrated upriver, and we believe environmental conditions at the time of passage were not the primary reason they fell back at Bonneville Dam.

In 1997, 66 sockeye salmon with transmitters fell back within 24 h of passage at Bonneville Dam. Using only these fallback events, the highest ratios of 5-day mean fallback events to 5-day mean passage occurred during late July and early August (Figure 40). During that period at the end of the sockeye salmon migration, 6 fallback events were recorded for radio-tagged sockeye salmon (3 for one fish) and only 27 passages of salmon with transmitters were recorded at the dam. Correlations

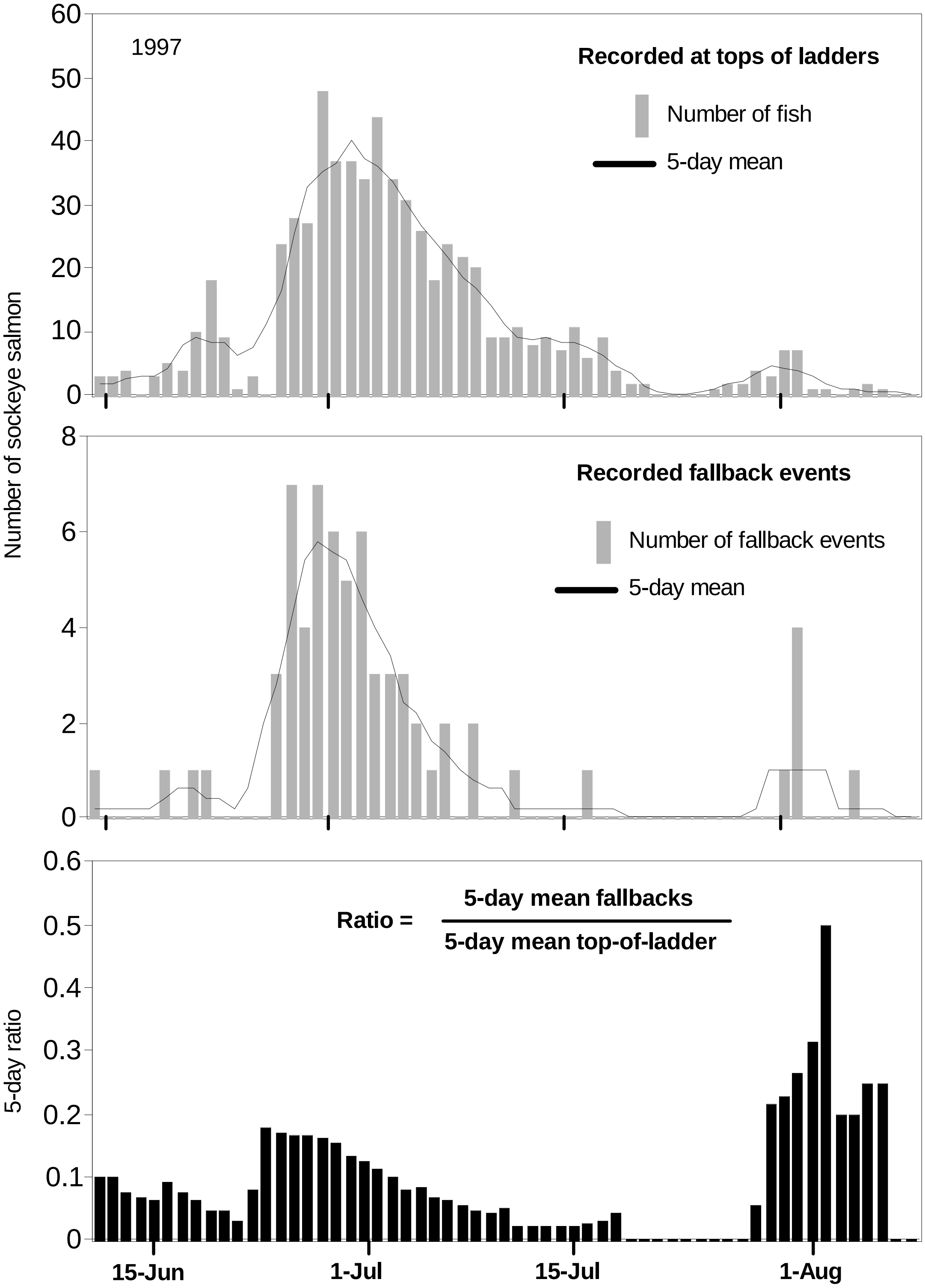

Figure 40. Daily number and 5-d moving average of recorded passages at tops of the fishways at Bonneville Dam, daily number and 5-d mean fallbacks within 24 h of passage, and the daily 5-d moving average fallback ratios for sockeye salmon with transmitters in 1997.

for sockeye salmon were distorted by the group of fallback events at the end of the migration period when flow, spill, and dissolved gas levels were low and Secchi disk depth visibility and water temperature were high. With all data included, ratio values were negatively correlated with daily flow, spill, and dissolved gas, and positively correlated with Secchi disk visibility and water temperature between 11 Jun and 8 August, the period when all radio-tagged sockeye salmon passed Bonneville Dam in 1997 (Figure 41), the opposite of results for spring/summer chinook salmon. When we excluded the last 12 days of passage (27 passages and 6 fallback events), fallback ratios were positively correlated with flow, spill, and dissolved gas levels and negatively correlated with Secchi disk visibility and water temperature (Figure 42). The r^2 values for flow and spill were ~0.19 and ~0.10, and values were ~0.32 for Secchi disk visibility and ~0.52 for water temperature. We note, however, that r^2 values reported for moving average ratios should only be viewed as indicative of general trends, as autocorrelation and variance errors can be created by moving average techniques.

We also used passage of sockeye salmon with transmitters and fallbacks within 24 h of passing Bonneville Dam, but grouped data in consecutive 5-day blocks and calculated fallback ratios and mean values for the independent variables for each block. With this method, each fallback event affected only the ratio for the block in which it occurred. As with spring/summer chinook salmon, consecutive 5-day blocks for sockeye salmon had dissimilar numbers of fish in each block and we ran analyses on the five possible sequences over the date range that radio-tagged sockeye salmon were passing Bonneville Dam. Sequences started on consecutive days, and each had 9 blocks. We present results for a sequence that we believe was representative. Due to several fallbacks at the end of the migration (including 3 by one fish) while few sockeye were passing the dam, we used data through 30 July only, excluding 13 passages (2% of all passages).

Explanatory power for the 5-d block method was limited by the number of blocks (9) and high variability in the number of fish per block (from 13 to 183; std = 57 fish). No weighted or unweighted linear models were significant for fallback ratios and flow, spill, or dissolved gas levels. The weighted model for Secchi depth was significant at $P = 0.07$ ($r^2 \sim 0.39$), with fallback ratios increasing with increasing turbidity. Water temperature was negatively correlated with fallback ratio with $P < 0.10$ ($r^2 = 0.35$) for the unweighted linear model and $r^2 = 0.54$ for the weighted model. Logistic regressions using maximum likelihood methods, weighting both the number of passages and the number of fallbacks, produced more significant models. The univariate logistic models for flow and dissolved gas were significant at $P = 0.06$ for flow and $P = 0.04$ for dissolved gas, with the probability of falling back increasing with flow and gas levels. Logistic models with water temperature and Secchi depth were significant ($P < 0.01$), with the probability of falling back increasing with turbidity and decreasing with increasing water temperature.

In another method, we grouped passage by sockeye salmon during

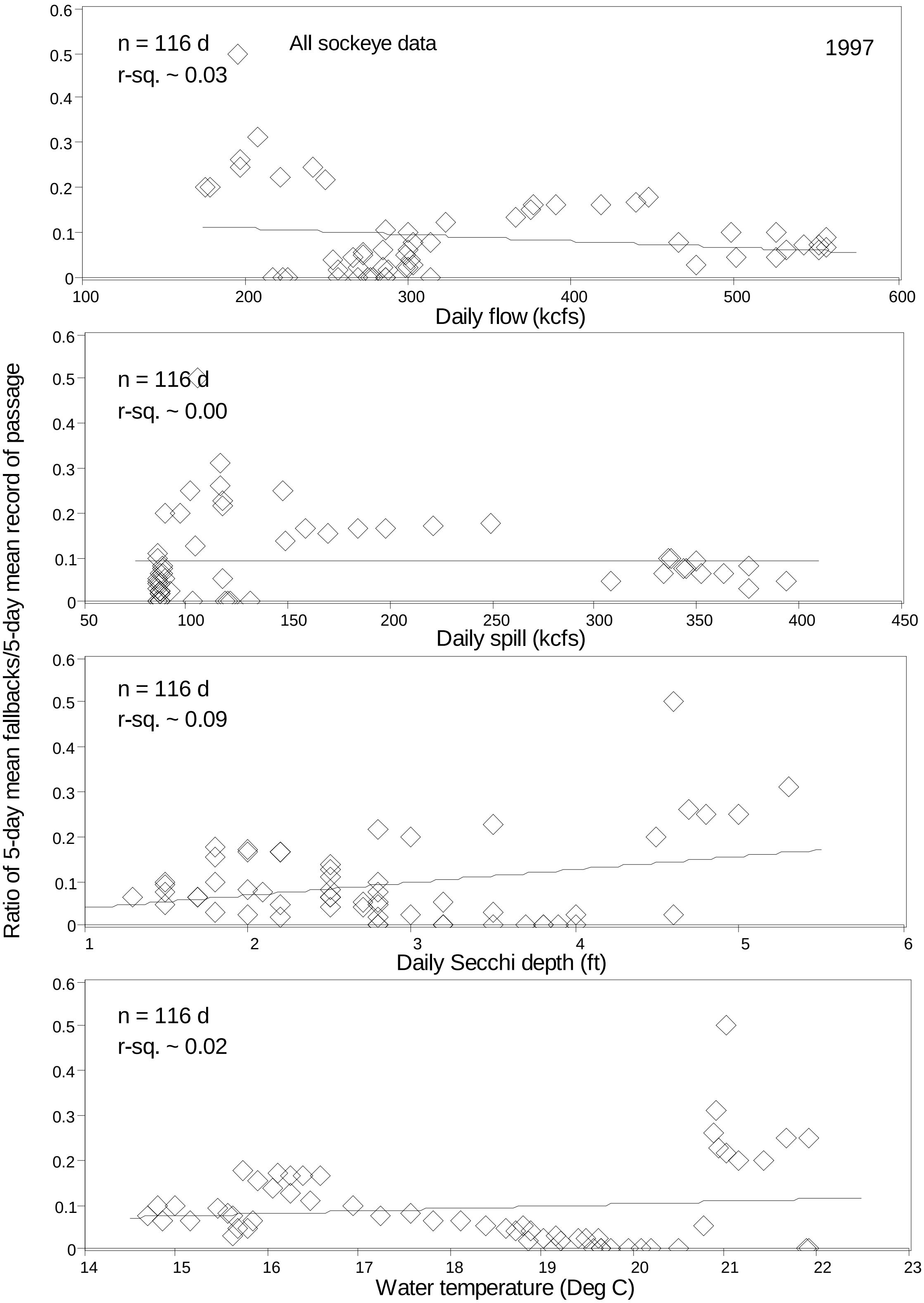

Figure 41. Regressions of daily mean flow, spill, Secchi disk visibility, and water temperature in the forebay with 5-d moving average fallback ratios for all sockeye salmon with transmitters at Bonneville Dam, 1997. Approximate r-sq values.

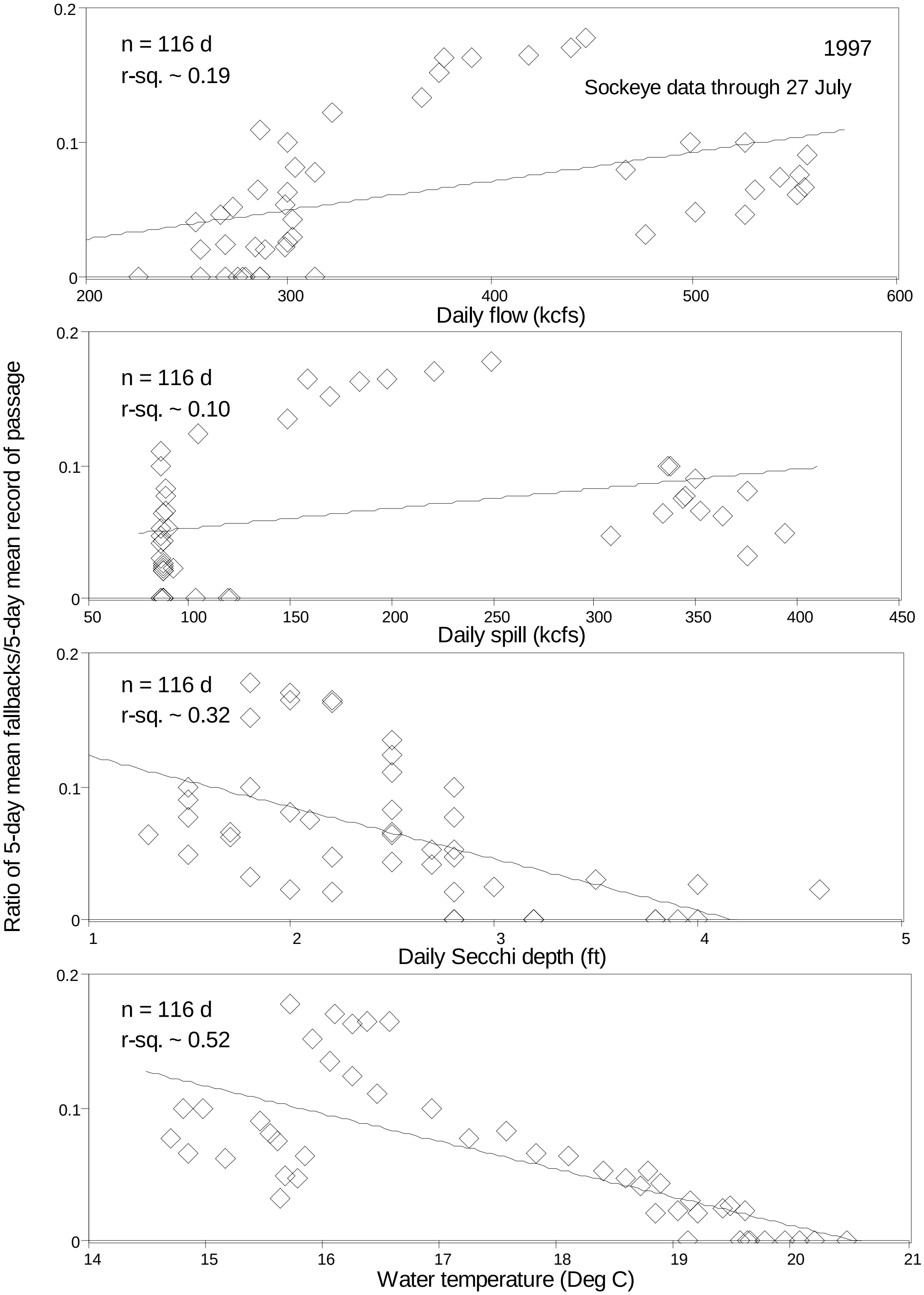

Figure 42. Regressions of daily mean flow, spill, Secchi disk visibility, and water temperature in the forebay with 5-d moving average fallback ratios for sockeye salmon with transmitters at Bonneville Dam through 27 July, 1997. Approximate r-sq values.

consecutive days until at least 25 fish with transmitters had passed the dam. Data through 26 July was included, excluding 29 passages at the end of the migration (5% of all passages). This produced 18 bins, with a mean of 34 fish/bin (median of 33 fish; std = 7). We then calculated mean flow, spill, Secchi disk visibility, water temperature, and a fallback ratio for each bin, and tested logistic, weighted and unweighted linear regression models. Because there was relatively low variability in the number of fish/bin, weighting had limited impact on results. As with any grouping method, some variability and sensitivity was lost among independent variables by taking mean values for each bin.

Results for the 25-fish bin method were similar to those for the consecutive 5-d block method, but there was less variability within blocks and models were probably more appropriate. No linear models with flow, spill, or dissolved gas were significant at $P < 0.05$ (Figure 43). Logistic models were positively correlated with flow, spill, and dissolved gas levels, but only the model for dissolved gas was significant ($P = 0.04$). All models for Secchi depth visibility were significant ($P < 0.05$), with fallback ratios increasing with increasing turbidity; r^2 values were about 0.25 for the linear models. Water temperature was negatively correlated with fallback ratio for all linear and logistic models with $P < 0.01$. The r^2 values with temperature were 0.36 for the unweighted linear model and 0.39 for the weighted model.

As with spring/summer chinook salmon, we grouped sockeye salmon by daily flow and spill conditions for each year and calculated fallback ratios for each group. Only fallbacks within 24 h of passage were used, and groups based on flow or spill had unequal numbers of fish in each group. With this method, fish from different portions of the run were pooled together, raising statistical concerns when applying results to the run at large. We believe, however, that it was a viable method for comparing fallback rates at specific spill and flow conditions given the lack of uniformly distributed conditions during the 1997 sockeye salmon migration.

In 1997, flow at Bonneville Dam during the passage of radio-tagged sockeye salmon ranged from about 170 kcfs to more than 550 kcfs through 30 July. We grouped sockeye salmon based on mean daily flow increments of 10 kcfs. Through 30 July, 23 groups (Table 12) had a mean of 27 sockeye salmon per group (median of 21). Fifty-two percent of 623 recorded passages of sockeye salmon at Bonneville Dam occurred at flows less than 320 kcfs, for which the aggregated fallback ratio was 0.058. Of 623 passages by radio-tagged sockeye salmon at Bonneville Dam, 298 (48%) occurred at flows greater than 320 kcfs. The aggregated fallback ratio for all passages when flows were 320 kcfs or more was 0.141, more than double the ratio for passage when flows were less than 320 kcfs. Although there was a weak positive correlation between fallback ratios and total flow, weighted and unweighted linear regression models of groups based on flow were not significant at $P < 0.05$.

Spill at Bonneville Dam during the passage of radio-tagged sockeye salmon in 1997 ranged from about 80 to 400 kcfs through 30 July. Using 10-kcfs increments, 18 groups were formed that

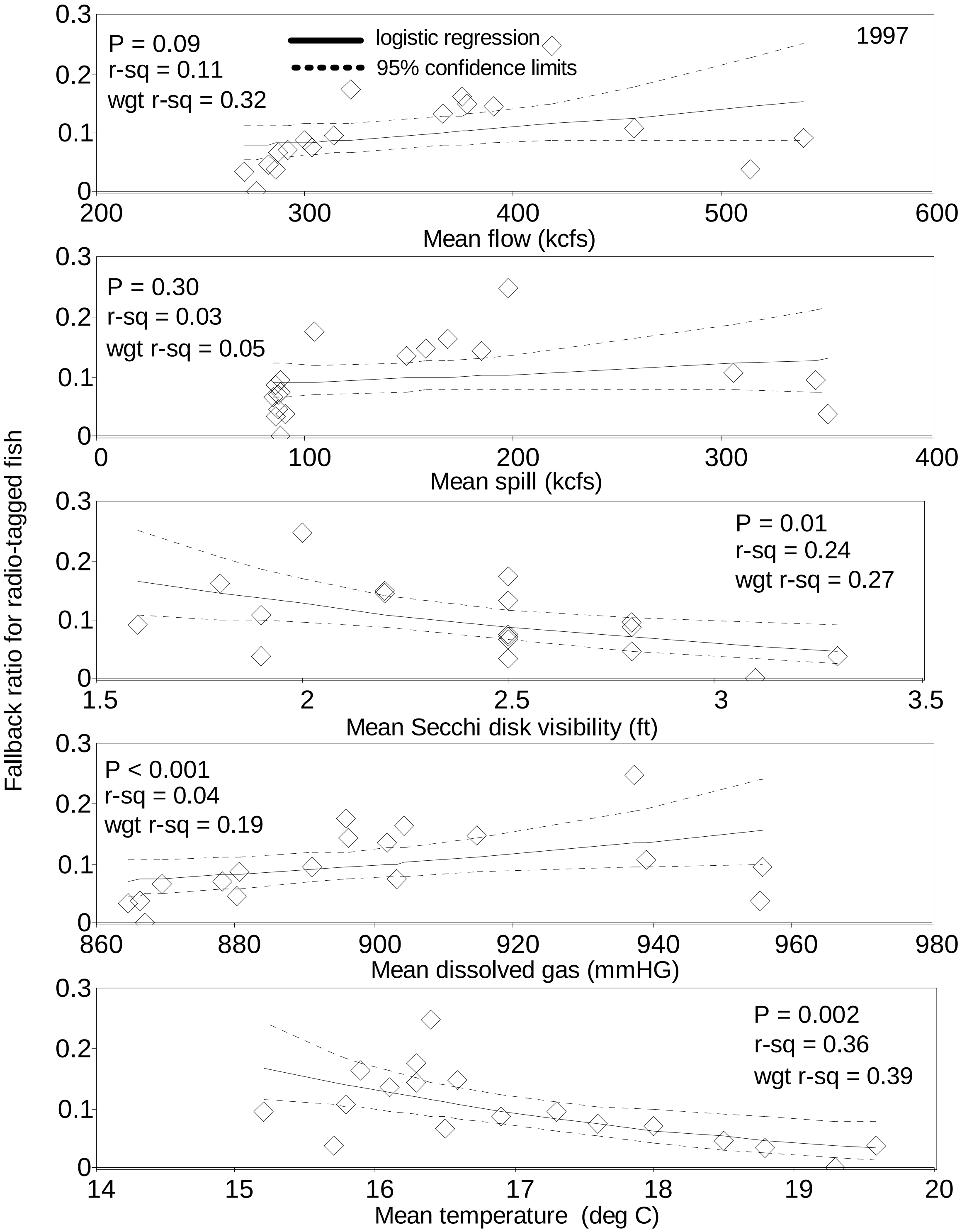

Figure 43. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of sockeye salmon fallbacks within 24 h at Bonneville Dam in 1997; includes r-sq values for weighted and unweighted linear regression models. All models based on variable-width time bins that included at least 25 fish.

Table 12. Recorded passages (past dam), fallbacks within 24 h of passage of the dam (24 h FB), and fallback ratios (FB/recorded passages) by flow and spill at Bonneville Dam for sockeye salmon (SK) through 30 July, 1997.

Sockeye vs flow			
Flow groups (kcfs)	Past dam	24 h FB	FB ratio
170-179	--	--	--
180-189	--	--	--
190-199	--	--	--
200-209	--	--	--
210-219	--	--	--
220-229	9	1	0.11
230-239	--	--	--
240-249	3	0	0.00
250-259	20	0	0.00
260-269	28	2	0.07
270-279	15	0	0.00
280-289	84	5	0.06
290-299	54	2	0.04
300-309	79	6	0.08
310-319	33	3	0.09
320-329	34	6	0.18
330-339	--	--	--
340-349	--	--	--
350-359	--	--	--
360-369	37	5	0.14
370-379	64	10	0.16
380-389	--	--	--
390-399	48	7	0.15
400-409	--	--	--
410-419	28	7	0.25
420-429	--	--	--
430-439	24	3	0.13
440-449	--	--	--
450-459	--	--	--
460-469	3	0	0.00
470-479	1	0	0.00
480-489	--	--	--
490-499	3	1	0.33
500-509	9	0	0.00
510-519	--	--	--
520-529	21	1	0.05
530-539	10	1	0.10
540-549	4	0	0.00
>550	12	1	0.08

Sockeye vs spill			
Spill groups (kcfs)	Past dam	24 h FB	FB ratio
80-89	295	18	0.06
90-99	11	0	0.00
100-109	35	6	0.17
110-119	16	1	0.06
120-129	2	0	0.00
130-139	--	--	--
140-149	37	5	0.14
150-159	27	4	0.15
160-169	37	6	0.16
170-179	--	--	--
180-189	48	7	0.15
190-199	28	7	0.25
200-209	--	--	--
210-219	--	--	--
220-229	24	3	0.13
230-239	--	--	--
240-249	--	--	--
250-259	--	--	--
260-269	--	--	--
270-279	--	--	--
280-289	--	--	--
290-299	--	--	--
300-309	18	1	0.06
310-319	--	--	--
320-329	--	--	--
330-339	16	2	0.13
340-349	8	0	0.00
350-359	5	1	0.20
360-369	3	0	0.00
370-379	4	0	0.00
380-389	--	--	--
390-399	9	0	0.00

* lines indicate midpoint of passage counts for radio-tagged sockeye salmon.

had a mean of 35 fish per group (median of 17). As with flow at Bonneville Dam, we observed an increase in fallback ratios with increased spill (Table 12). For 306 (49%) passages by sockeye salmon when spill was less than 100 kcfs, 18 fallback events were recorded and the aggregated fallback ratio was 0.059. For 317 (51%) passages that occurred at spill of more than 100 kcfs the aggregated fallback ratio was 0.136 (Table 12). As with flow, however, weighted and unweighted linear regression models of groups based on spill were not significant at $P < 0.05$.

We did not analyze relationships between turbidity, dissolved gas levels, water temperature and sockeye salmon fallback ratios using the grouping method.

We also created a binary data set that included every passage of Bonneville Dam by sockeye salmon with transmitters in 1997. Fish that fell back within 24 h of passage received a 1 and fish that did not fall back within 24 h received a 0. We then tested whether fish that fell back passed the dam under significantly different environmental conditions than those that did not fall back. There were 636 known passages by 562 radio-tagged sockeye salmon at Bonneville Dam in 1997. Following passage, 66 fell back within 24 h and 570 did not. We used standard t-tests to show general comparisons (data was pooled for all passages) and logistic regression to show fallback probabilities. Using the entire sockeye salmon dataset, we found that environmental conditions when fish passed the dam were not significantly different for fish that fell back than for fish that did not fall back (Table 11). When we only used data through 30 July, there were 623 recorded passages and 61 sockeye salmon fell back within 24 h of passage. With the truncated data set, turbidity and dissolved gas levels were significantly lower for fish that did not fallback ($P < 0.05$), and water temperatures were significantly higher ($P < 0.005$) for fish that did not fall back (Table 11). Logistic regression models of the binary data produced similar results.

Effects of Environmental Factors on Steelhead Fallbacks - 1996 and 1997

We limited the 1996 steelhead fallback analyses related to environmental conditions primarily because relatively few steelhead fell back in 1996. In addition, more than one-third of the 1996 run passed Bonneville Dam during the period of no spill that began on 1 September. We also stopped radio-tagging steelhead for almost 2 weeks in late July/early August when river temperatures exceeded 21 C, creating discontinuity in sampling and data collection.

As with chinook and sockeye salmon, we calculated daily fallback ratios using the 5-d moving average number of fallback events over 5 days and the number of steelhead with transmitters recorded at the tops of fishways over the same 5 days. Fallback events that occurred more than 24 h after a fish exited from the top of a fishway were not included in the analysis. We present this information to give a qualitative view of fallbacks at Bonneville Dam by steelhead tagged in 1996.

In 1996, 26 steelhead with transmitters fell back within 24 h of passage at Bonneville Dam. Using only these fallback events and passage of steelhead with transmitters over the dam, the highest 5-d moving average fallback ratios occurred during a week in late June/early July (Figure 44). Mean daily spill decreased from a mean of 171 kcfs during the second half of June to about 90 kcfs by early July and was held there for juvenile passage until 1 September. Steelhead fallback ratios were as high in early July after spill decreased to < 100 kcfs as in June when spill volumes were higher. There were no steelhead fallbacks within 24 h during the latter half of July, partly because of the period of no tagging, and none after 1 September when there was no spill.

Despite data gaps, we ran standard t-tests comparing environmental conditions at the time of passage for fish that did or did not fall back within 24 h. These tests show general relationships only and P values should be interpreted conservatively. Flow, spill, and turbidity were significantly ($P < 0.005$) lower for fish that did not fall back within 24 h, while temperature was significantly ($P < 0.05$) higher for fish that did not fall back than for those that did (Table 11).

We outfitted more steelhead with transmitters in 1997 than in 1996, and a larger number fell back within 24 h of passing Bonneville Dam. We also had fewer gaps in steelhead data in 1997. And, although spill was terminated on 1 September, we did a more complete suite of analyses relating fallback rates to environmental conditions than in 1996. All analyses used data through 31 October, by when approximately 99% of the radio-tagged fish had passed the dam.

We first calculated daily fallback/daily passage ratios for radio-tagged steelhead. With this method, fallback ratios on individual days ranged widely (up to 0.5), particularly on days when few radio-tagged fish passed the dam but one or more fell back, and many days had zero fallbacks within 24 h. To moderate the ratio variability problem, we calculated daily fallback ratios using the 5-d moving average number of fallback events and the moving average number of steelhead with transmitters recorded at the tops of fishways over the same 5 days. Fallback events that occurred more than 24 h after a fish exited from the top of a fishway were not included in the analysis because some fish had migrated upriver, and we believe environmental conditions at the time of passage were not the primary reason they fell back at Bonneville Dam.

In 1997, 67 steelhead with transmitters fell back within 24 h of passage at Bonneville Dam. Using only these fallback events, the highest ratios of 5-day mean fallback events to 5-day mean passage occurred during the first and third weeks of August (Figure 45). Ratio values were positively correlated with daily flow, spill, dissolved gas, and temperature with r^2 values of approximately 0.05, 0.26, 0.26, and 0.18, respectively (Figure 46). Ratio values were negatively correlated with Secchi disk visibility with an r^2 of 0.03. We note, however, that r^2 values reported for moving average ratios should only be viewed as indicative of general trends, as autocorrelation and variance errors can be created by moving average techniques.

We also used passage of steelhead with transmitters and fallbacks within 24 h of passing Bonneville Dam, but grouped data in consecutive 5-day blocks and calculated fallback ratios and mean values for the independent variables for each block. With this method, each fallback event affected only the ratio for the block in which it occurred. As with chinook and sockeye salmon, consecutive 5-day blocks for steelhead had dissimilar numbers of fish in each block and we ran analyses on the five possible sequences over the date range that radio-tagged steelhead were passing Bonneville Dam. Sequences started on consecutive days and each had 26 blocks. We present results for a sequence that we believe was representative.

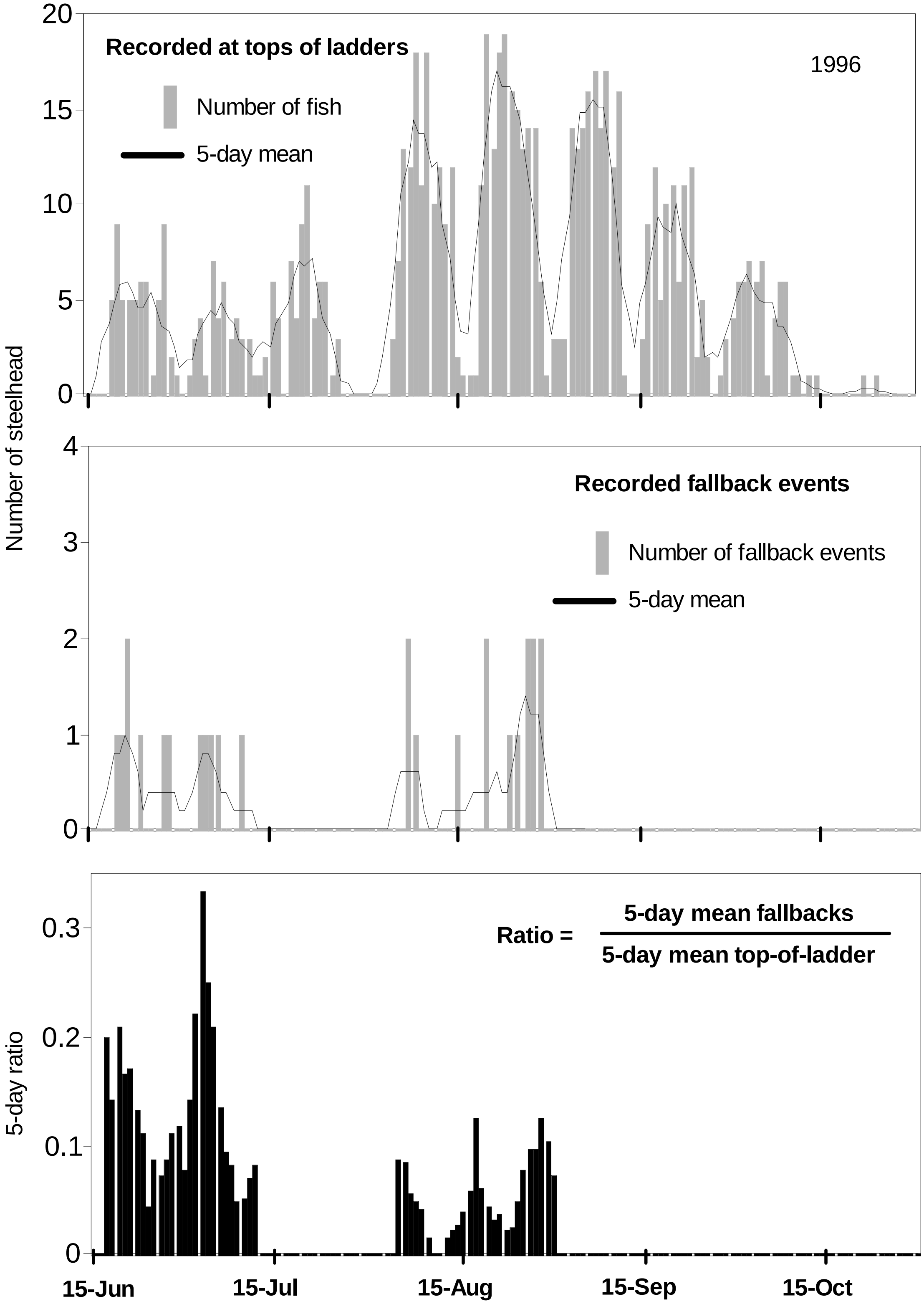

Figure 44. Daily number and 5-d moving average of recorded passages at tops of the fishways at Bonneville Dam, daily number and 5-d mean fallbacks within 24 h of passage, and the daily 5-d moving average fallback ratios for steelhead with transmitters in 1996.

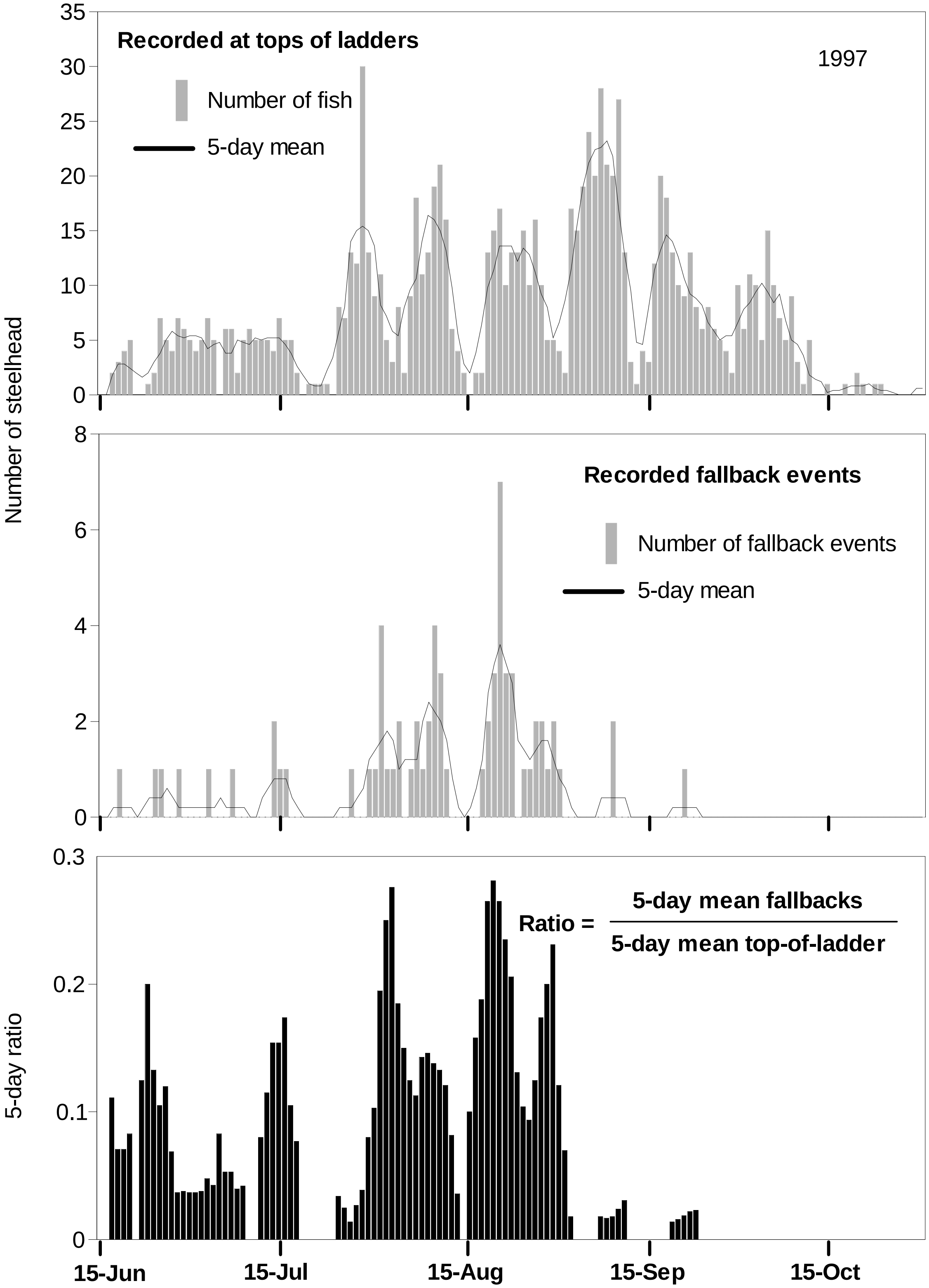

Figure 45. Daily number and 5-d moving average of recorded passages at tops of the fishways at Bonneville Dam, daily number and 5-d mean fallbacks within 24 h of passage, and the daily 5-d moving average fallback ratios for steelhead with transmitters in 1997.

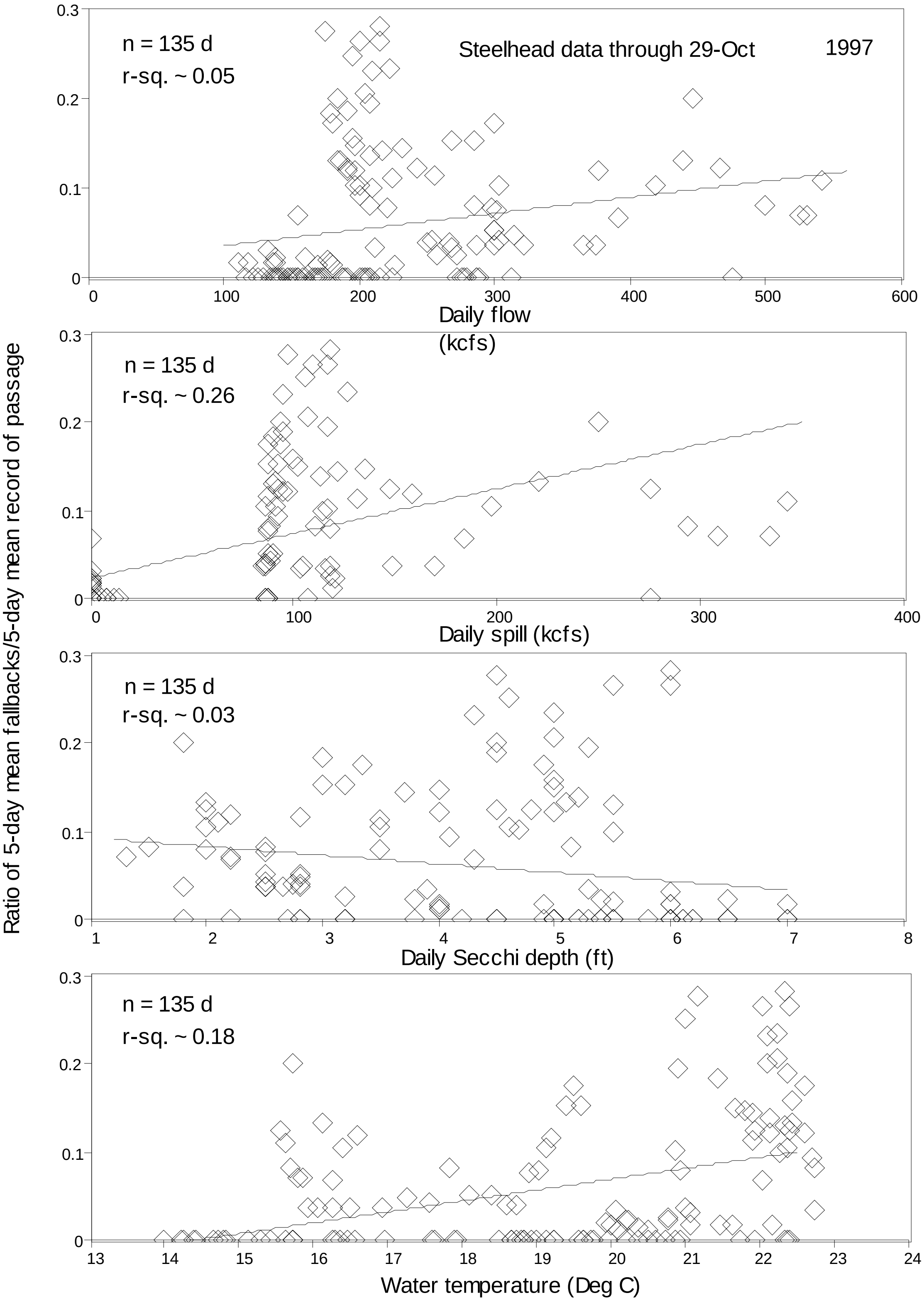

Figure 46. Regressions of daily mean flow, spill, Secchi disk visibility, and dissolved gas levels in the forebay with 5-d moving average fallback ratios for steelhead with transmitters at Bonneville Dam through 29 October, 1997. Approximate r^2 values.

The 26 blocks had a mean of 38 fish/block (median 31 fish/block) and the standard deviation was 26. Weighted and unweighted linear models were all significant ($P < 0.05$) for fallback ratios and spill, dissolved gas, and water temperature. Logistic models using maximum likelihood methods that weighted both the number of passages and the number of fallbacks, had more significant models ($P < 0.001$). Correlations in all cases were positive; linear model r^2 values were between 0.22 and 0.35 for spill and dissolved gas and were 0.15 and 0.17 for water temperature (Figure 47). The logistic model for flow was significant at $P < 0.05$. No models were significant for Secchi disk visibility and fallback ratios.

In another method, we grouped passage by steelhead during consecutive days until at least 25 fish with transmitters had passed the dam. This produced 31 bins, with an mean of 32 fish/bin (median of 30 fish; std = 6). We then calculated mean flow, spill, Secchi disk visibility, water temperature, and a fallback ratio for each bin, and tested logistic, weighted and unweighted linear regression models. Because there was relatively low variability in the number of fish/bin, weighting had limited impact on results. As with any grouping method, some variability and sensitivity was lost among independent variables by taking mean values for each bin.

Results for the 25-fish bin method were similar to those for the consecutive 5-d block method. Weighted and unweighted linear models were significant ($P < 0.05$) for fallback ratios and spill, dissolved gas, and water temperature. In all cases correlations were positive, and r^2 values were between 0.30 and 0.37 for spill and dissolved gas, and were about 0.13 for water temperature. Logistic models produced more significant results ($P < 0.001$) for spill, dissolved gas, and water temperature. No linear models were significant for Secchi disk visibility or flow, but a logistic model was significant for flow at $P < 0.05$, with the probability of falling back increasing with increasing flow.

We also created a binary data set that included every passage of Bonneville Dam by steelhead with transmitters through 31 October, 1997. Fish that fell back within 24 h of passage received a 1 and fish that did not fall back within 24 h received a 0. We then tested whether fish that fell back passed the dam under significantly different environmental conditions than those that did not fall back. There were 985 known passages by 916 steelhead at Bonneville Dam through 31 October, 1997. Following passage, 67 fell back within 24 h and 918 did not. We used standard t-tests to show general comparisons (data was pooled for all passages) and logistic regression to show fallback probabilities. We found spill, dissolved gas levels, and water temperature were significantly lower ($P < 0.005$) for fish that did not fall back (Table 11). The termination of spill on 1 September probably influenced these three relationships. Flow was also significantly lower ($P < 0.05$) for steelhead that did not fall back, which may also have been related to no-spill conditions after 1 September. Logistic models of the binary data produced similar results.

Effects of Environmental Factors on Fall Chinook Salmon Fallbacks - 1998

We did not analyze relationships between fallback and environmental conditions for the 1998 fall chinook salmon primarily because relatively few fell back at Bonneville Dam in 1998. In addition, all radio-tagged fish in 1998 passed the Dam during the period of no spill that began on 1 September. Only four of 38 (11%) of the fallbacks recorded for fall chinook salmon occurred within 24 h of passage at the dam, suggesting that environmental conditions at the dam were not the primary reason those fish fell back.

Multiple Regression Analyses: Environmental Variables and Fallback Ratios

We ran stepwise regression models for each year and species using fallback ratio data from the 5-d block and variable-day-bin methods described previously. Although there was considerable covariance among environmental variables related to fallback of salmon at Bonneville Dam, we initially included flow, spill, Secchi disk visibility, dissolved gas levels, and water temperature, a surrogate for passage date, as independent variables in all models.

During the 1996 spring/summer chinook salmon migration, flow and spill were highly correlated ($r > 0.95$), and both flow and spill were positively correlated with dissolved gas levels at $r \sim 0.51$ (Figure 48). Secchi disk visibility was negatively correlated with flow and spill ($r \sim 0.40$), while water temperature had weak positive correlations with dissolved gas and Secchi depth and weak negative correlations with flow and spill (Figure 48). Temperatures had a parabolic relationship with flow and spill: peak flow and spill were coincident with intermediate temperatures, while peak temperatures late in the migration and low temperatures early in the season were associated with lower flow and spill conditions.

With all 1996 variables in the first regression model, and chinook salmon fallback ratios from the 5-Day-Block method as the dependent variable, flow and water temperature were best correlated with fallback ratios in the stepwise procedure with an r^2 value of 0.42 (Table 13). No other variables met the 0.15 significance level for inclusion in the model. When flow was removed from the model, spill replaced flow as the most significant predictor of fallback ratio and the overall r^2 value was similar. Multiple regression models using Variable-Day-Bin fallback ratios also selected flow and water temperature first, with an r^2 value of 0.52 (Table 13). When we removed flow from the model, spill was first selected and dissolved gas was added to the model, but the r^2 value was similar.

During the 1997 spring/summer chinook salmon migration, flow and spill were also highly correlated ($r \sim 0.98$), and both flow and spill were positively correlated with dissolved gas levels at $r > 0.88$ (Figure 49). Secchi disk visibility was negatively correlated with flow, spill, and dissolved gas levels ($r > 0.55$), while water temperature had weak positive correlations with dissolved gas and Secchi depth (Figure 49). Temperatures had a parabolic relationship with flow and spill: peak flow and spill were coincident with intermediate temperatures, while peak temperatures late in the migration and low temperatures early in the season were associated with lower flow and spill conditions.

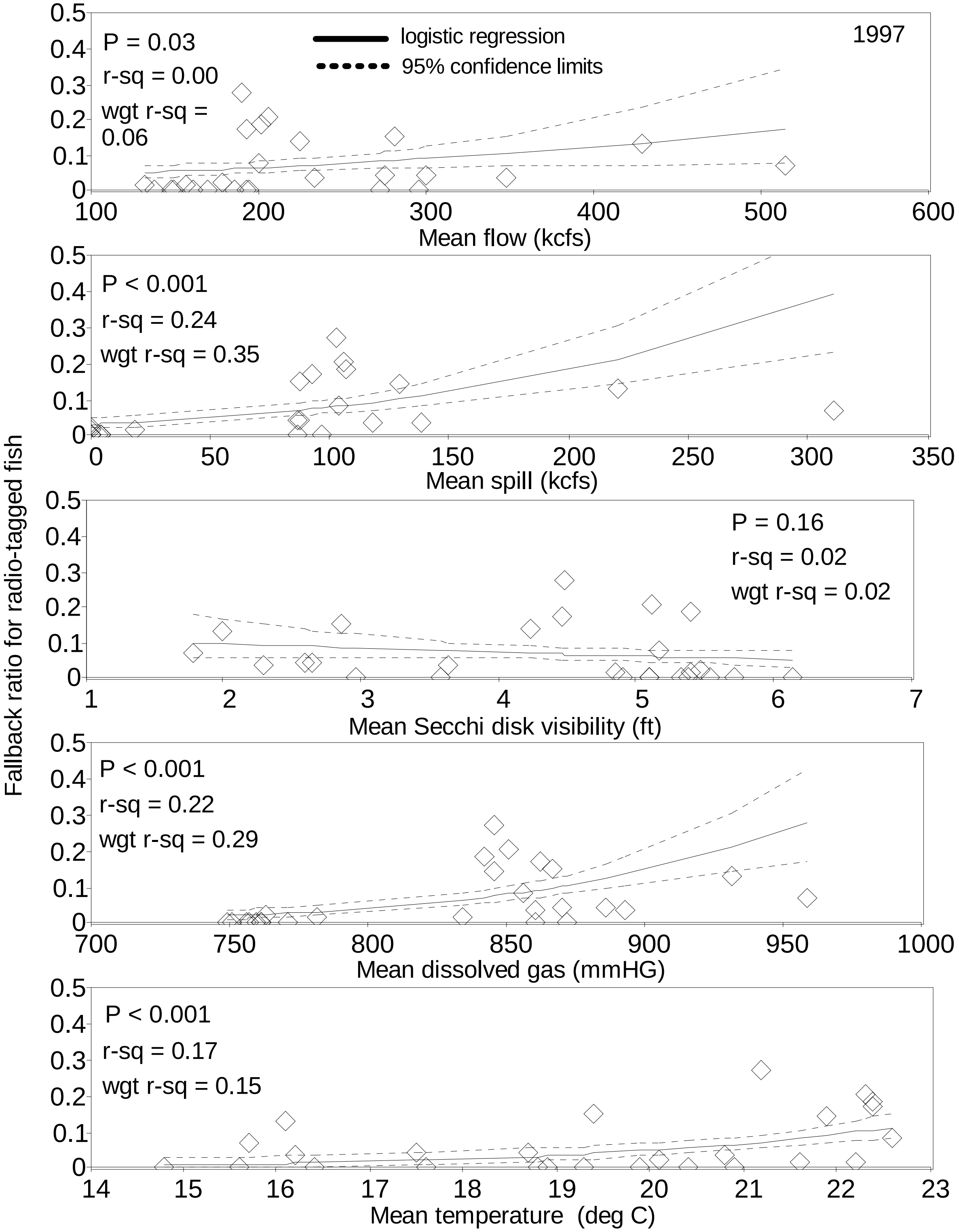

Figure 47. Logistic regression models for flow, spill, Secchi disk visibility, dissolved gas levels, temperature, and the probability of steelhead fallbacks within 24 h at Bonneville Dam in 1997; includes r-sq values for weighted and unweighted linear regression models. All models based on consecutive 5-d blocks.

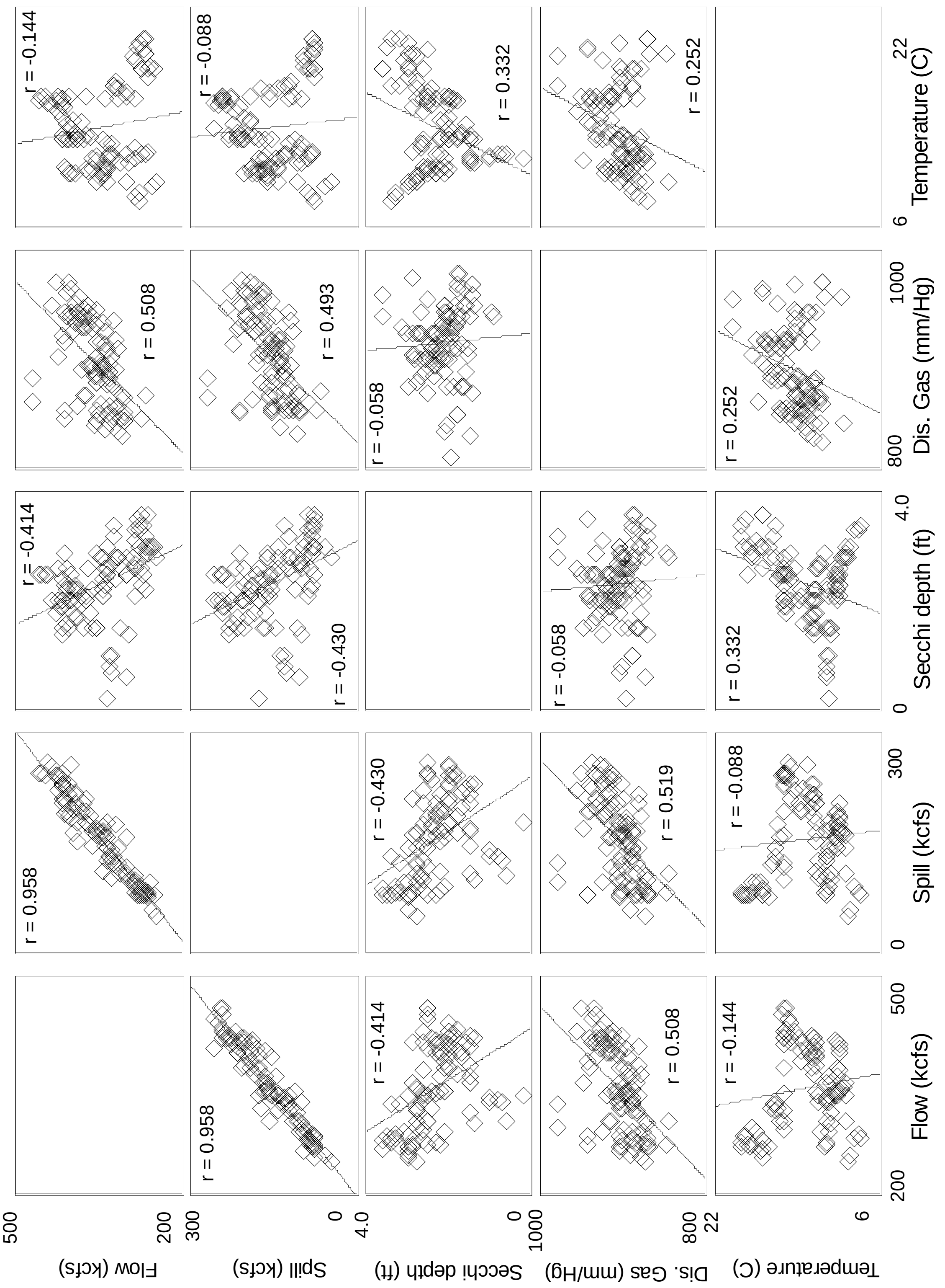

Figure 48. Scatter plots and correlation coefficients for environmental variables used in multiple regression models, based on daily mean values during the spring/summer chinook salmon migration at Bonneville Dam in 1996.

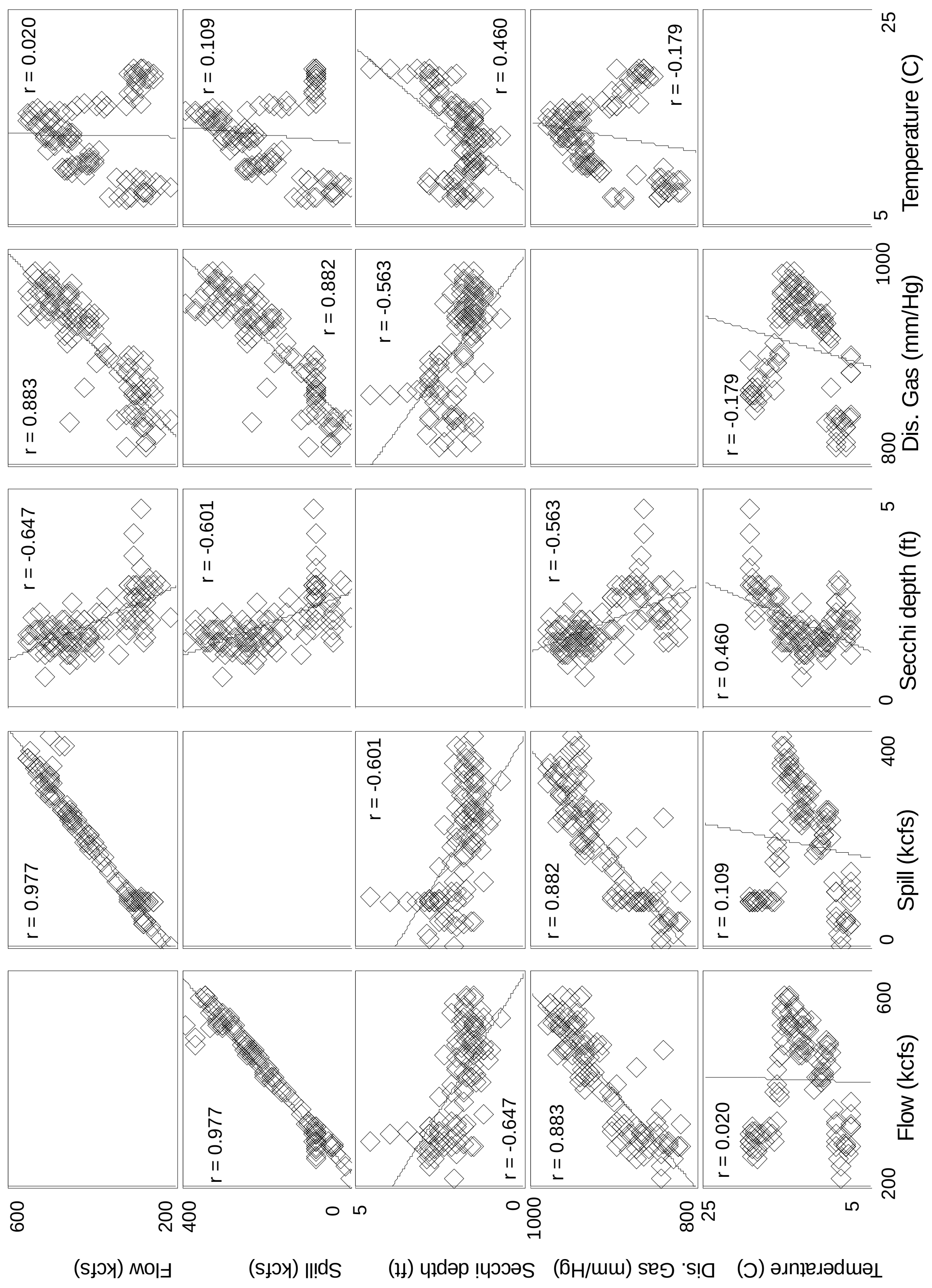

Figure 49. Scatter plots and correlation coefficients for environmental variables used in multiple regression models, based on daily mean values during the spring/summer chinook salmon migration at Bonneville Dam in 1997.

Table 13. Stepwise multiple regression model outputs for 1996 including models run, variables retained, and standard procedure outputs. All models have spring/summer chinook salmon fallback ratios as the dependent variable.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, 5-Day-Block model with all variables included from 7 April to 10 July						
	a. Flow		0.2679	0.2679	6.22	0.0232
	b. Water temperature		0.4205	0.1526	4.21	0.0569
Model 2, 5-Day-Block model with all variables except flow from 7 April to 10 July						
	a. Spill		0.2312	0.2312	5.11	0.0372
	b. Water temperature		0.4138	0.1826	4.98	0.0402
Model 3, Variable-Day-Bin model with all variables included from 7 April to 9 July						
	a. Flow		0.4545	0.4545	20.83	0.0001
	b. Water temperature		0.5163	0.0618	3.07	0.0927
Model 4, Variable-Day-Bin model with all variables except flow from 7 April to 9 July						
	a. Spill		0.3530	0.3530	13.64	0.0011
	b. Water temperature		0.4461	0.0931	4.03	0.0560
	c. Dissolved gas		0.4961	0.0500	2.28	0.1445

With all 1997 variables in the first regression model, and chinook salmon fallback ratios from the 5-Day-Block method as the dependent variable, spill was best correlated with fallback ratios in the stepwise procedure with an r^2 value of 0.33 (Table 14). No other variables met the 0.15 significance level for inclusion in the model. When spill was removed from the model, flow replaced spill as the most significant predictor of fallback ratio and the overall r^2 value was 0.30. Multiple regression models using Variable-Day-Bin fallback ratios first selected flow and dissolved gas for a model r^2 of 0.42. A model without flow selected spill, then water temperature and Secchi depth for an r^2 of 0.57 (Table 14).

During the 1998 spring/summer chinook salmon migration, flow and spill were correlated (r ~ 0.88), though not as strongly as in 1996 or 1997 due to a period of zero spill in early April, 1998. Both flow and spill were positively correlated with dissolved gas levels at r > 0.79 (Figure 50). Secchi disk visibility was negatively correlated with flow, spill, and dissolved gas levels (r > 0.69), while water temperature had a weak positive correlation with dissolved gas and a weak negative correlation with Secchi depth (r ~ 0.46) (Figure 50). Temperatures had a parabolic relationship with flow and spill: peak flow and spill were coincident with intermediate temperatures, while peak temperatures late in the migration and low temperatures early in the season were associated with lower flow and spill conditions.

With all 1998 variables in the first regression model, and chinook salmon fallback ratios from the 5-Day-Block method as the dependent variable, flow was the only variable selected by the stepwise procedure with an r^2 value of

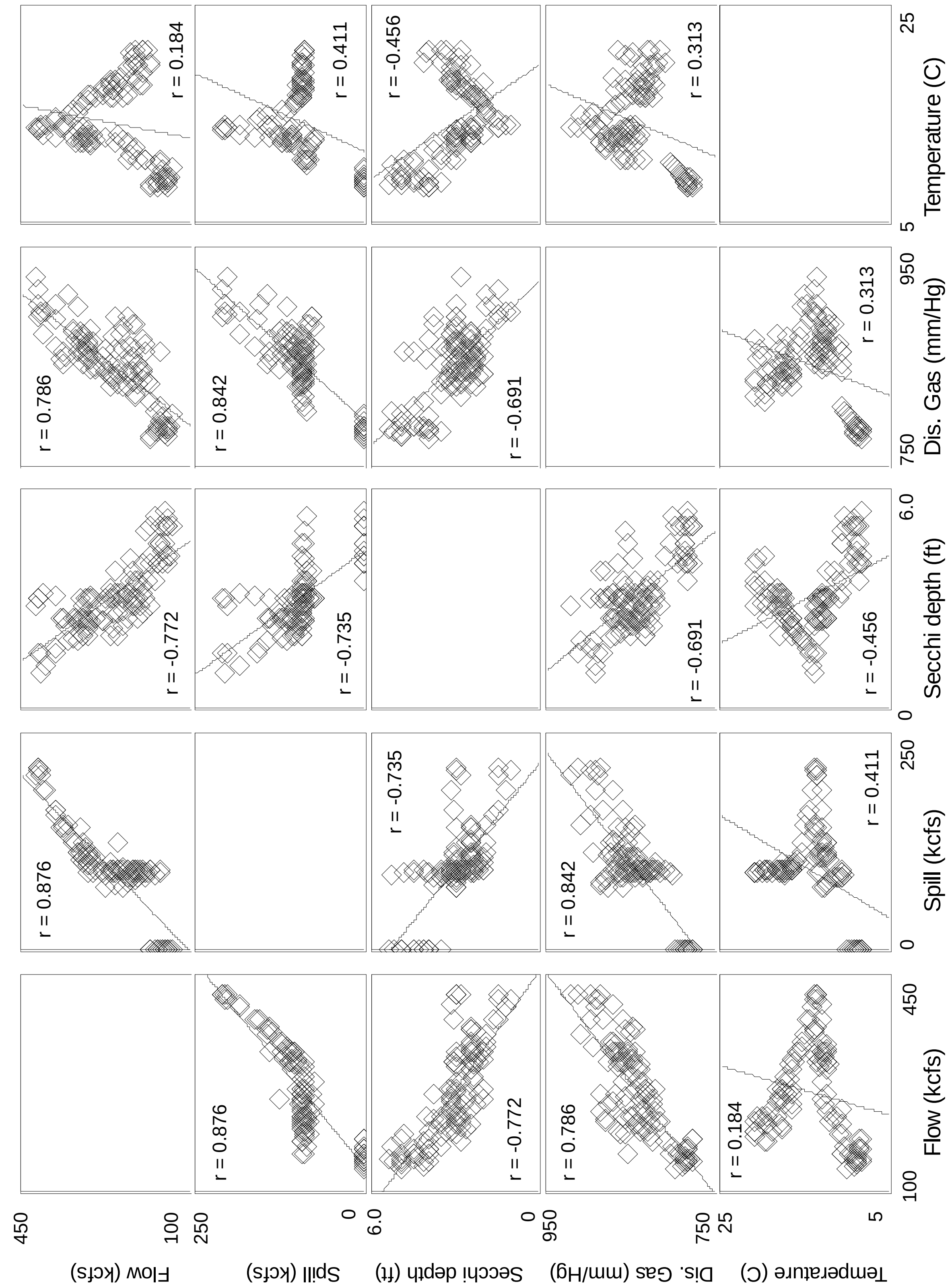

Figure 50. Scatter plots and correlation coefficients for environmental variables used in multiple regression models, based on daily mean values during the spring/summer chinook salmon migration at Bonneville Dam in 1998.

Table 14. Stepwise multiple regression model outputs for 1997 including models run, variables retained, and standard procedure outputs. All models have spring/summer chinook salmon fallback ratios as the dependent variable.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, 5-Day-Block model with all variables included from 6 April to 19 July						
	a. Spill		0.3307	0.3307	9.39	0.0064
Model 2, 5-Day-Block model with all variables except spill from 6 April to 19 July						
	a. Flow		0.2979	0.2979	8.06	0.0105
Model 3, Variable-Day-Bin model with all variables included from 6 April to 21 July						
	a. Flow		0.2812	0.2812	12.91	0.0011
	b. Dissolved gas		0.4163	0.1351	7.41	0.0104
Model 4, Variable-Day-Bin model with all variables except flow from 6 April to 21 July						
	a. Spill		0.2683	0.2683	12.10	0.0014
	b. Water temperature		0.4024	0.1342	7.19	0.0115
	c. Secchi depth		0.5703	0.1678	12.11	0.0015

Table 15. Stepwise multiple regression model outputs for 1998 including models run, variables retained, and standard procedure outputs. All models have chinook salmon fallback ratios as the dependent variable.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, 5-Day-Block model with all variables included from 2 April to 20 July						
	a. Flow		0.4738	0.4738	18.01	0.0004
Model 2, 5-Day-Block model with all variables except flow from 2 April to 20 July						
	a. Spill		0.4623	0.4623	17.20	0.0005
	b. Water temperature		0.5455	0.0832	3.49	0.0777
Model 3, Variable-Day-Bin model with all variables included from 2 April to 17 July						
	a. Dissolved gas		0.3452	0.3452	16.87	0.0003
Model 4, Variable-Day-Bin model with all variables except d. gas from 2 April to 17 July						
	a. Spill		0.3354	0.3354	16.15	0.0003
	b. Water temperature		0.3912	0.0558	2.84	0.1018

0.47 (Table 15). No other variables met the 0.15 significance level for inclusion in the model. When flow was removed from the model, spill replaced flow as the most significant predictor of fallback ratio, and water temperature was also selected for and overall r^2 value of 0.55. Multiple regression models using Variable-Day-Bin fallback ratios first selected dissolved gas, with an r^2 value of 0.35. With gas removed, spill and water temperature were selected with an overall r^2 value of 0.39 (Table 15).

During the 1997 sockeye salmon migration, flow, spill, and dissolved gas levels were all strongly correlated (r > 0.88) (also see Figure 49). Secchi disk

Table 16. Stepwise multiple regression model outputs for 1997 including models run, variables retained, and standard procedure outputs. All models have sockeye salmon fallback ratios as the dependent variable.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, 5-Day-Block model with all variables included from 11 June to 30 July						
	a. Water temperature		0.3522	0.3522	3.81	0.0920
Model 2, 5-Day-Block model with all variables except water temp from 11 June to 30 Jul						
	a. No variables selected					
Model 3, Variable-Day-Bin model with all variables included from 11 June to 26 July						
	a. Water temperature		0.3560	0.3560	8.84	0.0090
	b. Spill		0.4656	0.1096	3.08	0.0998
	c. Flow		0.6364	0.1707	6.57	0.0225
Model 4, Variable-Day-Bin model with all var. except temperature from 11 Jun to 26 Jul						
	a. Secchi depth		0.2448	0.2448	5.19	0.0369
	b. Spill		0.3775	0.1327	3.20	0.0939
	c. Flow		0.6663	0.2889	12.12	0.0037

visibility was negatively correlated with flow and dissolved gas levels (r > 0.77) and spill (r > 0.61), and was positively correlated with water temperature at r ~ 0.85. Because the date range of the sockeye salmon migration was within the chinook salmon migration, there was less of a parabolic relation between water temperature and flow and spill; during the sockeye migration water temperature was negatively correlated with flow, spill, and dissolved gas (r > 0.74).

We used sockeye salmon data through the end of July, because several fallbacks by sockeye salmon at the end of the migration appeared to distort analyses (discussed previously). With all 1997 variables in the first regression model, and sockeye salmon fallback ratios from the 5-Day-Block method as the dependent variable, water temperature was the only variable selected by the stepwise procedure with an r^2 value of 0.35 (Table 16). No other variables met the 0.15 significance level for inclusion in the model. When water temperature was removed from the model, no variables were selected. Multiple regression models using Variable-Day-Bin fallback ratios also first selected water temperature, but also included spill and flow for a model r^2 of 0.64 (Table 16). A model without water temperature selected Secchi depth, then flow and spill for an r^2 of 0.67.

During the 1997 steelhead migration, flow and spill were correlated (r ~ 0.88), with a period of zero spill in September and October, (also see Figure 49). Both flow and spill were positively correlated with dissolved gas levels at r > 0.82. Secchi disk visibility was negatively correlated with flow, spill, and dissolved gas levels (r > 0.69), and had a weak positive correlation with water temperature. Water temperatures were not strongly correlated with any other variables, in part due to a parabolic relationship with flow and the extended period of zero spill conditions.

We tested stepwise multiple regression models for steelhead through approximately 31 October, the date when about 99% of the steelhead tagged in 1997 had passed Bonneville Dam. With all 1997 variables in the first regression model, and steelhead fallback ratios from the 5-Day-Block method as the dependent variable, spill and flow were selected by the stepwise procedure with an r^2 value of 0.57 (Table 17). No other variables met the 0.15 significance level for inclusion in the model. When spill was removed from the model, flow was not selected; instead, dissolved gas levels and Secchi depth were selected with an r^2 of 0.45. When we excluded flow but included spill in the model, spill and water temperature were retained for an r^2 of 0.46 (Table 17). Multiple regression models using Variable-Day-Bin fallback ratios followed similar patterns as the 5-Day-Block models, with similar or slightly higher r^2 values (Table 17).

Final Distribution of Fish that Fell Back at Bonneville Dam

Migration summaries were complete for chinook salmon and steelhead tagged in 1996 and chinook and sockeye salmon tagged in 1997; preliminary summaries of lesser but good quality were complete for steelhead tagged in 1997 and chinook salmon tagged in 1998. We used the migration summaries to determine the final distribution of radio-tagged fish that fell back at Bonneville Dam and to identify fish that ended up in tributaries during historical spawning times. For the three years, a relatively high proportion of spring/summer chinook salmon (68% to 72%), sockeye salmon (64%), and fall chinook salmon (63%) that fell back at Bonneville Dam survived to end up in tributaries or migrate past the uppermost monitored sites. Somewhat lesser proportions of steelhead (57% and 34%) ended up in tributaries or past uppermost sites. The remaining fish were last recorded at dams or in mainstem Columbia or Snake river reservoirs or were recaptured at mainstem sites.

Of 112 chinook salmon that fell back at Bonneville Dam in 1996, 6 (5%) ended up in tributaries downriver from the dam, 25 (22%) in tributaries between Bonneville and The Dalles dams, 16 (14%) in the Deschutes and John Day rivers, 21 (19%) in the Snake River upriver from Lower Granite Dam or at the Lower Granite Trap, and 6 (5%) in other Columbia River tributaries upriver from McNary Dam (Table 18). Six (5%) additional fish were last recorded at the top of Priest Rapids Dam. The 31 (28%) spring/summer chinook salmon that fell back at Bonneville Dam and did not reach tributary sites or the top of Priest Rapids Dam were last recorded mostly (77%) at or downriver from Bonneville Dam, in the Bonneville pool, or at The Dalles Dam. About 13% of the 31 fish that did not reach tributary sites were recaptured in fisheries or their transmitters were found at mainstem sites. Twelve of the 112 chinook salmon that fell back at the dam in 1996 did not reascend; of these, 6 (50%) ended up in downriver tributaries and 6 (50%) were not recorded at tributary sites.

In 1997, 65.5% of the spring/summer chinook salmon that fell back at the dam successfully returned to tributaries or hatcheries, and another 4.3% passed

Table 17. Stepwise multiple regression model outputs for 1997 including models run, variables retained, and standard procedure outputs. All models have steelhead fallback ratios as the dependent variable.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, 5-Day-Block model with all variables included from 17 June to 24 October						
	a. Spill		0.2385	0.2385	7.52	0.0114
	b. Flow		0.5710	0.3325	17.82	0.0003
Model 2, 5-Day-Block model with all variables except spill from 17 June to 24 October						
	a. Dissolved gas		0.2185	0.2185	6.71	0.0160
	b. Secchi depth		0.4459	0.2274	9.44	0.0054
Model 3, 5-Day-Block model with all variables except flow from 17 June to 24 October						
	a. Spill		0.2385	0.2385	7.52	0.0114
	b. Water temperature		0.4620	0.2235	9.56	0.0052
Model 4, Variable-Day-Bin model with all variables included from 17 Jun to 24 Oct						
	a. Spill		0.3606	0.3606	16.35	0.0004
	b. Flow		0.5880	0.2275	15.46	0.0005
Model 5, Variable-Day-Bin model with all variables except spill from 17 Jun to 24 Oct						
	a. Dissolved gas		0.2974	0. 2974	12.27	0.0015
	b. Secchi depth		0.4948	0.1974	10.94	0.0026
Model 6, Variable-Day-Bin model with all variables except flow from 17 Jun to 24 Oct						
	a. Spill		0.3606	0.3606	16.35	0.0004
	b. Water temperature		0.5387	0.1781	10.81	0.0027
	c. Secchi depth		0.5950	0.0563	3.75	0.0633

Wells or Chief Joseph dams, or returned to mainstem traps for a potential survival of 69.8% (Table 18). Of 139 chinook salmon that fell back at Bonneville Dam in 1997, 16 (12%) subsequently ended up in tributaries between Bonneville and The Dalles dams, 17 (12%) in the Deschutes and John Day rivers, 44 (32%) in the Snake River upriver from Lower Granite Dam or at the Lower Granite Trap, and 13 (9%) in Columbia River tributaries upriver from McNary Dam (Table 18). The 42 (30%) chinook salmon that fell back at Bonneville Dam and did not reach tributary or the most upriver monitored sites were last recorded mostly (62%) at or downriver from Bonneville Dam, in the Bonneville pool or at The Dalles Dam. About 21% of the 42 fish that did not reach tributary sites were recaptured in fisheries or their transmitters were found at mainstem sites. Twelve of the 139 chinook salmon that fell back at the dam in 1997 did not reascend, none of which were recorded in tributaries downriver from Bonneville Dam (no tributaries downstream from the dam had fixed receivers in 1997).

In 1998, 62.9% of the chinook salmon that fell back at the dam successfully returned to tributaries or hatcheries, and another 4.8% returned to mainstem traps for a potential survival of 67.6% (Table 18). Of 105 chinook salmon that fell back at Bonneville Dam in 1998, 3 (3%)

Table 18. Final recorded location of chinook salmon (CK), steelhead (SH), sockeye salmon (SK), and fall chinook salmon (FCK) with transmitters that fell back at Bonneville dam in 1996, 1997, and 1998 and percent that survived to tributaries. Fish that reached tributary sites during spawning times and then returned to mainstem areas (i.e steelhead kelts) were included in tributary counts.

	1996 CK	1997 CK	1998 CK	1996 SH	1997 SH	1997 SK	1998 FCK
Number of fallback fish	**112**	**139**	**105**	**35**	**83**	**64**	**32**
Final location							
Lewis River			1				
Willamette River							1
Cowlitz River	2						
Santiam River	1						
Washougal River			1	1			1
Sandy River	3		1	1			1
Tanner Creek							7
Wind River	10	7	9				1
Little White Salmon River	12						
White Salmon River	1	4			1		1
Rock Cr./Eagle Cr.		1					1
Hood River		1	2		1		1
Klickitat River	2	3	7	1	2	1[c]	2
Deschutes River	8	15	8	2	5		1
John Day River	8	2	3	3	1		
Umatilla River	1			1			
Walla Walla River					1		
Yakima River	3	4	2	1			
Hanford Reach			2	1		3[c]	1
Wenatchee/Tumwater Dam		6			1	13	
Methow River			1			1	
Okanogan River						23	
Icicle River	2	3	1				
Similkameen River	1						
Lyons Ferry Hatchery					1		1
Tucannon River		1	1	1	1		
Clearwater River	6	17	12	1	2		
Snake River above Asotin	6	2		1	4		
Grande Ronde River		1			2		
Imnaha River	1	2	2				
Salmon River	3	22	13	6	4		
Total:	**70**	**91**	**66**	**20**	**26**	**37**	**19**
Percent that survived to tributaries:							
	62.5	**65.5**	**62.9**	**57.1**	**31.3**	**57.8**	**59.4**
Additional fish that survived to relevant non-tributary sites:							
L. Granite trap: to hatchery	4	1	1				
L. Granite trap, no trans.	1						
At/Near Ringold trap		1	3		1		
Top of Pr. Rapids Dam[a]	6			1[b]			
At or past Wells Dam/trap		4	1		1	4	1[d]
Percent that survived to tributaries, traps, top of Pr. Rapids (1996) or Wells dams:							
	72.3	**69.8**	**67.6**	**60.0**	**33.7**	**64.1**	**62.5**

[a] 1996 only; [b] recaptured near Methow River; [c] not included as survived; [d] passed Rocky Reach Dam

subsequently ended up in tributaries downstream from Bonneville Dam, 18 (17%) in tributaries between Bonneville and The Dalles dams, 11 (10%) in the Deschutes and John Day rivers, 28 (27%) in the Snake River upriver from Lower Granite Dam or at the Lower Granite Trap, and 4 (4%) in Columbia River tributaries upriver from McNary Dam (Table 18). The 34 (32%) chinook salmon that fell back at Bonneville Dam and did not reach tributaries or the most upriver monitored sites were last recorded mostly (72%) at or downriver from Bonneville Dam, in the Bonneville pool or at The Dalles Dam. About 9% of the 55 fish that did not reach tributary sites were recaptured in fisheries or their transmitters were found at mainstem sites. Twenty of 105 (19%) spring/summer chinook salmon that fell back at the dam in 1998 did not reascend, of which 3 (15%) ended up in a tributary downriver from Bonneville Dam.

In 1996, 57.1% of the steelhead that fell back at Bonneville Dam returned to tributaries or hatcheries or mainstem traps (Table 18). Of the 35 steelhead tagged in 1996 that fell back, 19 (54%) subsequently ended up in tributaries: 1 each in the Sandy, Washougal, Klickitat, Umatilla, Yakima, Tucannon, and Clearwater rivers, 2 in the Deschutes River, 3 in the John Day River, 1 in the Snake River near Asotin, WA, and 6 in the Salmon River (Table 18). The remaining 16 steelhead (46%) were last recorded at dam or mainstem sites: 6 at Bonneville Dam, 2 in the Bonneville Pool, 2 at The Dalles Dam, 2 at John Day Dam, 1 near Ringold trap, 1 near the Methow River, and 1 each at Ice Harbor and Lower Granite dams. About 19% of the 16 fish that did not reach tributary sites were recaptured in fisheries or their transmitters were found at mainstem sites. Five of 35 steelhead (14%) that fell back at Bonneville Dam did not reascend, of which two (40%) entered tributaries downstream from the dam.

For the 83 steelhead tagged in 1997 that fell back at Bonneville Dam, only one-third were subsequently recorded in tributaries, at hatcheries, or mainstem traps (Table 18). Of the 83 steelhead that fell back, 26 (31%) subsequently ended up in tributaries, 4 (5%) in tributaries between Bonneville and The Dalles dams, 6 (7%) in the Deschutes and John Day rivers, 12 (14%) in the Snake River upriver from Lower Granite Dam, and 1 each in the Walla Walla and Wenatchee Rivers, Lyons Ferry Hatchery, Ringold trap, and Wells Dam trap (Table 18). The 55 (66%) steelhead that fell back at Bonneville Dam and did not reach tributary or the most upriver monitored sites were last recorded mostly (56%) at or downriver from Bonneville Dam, in the Bonneville pool or at The Dalles Dam. About 31% of the 55 fish that did not reach tributary sites were recaptured in fisheries or their transmitters were found at mainstem sites. Nineteen of 84 steelhead (23%) that fell back at Bonneville Dam did not reascend, none of which entered tributaries downstream from the dam (no tributaries downstream from the dam had fixed receivers in 1997).

Overall, 64.1% of the sockeye salmon that fell back at Bonneville Dam in 1997 successfully returned to tributaries, hatcheries, or were last recorded at Wells or Chief Joseph dams (Table 18). Of the 64 sockeye salmon that fell back at the dam, 13 (20%) were last recorded in the Wenatchee River or at Tumwater Dam on the Wenatchee River, 1 in the Methow River, and 22 (34%) in the Okanogan River or its tributaries. Another four sockeye salmon (6%) were last recorded at Wells or Chief Joseph dams (Table 18).

Because tributary monitoring was limited upriver from Wells Dam, we treated fish last recorded at those sites as successful migrants. Last records for the 23 (36%) sockeye salmon that fell back at Bonneville and did not reach tributary sites were mostly (57%) last recorded at or downriver from Bonneville Dam, or in the Bonneville pool or at The Dalles Dam. Additional fish were last recorded at John Day, McNary, Rock Island, and Rocky Reach dams as well as at fixed receivers at the downstream end of the Hanford reach of the Columbia River. One fish was last recorded in the Klickitat River. About 43% of the 23 fish that did not reach tributary sites were recaptured in fisheries or their transmitters were found at mainstem sites.

Overall, 62.5% of the fall chinook salmon that fell back at Bonneville Dam in 1997 successfully returned to tributaries, hatcheries, the Hanford Reach, or were last recorded at Wells dam (Table 18). Of the 32 fall chinook salmon that fell back at the dam, 10 (31%) were last recorded in tributaries downstream from Bonneville Dam, 6 (19%) in tributaries between Bonneville and The Dalles dams, and one each in the Deschutes River, at Lyons Ferry hatchery, in the Hanford Reach, and at Wells Dam. Last records for the 12 (38%) fall chinook salmon that fell back at Bonneville and did not reach tributary sites were all at or downriver from Bonneville Dam, or in the Bonneville pool. None of the 12 fall chinook salmon that did not reach tributary sites were recaptured in fisheries. Twenty (63%) of the 32 that fell back at the dam did not reascend, of which 10 (50%) were last recorded in tributaries downstream from the dam.

We also used general migration summaries to identify fish that fell back at Bonneville Dam after spawning in upstream tributaries. These events were not included in fallback summaries reported above, as post-spawn fallbacks were not related to dam operations, did not occur as a result of straying during migration, and did not affect survival. A total of 7 spring/summer chinook salmon (1 in 1996, 2 in 1997, and 4 in 1998) fell back after likely spawning in Bonneville pool tributaries, 6 in the Wind River and 1 in the White Salmon River. Four steelhead kelts (2 in 1996, 2 in 1997) fell back at Bonneville Dam after likely spawning in the Deschutes, Walla Walla, Clearwater, and Grande Ronde rivers. No sockeye or fall chinook salmon were recorded falling back at the dam after potential spawning.

Escapement to tributaries for fish that did or did not fall back

In a separate analysis, we compared escapement to monitored tributaries, hatcheries, spawning areas, or the uppermost monitoring sites for radio-tagged fish that did or did not fall back at Bonneville Dam. Escapement estimates in Table 19 differ from the survival estimates in Table 18 in two ways: first, all fish that we know or believe regurgitated transmitters at mainstem sites during their upstream migration were removed from escapement analyses; second, because telemetry coverage upstream from Priest Rapids Dam differed in all years, all spring/summer chinook salmon that passed Priest Rapids Dam were considered to have escaped. Results for 1997 and 1998 are preliminary and may change slightly as general migration analyses are completed.

For all years and species, the proportion of fish that escaped to tributaries, hatcheries, traps, or spawning areas was higher for fish that did not fall back than for fish that did fall back (Table 19). In the three years 1996-1998, spring and summer chinook salmon that did not fall back at Bonneville Dam had passage success rates of 80.1%, 78.4%, and 83.9% versus rates of 76.2%, 70.7%, and 68.7% for fish that fell back at the dam. Only the 1998 difference was statistically significant (X^2 P < 0.001). For steelhead, fish that did not fall back had passage success rates of 63.7% in 1996 and 62.3% in 1997 versus 60.0% and 35.0% for those that fell back; the difference was significant in 1997 (P < 0.001). For sockeye salmon, escapement was higher (74.9%) for fish that did not fall back at Bonneville Dam than for fish that did fall back (65.1%), a difference significant at P = 0.095. Escapement was also higher for fall chinook salmon that did not fall back (70.1%) than for fall chinook salmon that did fall back (62.5%), but the difference was not significant (P = 0.36) (Table 19).

Table 19. Number and percentage of unique spring/summer chinook salmon (CK), sockeye salmon (SK), steelhead (SH), and fall chinook salmon (FCK) with transmitters that either did or did not fall back (FB) at Bonneville Dam, and the percentage that escaped to tributaries, hatcheries, traps, spawning areas, or the top of Priest Rapids[a] Dam in 1996, 1997[b] and 1998[b]. Fish known or presumed to have regurgitated transmitters at mainstem sites not included in comparisons.

Year	Did not fall back at Bonneville		Fell back at Bonneville		
Species	Number	Percent that escaped	Number	Percent that escaped	X^2 P
1996 CK	675	80.1	105	76.2	0.349
1997 CK	792	78.4	139	70.7	0.040
1998 CK	793	83.9	99	68.7	< 0.001
1996 SH	659	63.7	35	60.0	0.655
1997 SH	811	62.3	80	35.0	< 0.001
1997 SK	490	74.9	63	65.1	0.095
1998 FCK	872	70.1	32	62.5	0.360

[a] spring/summer chinook salmon that passed Priest Rapids Dam were designated escaped
[b] escapement estimates for non-fallback fish preliminary for 1997 and 1998.

Discussion

During each of the years 1996-1998 significant numbers of salmon and steelhead fell back over Bonneville Dam. The reasons for the fallbacks are varied, but at Bonneville Dam, we believe spill, the location of the fishway exit on Bradford Island, and the fish's tendency to migrate along the shorelines are the primary factors involved in the fallbacks. To reduce the proportion of fish that fall back over the dam will require alteration of the volume and perhaps location of spill, and the number of fish that leave the Bradford Island fishway and migrate upstream around the Island into the forebay of the spillway. Relatively few fish fallback through the powerhouses, juvenile bypass systems, or navigation lock.

The percentages of spring/summer chinook and sockeye salmon (11.3% to 14.6%) that fell back over the dam and fallback rates (13.7% to 19.9%) were highest for spring and summer chinook salmon in 1997. Fallback rates for steelhead were 9.9% for fish tagged in 1997 and 5.2% for fish tagged in 1996. The fallback rate for fall chinook salmon was 4.2% in 1998. For all three years, percentages of spring/summer chinook salmon that fell back and fallback rates were significantly related to flow and spill conditions. In 1997, a relatively high-flow year with large volumes of spill (200-400 kcfs during May and June), fallback rates and the percentage of fish that fell back were higher than in 1996 and 1998, years with lower flows and spill volumes (100-250 kcfs) during most of May and June.

Within individual years, 24-h fallback ratios (the number that fell back within 24 h of passage divided by the number that pass) for spring/summer chinook salmon increased with flow, spill, and dissolved gas levels and decreased with decreasing turbidity levels. Similar relations were observed for 1997 sockeye salmon during all but the tail end of the migration, and for steelhead tagged in 1996. Flow and spill were highly correlated, as might be expected, but the volume of spill was the important variable in fallbacks; there would be relatively few fallbacks with high flows and no spill. Dissolved gas levels were correlated with volumes of spill, but we believe fallbacks occurred because of the opportunity to fall back through the spillway, not because of high dissolved gas levels. Turbidity of the river was another coincident variable, in our view, and was not a main factor in causing fallbacks. Turbidity increased as flows increased in the spring and decreased as flows decreased in summer.

The importance of spill in contributing to fallbacks is illustrated by the small number of fallbacks that occurred when there was no spill at the dam. During the three years, the only periods with no spill when spring and summer chinook salmon were migrating past the dam occurred on one day in April 1997, and 1-19 April in 1998. In 1997, no spring chinook salmon fell back on the one day without spill. In 1998, 7 of 152 (4.6%) spring chinook salmon with transmitters that passed over the dam during the 19 days of no spill in April fell back over the dam. During the remainder of April and all of May there was spill (up to 150 kcfs) and 576 passages by spring chinook salmon with 95 fallbacks, a 19.2% rate. During June and July of 1998 when summer chinook salmon passed the dam and there was spill, there were 322 passages with 44 fallbacks, a 15.2% fallback rate.

Fallback rates by steelhead and fall chinook salmon were also low when there was no spill. The periods of no spill when steelhead were passing Bonneville Dam in 1996 and 1997 were most of the time in September and October. In 1996 there was no spill throughout September and October, and there were 291 passages by steelhead with 3 fallbacks (1.0%), compared to 451 passages during the June through August spill period with 29 fallbacks (6.8%). In 1997, there were 451 passages of steelhead during September and October with 16 fallbacks (3.6%), with two of the fallbacks during six days in mid October when significant volumes of water (20-40 kcfs) were spilled from mid morning to evening and few steelhead with transmitters passed over the dam. During the June through August period when there was spill, there were 526 passages by steelhead with 72 fallbacks, a 15.3% fallback rate. All fall chinook salmon passed the dam during no spill conditions, and 4.2% fell back mostly via the navigation lock. Spill then provides a route for fish to fallback, especially those that enter the forebay of the spillway. Eliminating spill is not possible during the spring runoff, and spill is currently used as a route for downstream migrants to pass the dam during the summer. If spill cannot be eliminated or reduced, then we need to explore ways to keep fish away from the spillway forebay.

We believe most fish that fell back at Bonneville Dam when there was spill did so via the spillway, based on our examination of records of fish in the forebay and at the dam or in the tailrace before and after fallback. The routes of fallback when there was no spill were determined for some fish, but for others we were not sure of the route because not all routes were monitored. Of the seven spring chinook salmon that fell back when there was no spill in April of 1998, five passed through the ice and trash sluiceways, and the other two likely passed through powerhouse 1 or the navigation lock. Of the 14 steelhead that fell back during the no-spill period in September and October of 1997, 5 fell back through the ice and trash sluiceways, four through the navigation lock, and the remainder we are not sure which route they took. At least 60% of the fall chinook salmon that fell back in 1998 fell back via the navigation lock.

The second important factor that contributes to the relatively high fallback rates at Bonneville Dam is the location of the exit for the Bradford Island fishway that collects fish from powerhouse 1 and the south side of the spillway. Most of the spring/summer chinook salmon, sockeye salmon, and steelhead (93-97%) that fell back within 24 h of passage in the three years of study had passed over the dam via the Bradford Island fishway. Depending on the distribution of discharges from the dam, half or more of the fish pass the dam via the Bradford Island fishway. In 1996, of all spring and summer chinook salmon with transmitters that returned to the dam after release, 62% approached the entrances to the Bradford Island fishway first versus 38% at the Washington-shore fishway entrances (unpublished data, Idaho Cooperative Fish and Wildlife Research Unit). Of fish that passed over the dam, about 53% used the Bradford Island fishway. When fish exit the fishway into the forebay of powerhouse 1, most of them (91% of 359 fish tracked in 1997 and 1998) migrate upstream along the south side of Bradford Island (Bjornn et al. 1999). At the upstream tip of Bradford Island the fish can cross the channel to the Oregon shore (27% did so in 1997 and 1998), go around the tip into the forebay of the spillway (39%), or go around the tip and across the river to the Washington shore (34%). Fallback rates and percentages of sockeye salmon that fell back were more than 30 times higher for fish that passed over the dam via the Bradford Island fishway versus the Washington-shore fishway, and more than 80% of all fallback events by steelhead were by fish that passed via the Bradford Island fishway.

Obviously then, one way to reduce the proportion of salmon and steelhead that fallback at Bonneville Dam is to relocate the exit of the Bradford Island fishway to the Oregon shoreline. Next best would be to build a new fishway on the Oregon shore that would collect fish from the tailrace of the navigation lock and powerhouse 1, and perhaps be connected to the B-branch fishway (south shore of spillway entrance) by a surface level channel. If fish released on the Oregon shore would migrate up that shoreline until they are out of the influence of the spillway, the fallback rates could be reduced to low single digits. Tests are currently underway to monitor the migration routes of fish released in various location near the Oregon shore in the forebay of powerhouse 1.

The third important factor, the tendency of fish to migrate along the shoreline, is one we cannot change or control, but we can take advantage of the trait to devise ways to reduce the fallback rate. If the fish were unpredictable in their migration behavior releasing the fish on the Oregon shore would be a chancy way to reduce the number of fish exposed to the spillway forebay. Because we would expect most fish released on the Oregon shore to migrate up that shoreline out of the forebay, a new fishway exit may be a solution to the fallback problem.

The consequences of fallbacks by salmon and steelhead at Bonneville Dam include injury and loss of some fish that fallback, delay in migration, use of limited energy reserves, and counts of salmon at dams that are not accurate estimates of escapement. In the three years, 81-91% of the spring and summer chinook salmon that fell back at Bonneville Dam reascended the dam. Of the sockeye salmon that fell back in 1997, 95% reascended and passed over the dam, and 86% and 77% of the steelhead in 1996 and 1997 reascended and passed over the dam. Sixty-nine percent of the fall chinook salmon that fell back in 1998 repassed the dam. A few of the fish that did not reascend Bonneville Dam entered tributaries downstream from the dam, presumably because that is where they were destined to go. If we assume that fish we did not find in tributaries downstream from the dam died before spawning, they would have amounted to 0.4% to 2.0% of the salmon and steelhead with transmitters that passed the dam. If those rates were applied to all fish passing the dam, the number of fish lost after fallbacks at the dam would range from 400 to 2,000 fish out of a run of 100,000 fish. Although those losses are associated with fallback and failure to reascend the fishways, some of the losses may be natural and merely happened to occur as the fish were passing Bonneville Dam.

From complete migration summaries for each fish prepared from records at all sites and mobile tracking throughout the basin, we estimated the percentage of salmon and steelhead that were subsequently recorded in tributaries or the uppermost monitoring sites and were considered to have successfully negotiated passage through the Columbia and Snake rivers hydrosystem. In general, adult salmon and steelhead that fell back at Bonneville Dam were less successful at getting into tributaries or past the uppermost monitoring sites than fish that did not fallback (Bjornn et al. 2000a). In the three years 1996-1998, spring and summer chinook salmon that did not fall back at Bonneville Dam had passage success rates of 80%, 78%, and 84% versus rates of 76%, 71%, and 69% for fish that fell back at the dam. Differences were statistically significant in 1997 and 1998. For steelhead, fish that did not fall back had passage success rates of 64% and 62% versus 60% and 35% for those that fell back in 1996 and 1997, with the difference in the latter year significant. Sockeye salmon that did not fall back at Bonneville Dam in 1997 had a passage success rate of 75% versus 65% for those that did (difference significant at

$P < 0.10$). Fall chinook salmon that did not fall back in 1998 had a passage success rate of 70% versus 63% for those who did, but the difference was not significant.

Counts of adult salmon and steelhead that pass through the fishways at the dams are used as estimates of escapement past each of the dams. When fish fall back at the dams and reascend the fishways, they cause the counts to be biased because some fish are counted more than once, and some fish that were counted fall back and do not end up escaping upstream past the dam. The positive bias in the counts caused by fallbacks can be offset by passage through the navigation locks, but relatively few fish pass the dam via the navigation lock. The amount of bias in counts of fish as estimates of escapement varies annually and is related to the factors that contribute to fallback rates. Positive biases because of fallbacks in estimates of escapement of spring and summer chinook salmon past Bonneville Dam based on counts at the dam were about 9,200 fish in 1996, 23,000 in 1997, and 7,800 in 1998. Positive biases were about 1,500 sockeye salmon in 1997, 1,600 steelhead in 1996, 15,800 steelhead in 1997, and 200 fall chinook salmon in 1998. In summary, the percentage of adult salmon and steelhead that fall back at Bonneville Dam and the fallback rates (includes multiple fallbacks) vary annually and the variability is related primarily to the amount of water spilled. The fallback rate at Bonneville Dam would likely be reduced if fish that use the Bradford Island fishway could exit the fishway on the Oregon shore. The amount of bias in escapements past the dam can be estimated by monitoring passage of tagged fish (radio transmitters or PIT tags) for several years and developing relations between spill volume and fallback rates. Once a relation has been developed it can be used to estimate fallback rates and potential bias in escapement estimates without having to monitor tagged fish.

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