Technical Report 2001-3

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

ADULT CHINOOK SALMON AND STEELHEAD FALLBACKS VERSUS SPILL AT BONNEVILLE DAM IN 2000

A report for Project ADS-00-1

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

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Preface

Radio telemetry studies on passage of adult salmon and steelhead through the lower Columbia River began with fish being tagged and released at Bonneville Dam in 1996. The goal of these studies was to observe behavior and assess potential sources of delay and mortality for adult salmon and steelhead during their upstream migration. At this writing we have completed four field seasons during which we have collected information on passage of spring and summer chinook salmon (four years of data), steelhead (three years), fall chinook salmon (two years), and sockeye salmon (one year). Insights gained from this research will be used to develop strategies for managing and recovery of ESA listed anadromous salmonid populations in Columbia River Basin.

Acknowledgements

Many people made this study possible. Notable among them was Kevin Traylor who helped maintain and download telemetry receiver equipment. We would like to thank Mike Langeslay for his valuable assistance facilitating our cooperation with the U.S. Army Corps of Engineers. We would also like to acknowledge assistance provided by Biologist Tammy Mackey and the operators at Bonneville Dam.

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Abstract

A randomized block test was conducted to evaluate effects of high and low spill on fallback rates of adult salmon and steelhead at Bonneville Dam in 2000. Periods of low spill (50-75 kcfs) were alternated with periods of high spill (80-145 kcfs) during which the proportion of chinook salmon and steelhead that fell back were compared. Overall, 1,624 chinook salmon and steelhead passed through the two fishways, of which 180 fish (11.1%) fell back at Bonneville Dam, and of those, 1,449 fish and 168 fall backs were used in the analysis. Percent fallback for salmon and steelhead that passed through both fishways averaged 9.5% (± 2.45%) during the low-spill treatment and 13.5% (± 3.7%) during the high-spill treatment. When fallbacks that occurred more than 24 h after fish first exited fishways and those fallbacks from fish that moved upstream at least as far at Cascade Locks, Oregon (2.5 km) before falling back were removed from analysis, percent fallback averaged 6.2% (± 2.1%) during the low-spill treatment and 9.3% (± 2.5%) during the high-spill treatment. Fish that passed the dam using the Bradford Island fishway averaged percent fallback of 14.9% (± 3.9%) during the low-spill treatment and 20.6% (± 4.9%) during high spill. When fallbacks from the Bradford Island fishway that occurred more than 24 h after fish first exited fishways and those fallbacks from fish that moved upstream before falling back were removed from analysis, percent fallback averaged 10.2% (± 2.9%) during the low-spill treatment and 15.8% (± 3.6%) during high spill, the only comparison with a significant difference in percent fallback between high and low-spill treatments. Percent of fish that fell back were not significantly related to spill in regression analysis, which contrasts with results of our analysis of fallback at Bonneville Dam from previous years. It appears that a component of the fallback that occurs at Bonneville Dam each year may be independent of spill level.

Introduction

Fallback of adult salmon and steelhead has been documented at Columbia and Snake River dams in numerous studies since the 1960's (see review by Bjornn and Peery 1992; Bjornn et al. 1998; 2000a). One objective of the Adult Salmon and Steelhead Passage Project, conducted since 1996, has been to evaluate fallback at the lower Columbia River dams. Specifically, we have used radio telemetry to determine the level of fallback by adult salmon and steelhead at each dam and have attempted to determine factors that affect fallback and fates of fish that fell back at dams during 1996-98 and 2000 (e.g. Bjornn et al. 2000a). With current telemetry technology, we have been able to closely monitor the movements of large numbers of adult salmon and steelhead, allowing more accurate evaluation of fallback at dams than was possible during earlier studies. In the study reported here, conducted in 2000, we evaluated the effects of two levels of spill on percent of adult chinook salmon and steelhead that fell back at Bonneville Dam.

Fallback of salmon and steelhead occurs at all dams, but the unique situation at Bonneville Dam has warranted special attention. During early studies (conducted between 1966 and 1984), fallback rates reported for spring and summer chinook salmon ranged from 1% to 39% at Bonneville Dam, most estimates being > 10% (Bjornn and Peery 1992). During the three years we monitored fallback, 1996-98, fallback rates (total number of fallback events divided by total number of passage events and includes multiple fallbacks) for spring and summer chinook salmon were 16.4%, 19.9%, and 15.9%, respectively, resulting from fallbacks by 13.9%, 14.7%, and 11.4% of the spring and summer chinook salmon that passed the dam (Bjornn et al. 2000a). Fallback rates for adult steelhead were 5.2% and 9.9% during 1996 and 1997, and 4.2% for fall chinook salmon during 1998 (see Bjornn et al. 2000a for how fallback estimates were calculated). Fallback at Bonneville Dam appeared related to the behavior of the adult migrants and to the unique configuration of the fishways at the dam. Salmon and steelhead tend to migrate upstream along shorelines in the lower Columbia River (Bjornn et al. 1999; 2000b). Fish that use the Washington-shore fishway enter at the north side of the spillway and along powerhouse II, and they exit the fishway on the Washington shoreline. Fish that use the Bradford Island fishway enter at the south end of the spillway and along powerhouse I, and they exit the fishway on the south shore of Bradford Island. A large proportion of the fish that exited the Bradford Island fishway tended to move upstream along the shoreline and around the eastern tip of Bradford Island into the spillway channel at Bonneville Dam (Bjornn et al. 1999). Once in the forebay of the spillway, some fish continued along the shoreline of the island to the spillway while others crossed to the north side of the river. Those fish in the vicinity of the spillway while water is being spilled are at greater risk of falling back than fish that moved upstream along the Washington and Oregon shorelines. During the years 1996-98, 71-84% of all fallback events by spring and summer chinook salmon at Bonneville Dam were from fish that exited the Bradford Island fishway (Bjornn et al. 2000a).

Although the location of the fishway exit on Bradford Island is a major factor contributing to high fallback rates at Bonneville Dam, other factors should not be discounted. For example, during 1996-

98, 35% to 60% of the fallback events occurred after the fish had moved upstream 2.5 km or more and were recorded at sites upstream from Bonneville Dam. Fallbacks by fish that returned to the dam after having migrated upstream a significant distance would likely be independent of which ladder was used to pass the dam.

We suspect that most fallback events at Bonneville Dam occurred through the spillway. The strongest evidence for this was seen with steelhead, where 80% of the fallback events during 1996 and 1997 occurred on days with spill at the dam, and from the low rate of fallback for fall chinook salmon (4%) in 1998 during periods with no spill. Thus, we hypothesize that the propensity for fish to fallback at Bonneville Dam is higher during periods with higher spill and flow conditions. We used a number of analyses to look for correlations for spill, as well as flow, turbidity, temperature, and dissolved gas levels on fallback rates for spring and summer chinook salmon during the 1996-98 migrations (Bjornn et al. 2000a). In many of the analyses we found positive correlations between fallback ratios and spill or flow. In the 1996-98 telemetry studies a wide range of flow and spill, much that was uncontrolled during the migration season, occurred at Bonneville Dam, and fallback rates were related to those flows and spill.

The effects of spill and other river conditions on salmon migrations is of concern because controlled spill is one of the ESA recovery measures used to improve in-river passage and survival of smolts migrating downstream. When spill is provided for downstream migrants, total dissolved gas levels may increase and fallback rates of upstream migrating adult salmon and steelhead may increase compared to low or no-spill conditions. The test conducted in 2000 was developed to assess the effects of two levels of spill at the lower Columbia River dams on passage of adult salmonids. The test consisted of alternating periods of high and low-spill levels through the spring and summer, during which we compared fallback and passage times of adult chinook salmon and steelhead outfitted with radio transmitters. The null hypothesis was that fallback percentages and passage times for salmon and steelhead would not differ significantly between periods with high and low-spill levels at Bonneville Dam.

Methods

Data Collection

A schedule of spill was established to provided 6 d blocks with 3 d of high and 3 d of low daytime spill levels from 14 April until the end of August at Bonneville Dam in 2000. Within each block, the order that the high- and low-spill treatments occurred was selected in a random manner. Before the field season spill levels were set at 75 kcfs during the day (0600-1800 hrs) for the low treatment and as much water as could be spilled until the maximum allowed total dissolved gas (TDG) level was reached, around 120 kcfs, for the high-spill treatment. Night time spill was at the TDG limit throughout the study. We had expected that spill treatments would be altered during the year to accommodate periods when high river flows would not allow the low-spill treatment. However, it was obvious early in study that maximum TDG levels (115% measured at the Camas/Washougal, WA, meter site about 42 km downstream from Bonneville Dam) were being reached at relatively low spill levels (< 100 kcfs) at Bonneville Dam, and that limited the amount of water that could be spilled at the dam through the spring (Figure 1). It appeared that spill levels associated with related studies being conducted at The Dalles and John Day dams raised the levels of TDG in the river prior to reaching Bonneville Dam. Because the low-spill treatment was consistently maintained near 75 kcfs and relatively close to the high- spill level, we chose to use blocks with spill levels greater than80 kcfs as the high-spill treatment. This resulted in 81 d during which the low-spill treatment occurred, and 71 d during which the high-spill treatment occurred.

Percent of fish that fell back and passage times were evaluated by monitoring radio-tagged adult spring and summer chinook salmon, steelhead, and fall chinook salmon. Adult salmon and steelhead were collected and tagged at the Adult Fish Facility (AFF) adjacent to the Washington-shore fishway at Bonneville Dam (Figure 2). During the day, a picketed-lead weir was dropped into the ladder to divert adult migrants into a smaller bypass ladder that lead to the trap holding pool in the AFF building. Salmon swam from the holding pool over one of two false weirs into sorting chutes. Project personnel standing on an overhead

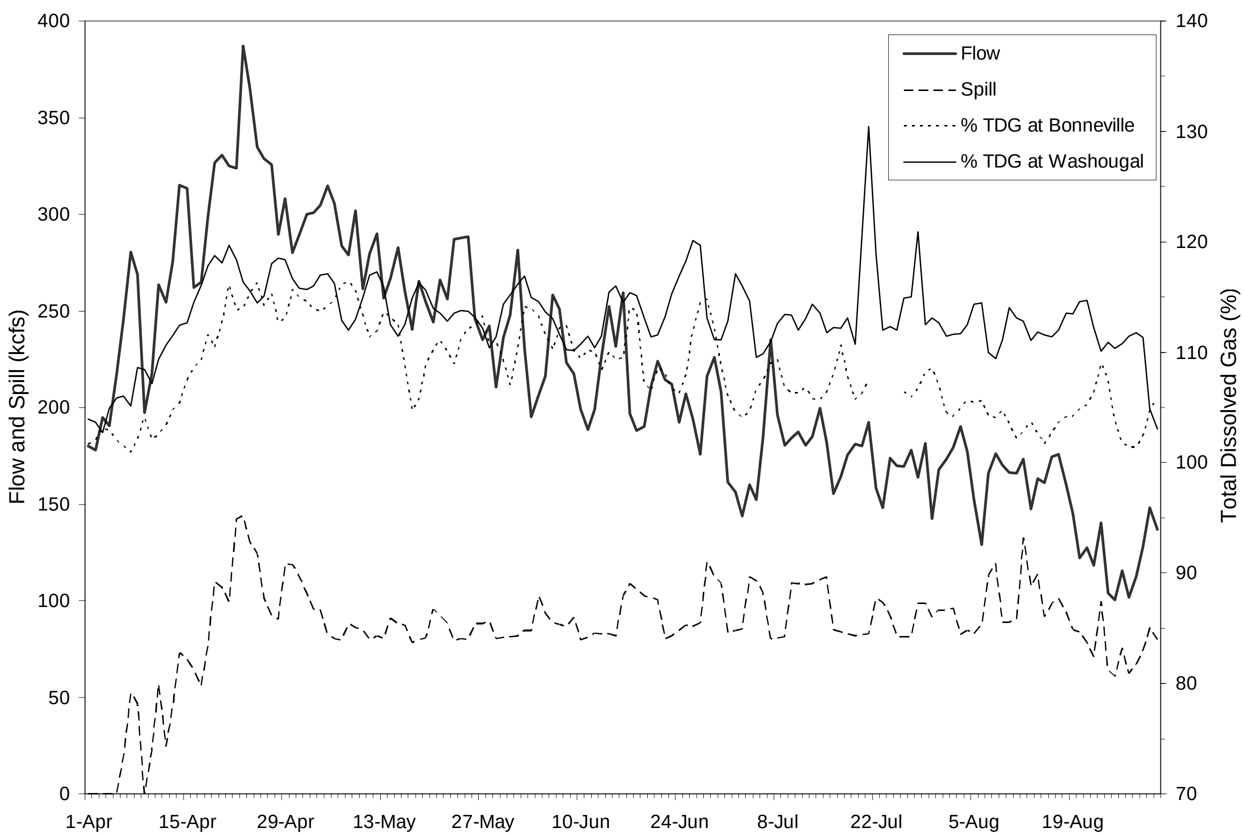

Figure 1. Flow, spill, and total dissolved gas (TDG) levels measured at Bonneville Dam and TDG measured downstream at Washougal, WA, during study period in 2000.

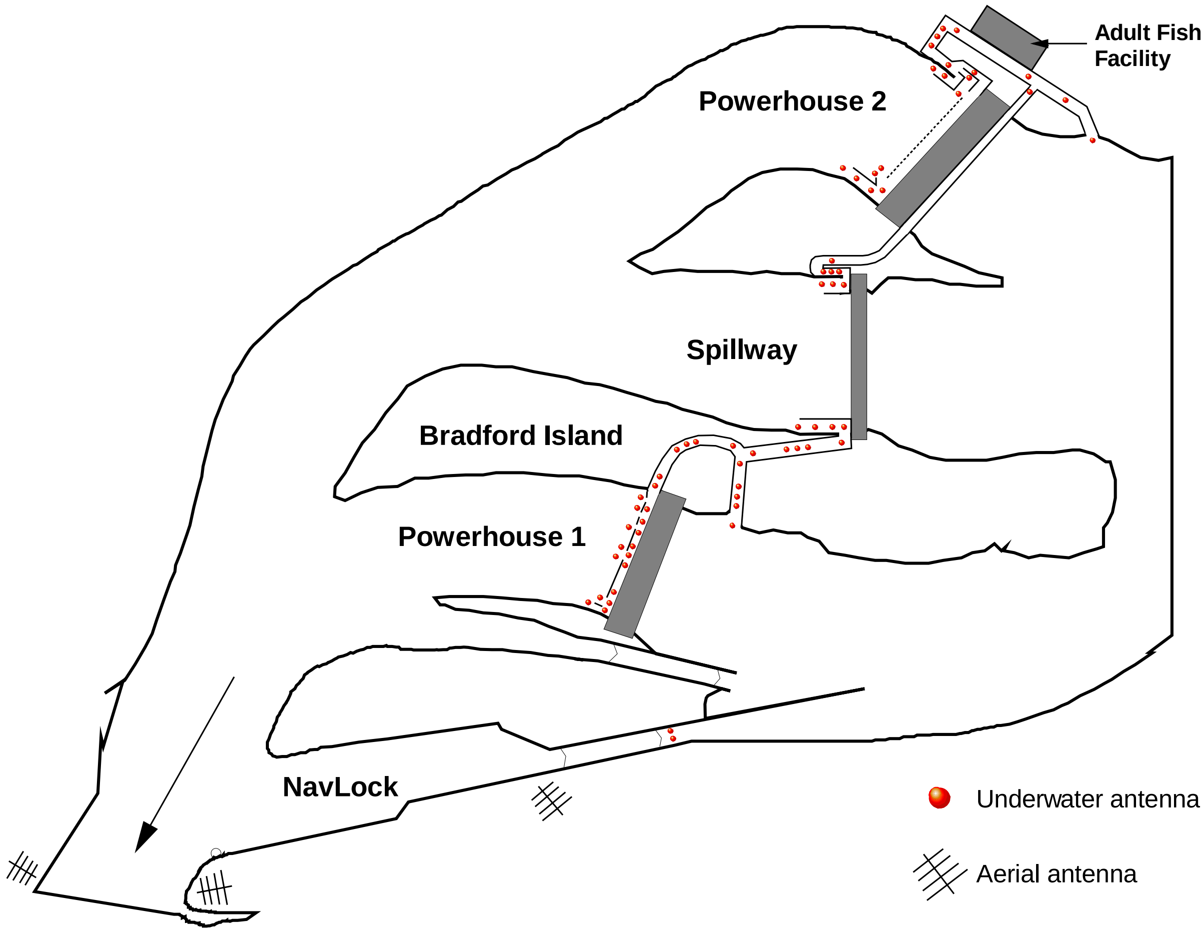

Figure 2. Radio receiver antenna placement and Adult Fish Facility where adult salmon and steelhead were tagged at Bonneville Dam in 2000.

catwalk diverted fish to be tagged into a 750 L anesthetic tank (clove oil) by activating slide gates. Fish not selected continued down the chutes and passed to a second bypass ladder through which they returned to the main fishway and continued their ascent of the dam.

Anesthetized fish were moved to a smaller tank where they were measured, examined for marks and injuries, and tagged. Each fish received a radio transmitter inserted into the stomach through the mouth. A visual implant (VI) tag, inserted under the clear tissue posterior to the eye, was used as a secondary visual mark in case the transmitter was regurgitated by the fish. A coded-wire tag (CWT), injected into the dorsal sinus, or a passive integrated transponder (PIT) tag, injected to the abdomen, were used so that fish with transmitters could be diverted into the adult trap facility upstream at Lower Granite Dam for inspection. Tagged fish were then moved to a 2,271 L aerated fiberglass tank filled with river water on a trailer to recover for at least one hour (usually 2-4 h). Fish in the recovery tank were transported 9.5 km downstream from Bonneville Dam and released at one of two boat ramps on the Washington and Oregon shores with an exit chute attached to the rear of the tank. Equal numbers of tagged fish were released on the north-shore (Skamania, WA) and south-shore (Dodson, OR) of the river (Figure 1). Fish usually swam away from the boat ramp and out of view immediately after release. Salmon that returned after one year in the ocean (‘jacks’) were not tagged, nor were fish with serious injuries. Otherwise fish were collected and tagged in the order that they appeared in the trap. Fish were tagged daily in proportion to the run size: more fish were tagged per day during peaks of runs than were tagged during the early and late segments of the runs. During the study period (1 April-31 August 2000) a total of 973 spring (728) and summer (245) chinook salmon, 541 steelhead, and 299 fall chinook salmon were outfitted with transmitters and released into the river downstream from the dam. Radio-tagged salmon and steelhead were also released into the forebay during this period, but those fish were not included in the fallback analysis. Likewise, fall chinook salmon and steelhead released after cessation of spill were not included in this study.

Radio-tagged fish were monitored at Bonneville Dam using a series of fixed-site radio receivers. Transmitters and receivers used were manufactured by Lotek Engineering Inc[1], of New Market, Ontario, Canada. Three sizes of transmitters were used, a 7-volt transmitter (83 mm long x 16 mm diameter used in fish 60 cm in length or larger), a 3-volt transmitter (43 mm long x 14 mm diameter for fish less than 60 cm in length, usually in A-run steelhead), and some fish received an archival radio transmiter (90 mm x 20 mm). Each transmitter was encased in epoxy and had a 43 cm wire antenna that exited the mouth and was bent back so that it trailed along the body of the fish.

Transmitters emitted a digitally coded signal every 5 s. Transmitter signals were interpreted by radio receivers as a unique numerical code on the transmitted frequency (channel). Transmitter frequencies ranged from 149.320 (channel 1) to 149.880 MHz (channel 25) in 0.02 MHz increments.

Two types of telemetry receivers were used during the project. SRX-400 (SRX) sequentially scanning receivers, set to scan each channel for 6 s, were used with aerial antennas to determine when fish with transmitters entered the tailrace at the dam. SRX receivers linked with digital-spectrum processors (SRX/DSP’s) could scan all channels simultaneously, and were used with underwater coaxial-cable antennas to monitor fish activity in and around fishways at dams. Underwater antenna were placed inside and outside fishway entrances and exits, and at strategic locations in collection channels and ladders of the fishways. Each SRX/DSP receiver could monitor up to seven separate underwater antennas. At Bonneville Dam in 2000, SRX receivers with aerial antennas, one on each shore, were located 1.1 km downstream from powerhouse 1 on the Oregon shore and 3.2 km downstream from powerhouse 2 on the Washington shore (Figure 2). SRX/DSP receivers with underwater antennas were used to monitor each fishway entrance and exit at powerhouse 1, the spillway, and the main fishway entrances at powerhouse 2. Orifice gates at powerhouse 2 were not monitored in 2000.

Upon reaching the dam, fish were recorded at fixed-site receivers, as described above. When a fish with a transmitter was detected, a receiver

[1] Does not constitute a product endorsement by the authors.

created a record of the channel, code, date, time, signal strength, and antenna number (if multiple antennas were used). Data stored in receivers were regularly downloaded to laptop computers. To process telemetry data, downloaded files were initially screened to remove obvious errors and records produced from background electronic noise. Screened data were then coded, which involved assigning codes to appropriate records that defined specific behavior by the fish (e.g. an approach, entrance, or exit from a fishway). Coding was facilitated by using of a semi-automated program developed with ArcView software (Version 2 for Windows).

Coded data were used to identify when and where fish with transmitters first entered the tailrace, first approached and first entered a fishway entrance, first entered and last exited the transition pools at the base of the fishways, and when fish exited the fishways and moved into the forebay at Bonneville Dam. Receivers and aerial antennas placed at Cascade Locks, Oregon, mouths of tributaries in the Bonneville pool, and at the tailrace of The Dalles Dam were also used to determine when fish moved upstream and left the forebay at the dam.

Data Analysis

The objective of this study was to compare the percent of fish that fell back and passage times for salmon and steelhead between periods with high and low spill levels. Prior to initiating the study we determined from existing data that a sample size of 32 replicates was needed to detect a significant difference of 5% in fallback between the two spill treatment levels. This sample size could not be attained from passage of any single group of fish planned to be tagged and released downstream from Bonneville Dam in 2000. Therefore the analysis described here included data from all three groups of fish (spring/summer chinook salmon, steelhead, and fall chinook salmon) tagged and released downstream from Bonneville Dam during 2000.

A fallback was determined to have occurred if a fish was recorded on a receiver in the tailrace of Bonneville Dam after exiting from the top of a fishway. Because we wanted to treat each fish equally, whether it fell back or not, each fish assigned to a spill treatment based on the time they exited a fishway at Bonneville Dam and the spill at that time. Fish that exited from the ladders and those fish thought to have fallen back after dark were excluded from analysis. A replicate for analysis consisted of a period of time during which at least ten fish exited from the fishway under one spill level. Spill at the high or low level generally occurred for three days, according to the schedule established at the beginning of the test. However, because the high-spill level was not consistently maintained, there were 81 d of low spill versus 71 d of high spill during the study period. We occasionally accepted a block with nine fish exits as a single replicate (see Appendix A for block divisions) to maintain consistent numbering of replicates of the two treatments through the study.

Fallback proportions were calculated for the replicates by dividing the number of fish that fell back during the block of time by the number of fish that exited the fishways during that same time period. Analysis of variance (ANOVA) was used to compare fallback rates between periods with high and low passage times. Proportions were arcsine transformed to normalize the data. We performed four separate analyses on the fallback data, (1) for all unique fallback events from both fishways (Bradford Island and Washintgton shore) regardless of when fish fell back, (2) for all fallback events that occurred within 24 h after fish exited the fishways and prior to fish being recorded at sites upstream from Bonneville Dam, (3) for all unique fallback events from fish that exited from the Bradford Island fishway only, and (4) for fallback events that occurred within 24 h after fish exited from the Bradford Island fishways and prior to fish being recorded at sites upstream from Bonneville Dam.

Fallback percentages were also related to spill, flow, TDG levels, and water temperature using simple regression analysis. Hourly levels of environmental variables collected at Bonneville Dam by USACE personnel were downloaded from the internet web site (http://www.nwd-wc.usace.army.mil/TMT/tdg_data/months.html) and assigned to each fish based on the time they exited fishways. Fallback percentages for each block of time were regressed on mean spill, flow, TDG, or water temperature for all fish that exited during that treatment within a block. Because river environmental variables tend to be highly correlated, each was related to fallback rates separately in univariate regression analyses. A significance level of alpha = 0.05 was used for all tests.

We related time for fish to locate and enter the fishways to spill level at Bonneville Dam. Passage times for each fish were calculated from the time they first reached the tailrace at Bonneville Dam until they first approached a fishway entrance and first entered a fishway. Similar to the fallback analysis, blocks during which at least nine or ten fish with passage times were used as replicates in analysis. Each fish was assigned to a spill treatment based on the spill at the time they first entered the tailrace. Because a few fish had significantly longer passage times than the majority of the run, we used median times for the fish in each group as the measure of passage.

Results

Of the 1,813 chinook salmon and steelhead released downstream from Bonneville Dam prior to cessation of spill on 31 August 2001, 1,624 were recorded exiting from the top of one of the two fishways, and 180 (11.1%) of those were identified as fish that fell back at the dam at least once (Table 1). Some salmon and steelhead fell back and reascended the dam multiple times, resulting in an additional 203 exits at the top of the fishways and an additional 42 fallbacks during the study period, for a total of 222 fallback events from 1,827 exits (12.2% fallback rate) for the year. Only the initial fallback events by each fish were used in our analysis. Of the 1,624 salmon and steelhead that exited from the fishway, 1,566 fish exited during one of the two daytime treatment periods, resulting in 173 unique fallback events and a percent fallback of 11.0% (Table 1). Most of the 58 fish eliminated from the analysis had exited the fishways at night when spill treatments were not maintained. There was a period of five blocks during which only the low-spill treatment occurred at the end of the spill season. Fish that passed Bonneville Dam at that time were not used in analysis since there were no corresponding high-spill treatment blocks for comparison. Fish in the late-period blocks were excluded from the analysis (68 fall chinook salmon, 49 steelhead, and 5 fallback events), leaving 1,449 unique fish that exited both fishways and 168 fallback events with a

Table 1. Number of spring/summer chinook salmon (Sp./Su. chin), steelhead, and fall chinook salmon released downstream from Bonneville Dam from 1 April until 31 August, and the number of those fish recorded at the dam and that exited from a fishway, the number and percent that fell back at least once at the dam, and the total number of exits and fish that fell within spill treatments and were used in analysis.

		Total that			Used in analysis		
Group	Released	exited	fell back	%	exited	fell back	%
			Passage at both fishways				
Sp./Su. chin.	973	945	124	13.1	897	119	13.3
Steelhead	541	502	48	9.6	446	47	10.6
Fall chinook	299	177	8	4.5	106	2	1.9
Total	1,813	1,624	180	11.1	1,449	168	11.6
			Passage at Bradford Island fishway only				
Sp./Su. chin.	973	556	105	18.9	531	101	19.0
Steelhead	541	269	46	17.1	228	45	19.7
Fall chinook	299	130	6	4.6	73	2	2.7
Total	1,813	955	157	16.4	832	148	17.8

percent fallback of 11.6% available for analysis (Table 1).

Unique Fallbacks From Both Fishways

There was no significant difference in fallback percentages between periods with high and low spill levels for chinook salmon and steelhead that were recorded exiting from both fishways at Bonneville Dam. There were 40 replicate blocks of the high-spill treatment and 45 replicates with the low-spill treatment. The last 5 blocks of the low-spill treatment were not used in this analysis since there were no corresponding high-spill blocks during that period (see Appendix A for block groupings). From the 1,449 unique fish that exited either fishway there were 168 fallback events (11.6% fallback) used in this analysis. Fallback averaged 9.5% (95% confidence interval ± 2.4%) during the low-spill periods, and 13.5% (± 3.7%) during the high-spill periods (Table 2). Spill levels averaged 71 kcfs (± 2 kcfs) during the low-spill treatment and 103.6 kcfs (± 4 kcfs) during the high-spill treatment (ANOVA $P < 0.0001$), based on the time fish left the fishways. Fallback percentages were also not related to mean spill levels based on results of the regression analysis (Figure 3 and Table 3). Fallback percentages were significantly related to flow and TDG levels, and negatively related to average water temperature and date during the study period (Table 3 and Appendix B). Fallback had the highest correlations with water temperature and date, which were highly correlated with each other, and then with flow and TDG levels (Table 4). Spill levels at Bonneville Dam in 2000 were not well correlated with other environmental variables (Table 4).

When fallbacks that occurred after fish were recorded at sites upstream from Bonneville Dam, and those fallbacks that occurred later than 24 h after fish first exited from the fishways were removed, there remained 115 unique fallback events of which 109 (67 spring/summer chinook salmon, 43 steelhead, and 2 fall chinook salmon) were used in analysis. Those 109 fallback events resulted from the same 1,449-fishway exits used in the analysis described above, for an overall 'near-time' fallback of 7.5%. Near-time fallback averaged 6.2% (± 2.1%, n = 40) during the low-spill treatment, and 9.3% (± 2.5%, n = 40) during high-spill treatment, which were not significantly different based on the ANOVA analysis (Table 2). In the regression analysis, near-time fallback percentages were not significantly related to mean spill (Figure 3), flow, TDG, date, or water temperature at the time chinook salmon and steelhead exited from the fishways at Bonneville Dam in 2000 (Table 4 and Appendix B).

Fallbacks of Fish That Used the Bradford Island Fishway

A total of 955 salmon and steelhead were recorded as they exited from the Bradford Island fishway (not including multiple passages by fallback fish), of which 157 fish (16.4%) fell back at the dam (Table 1). Of the 955 fish that exited the Bradford fishway, 832 exits and 148 fallback events were used in our analysis, resulting in 27 replicate blocks of spill treatments. There were 32 replicate blocks of the low-spill treatment, but the last 5 blocks were not used in this analysis since there were no corresponding high-spill blocks during that period. For fish that used the Bradford Island fishway, fallback averaged 14.9% (± 3.9%) during the low-spill treatment, and 20.6% (± 4.9%) during the high-spill periods (Table 2). Spill levels at the time fish exited the Bradford fishway averaged 70.6 kcfs (± 2.9 kcfs) during the low-spill treatment and 104.2 kcfs (± 5.2 kcfs) during the high-spill treatment (ANOVA $P < 0.0001$). Fallback percentages were significantly related to flow and TDG levels, negatively related to average water temperature and date, and nearly significant for spill level (logistic regression $P = 0.056$; Figure 4) based on results of regression analysis (Table 3 and Appendix B). Correlations with fallback rates were similar for all five environmental variables, being highest with date and temperature and lowest with spill (Table 4).

There were 112 unique near-time fallback events for salmon and steelhead that passed the dam using the Bradford Island fishway, of which 107 (63 spring/summer chinook salmon, 42 steelhead, and 2 fall chinook salmon) were used in analysis. Those 107 fallback events resulted from the same 832 Bradford fishway exits used in the analysis described above, for overall near-time fallback of 12.9%. Near-time fallback from the Bradford Island fishway averaged 10.2% (± 2.9%, n = 27) during the low-spill level, and 15.8% (± 3.6%, n = 27) during high-spill treatment, and these values were significantly different based on the ANOVA analysis (Table 2). None of the five environmental variables we tested were significantly related to the Bradford Island fishway near-time fallback percentages based on the regression analysis, although spill was nearly not significant (logistic regression $P = 0.054$) (Table 3 and Figure 4).

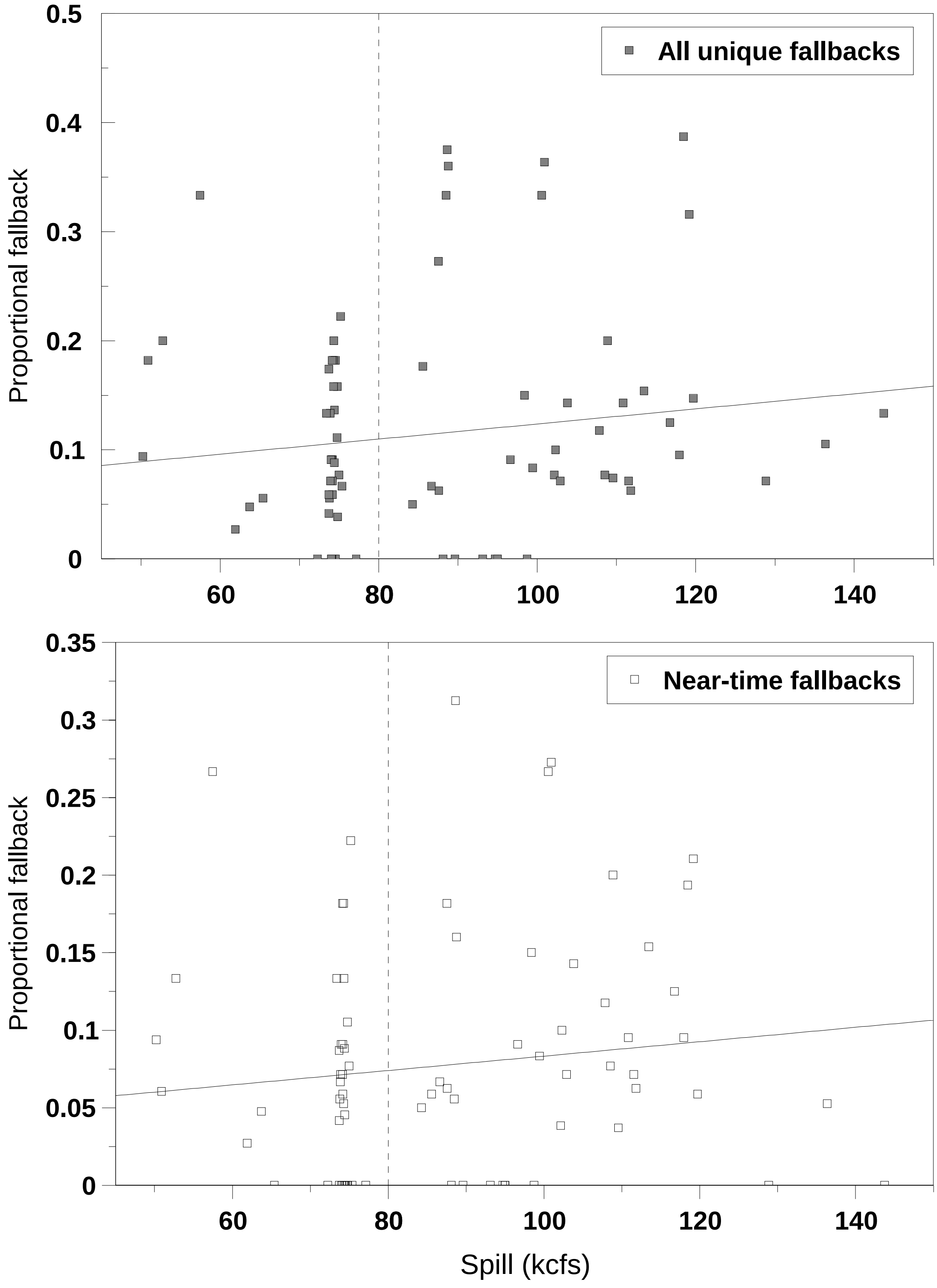

Figure 3. Fallback per block versus mean spill level at time fish left fishways for all unique chinook salmon and steelhead that fell back, and for fish that fell back within 24 h of first passing Bonneville Dam (near-time fallbacks) in 2000. Vertical dashed line represents separation between high- and low-spill treatments.

Table 2. Percent fallback and 95% confidence limits and sample size and ANOVA significance levels for adult salmon at Bonneville Dam during 2000. ANOVA analysis were for fallback events for eligible fish that passed from either fishway, and near-time fallbacks from either fishway, and for eligible fish that passed from the Bradford Island fishway and near-time fallbacks from the Bradford Island fishway.

	% Fallback			ANOVA
Analysis	Low spill	High spill	N	P
Either fishway	9.5 ± 2.4	13.5 ± 3.7	40	0.156
Either fishway, near-time fallbacks	6.2 ± 2.1	9.3 ± 2.5	40	0.069
Bradford fishway	14.9 ± 3.9	20.6 ± 4.9	27	0.081
Bradford fishway, near-time fallbacks	10.2 ± 2.9	15.8 ± 3.6	27	0.031

Discussion

We believe that evaluating effects of spill on fallback at Bonneville Dam should rely primarily on the near-time fallback percentages. Our rationale is that fallback events that occur more than 24 h after a fish has passed the dam are less likely to be related to flow and spill at the dam and location of the fishways than to some other factors that cause the fish to move up and then down the river. This would be especially true for fish that moved upstream at least as far as Cascade Locks, Oregon 2.5 km) before returning (downstream and falling over Bonneville Dam. Fish actively moving downstream at the time they reached Bonneville Dam likely continued downstream and fell back at the dam regardless of whether spill was high or low.

In previous studies we have found significant correlations between spill volume and fallback rates and percentages at Bonneville Dam (Bjornn et al. 2000a). In this study we found somewhat ambiguous results in correlations of percent fallback of adult chinook salmon and steelhead versus spill levels at Bonneville Dam during spring and summer 2000. Near-time fallback percentages were not significantly different between spill treatments for fish that exited from both fishways, and were significantly higher during the high-spill treatment than the low-spill treatment for fish that exited from the Bradford Island fishway. The experimental design of the study appears to have been effective. Prior to performing this study, we determined that a difference of 5% in fallback would be detectable with a sample size of about 30-32 replicates per treatment, and this held true. For all near-time fallbacks, a difference of 3% in fallback rates between treatments with 40 replicates was not significant, but a difference of over 5% in fallback rates with 27 replicates from Bradford Island fish was significant. However, in the regression analysis, near-time fallbacks were consistently not related to spill levels. The ambiguousness of the results was related to the high level of variation in the data. Fallback rates per replicate block ranged from 0 to over 30% or 40% regardless of spill treatment (Figures 3 and 4).

Table 3. Results of univariate linear and logistic regression analysis relating effects of mean spill, flow, total dissolved gas levels (TDG), and water temperature at time fish left fishways to fallback for all unique fish that fell back at Bonneville Dam and for those fish that fell back within 24 h of passing the dam (near-time fallbacks).

		Linear regression			Logistic
Variable	N	Slope	R2	P	P
All fish that fell back from both fishways					
Spill	80	0.0007	0.018	0.235	0.106
Flow	80	0.0004	0.068	0.020	0.004
TDG	80	0.0063	0.065	0.023	0.005
Temp.	80	-0.0086	0.127	0.001	0.0001
Date	80	-0.0008	0.117	0.002	0.0002
Near-time fallback events from both fishways					
Spill	80	0.0005	0.014	0.292	0.163
Flow	80	0.000005	0.0000	0.967	0.803
TDG	80	0.0006	0.001	0.783	0.601
Temp.	80	-0.0019	0.011	0.351	0.298
Date	80	-0.0002	0.008	0.437	0.383
All fish that fell back from the Bradford Island fishway					
Spill	54	0.0013	0.047	0.116	0.056
Flow	54	0.0006	0.108	0.015	0.006
TDG	54	0.0082	0.081	0.037	0.014
Temp.	54	-0.0103	0.133	0.007	0.003
Date	54	-0.0009	0.120	0.010	0.004
Near-time fallback events for fish from the Bradford Island fishway					
Spill	54	0.0011	0.056	0.084	0.054
Flow	54	0.00007	0.003	0.695	0.565
TDG	54	0.0004	0.0003	0.901	0.546
Temp.	54	-0.0022	0.011	0.455	0.453
Date	54	-0.0002	0.008	0.532	0.489

Contributing to variable results may have been problems implementing the high-spill treatments and the somewhat arbitrary limit of 80 kcfs we used to demarcate the low- and high-spill levels. During the spring, spill levels > 100 kcfs could not be attained because of excessive TDG levels, resulting in a relatively narrow range of spill volume

Table 4. Correlation matrix for mean environmental variables of river flow, total dissolved gas (TDG) levels, water temperature, date, and spill at time fish left fishways and all unique fallback events (All FB's) and near-time fallback events (NT FB's) for chinook salmon and steelhead fish at Bonneville Dam in 2000. Sample size = 80 blocks.

	Flow	TDG	Temp.	Date	Spill	All FB's	NT FB's
For fish passing both fishways							
Flow		0.75	-0.92	-0.94	0.17	0.26	0.01
TDG	0.75		-0.74	-0.75	0.21	0.25	0.03
Temp.	-0.92	-0.74		0.98	-0.001	-0.35	-0.11
Date	-0.94	-0.75	0.98		-0.01	-0.34	-0.09
Spill	0.17	0.21	-0.001	-0.01		0.13	0.12
For fish passing Bradford Island fishway only							
Flow		0.76	-0.94	-0.95	0.16	0.33	0.05
TDG	0.76		-0.72	-0.73	0.24	0.29	0.02
Temp.	-0.94	-0.72		0.98	0.03	-0.36	-0.10
Date	-0.95	-0.73	0.98		0.01	-0.35	-0.09
Spill	0.16	0.24	0.03	0.01		0.22	0.24

during the test relative to spring-time spill levels in previous years. Had there been more separation between the high- and low-spill treatment levels, results may have been more conclusive. Also, because the test was designed specifically to compare low- and high-spill levels, periods of time with no spill or very low spill (< 50 kcfs) were not used in the analysis. Had no-spill periods (and their resulting low fallback rates) been included, it is more likely that fallback rates would have been significantly related to spill in the regression models.

For spring and summer chinook salmon, the percentage of fish that fell back in 2000 was 13.1% (124 fallbacks from 945 unique fish exits, Table 1). The 2000 percentage of fish that fell back was within the range observed during the previous three years of this study (13.9%, 14.7%, and 11.4% during 1996, 1997, and 1998; Bjornn et al. 2000a). The percentages given above are based on the number of fish recorded as they exited the fishways, and may become slightly lower as we complete analysis of the 2000 dataset and identify all fish that passed Bonneville Dam but were not recorded at the tops of the fishways. The overall percentage of spring and summer chinook salmon that fell back after passing the dam via the Bradford Island fishway (18.9%) and the percentage of all fallbacks that were by fish that used the Bradford fishway (85%) were also within the ranges we observed previously (Bjornn et al. 2000a). Overall, 2000 appeared to be a typical year with respect to patterns of fallback at Bonneville Dam.

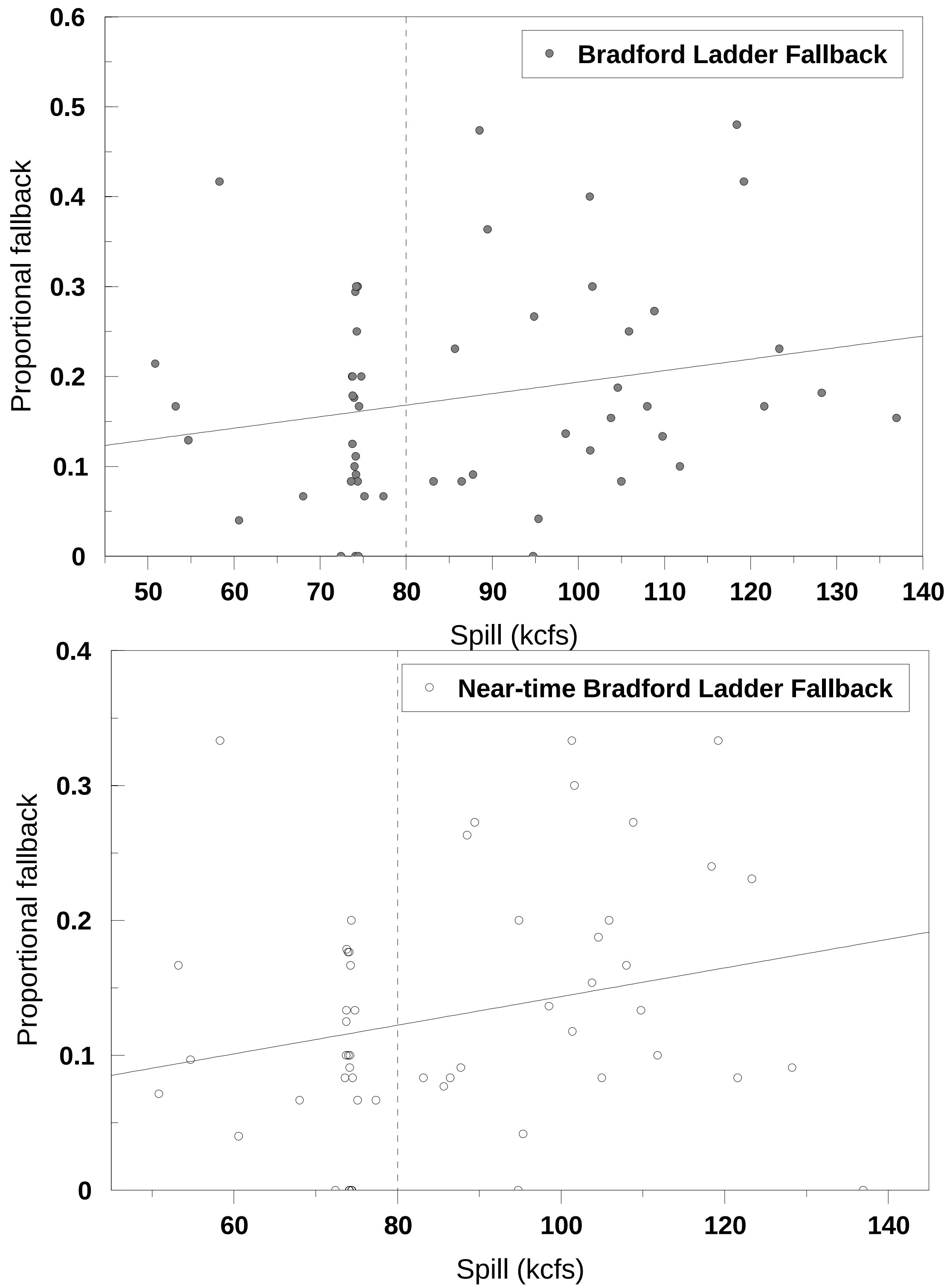

Figure 4. Fallback per block versus mean spill level for all unique chinook salmon and steelhead that fell back after exiting from the Bradford Island fishway, and for fish from the Bradford Island fishway that fell back within 24 h after first passing Bonneville Dam (near-time fallbacks) in 2000.

The percentage of adult salmon and steelhead that fall back over Bonneville Dam is related to spill, despite the lack of a significant correlation in the 2000 test data. When no water was spilled, the percentages of fish that fell back in each of the blocks were low (0-5%), and when water was spilled at the dam the percentages that fell back were higher. The percentage of fish that used either fishway and fell back averaged 9.5% during the low-spill treatment, and was 6.2% for near-time fallback fish. The percentage of near-time fallback fish that exited the Bradford Island fishway was significantly lower during the low-spill treatment, averaging 10.2%, than during the high-spill treatment at 15.8%. Also, the percentages of spring and summer chinook salmon that fell back after they exited the Bradford Island fishway in 1996 and 1997 were 21.7% and 22.8% with high spill levels (200-400 kcfs) versus 16.5% and 18.9% in 1998 and 2000 with lower spill levels (mostly < 150 kcfs), another indication of the role spill plays in fallback rates at Bonneville Dam.

In the range of flows and spill that occurred in 2000, and were included in the test, there was evidence that a higher percentage of fish fell back at the high-spill level than at the low-spill level, especially for fish that used the Bradford Island fishway. There is also a base percentage of the fish that fall back at the dam, regardless of spill level, that probably includes fish that migrate upstream past their natal stream and must return downstream to complete their migration, and the fish that seem confused as to where to go. The latter group is best typified by the fish that migrate upstream some distance then turn around, come back downstream to the dam, fallback, and then reascend and continue their migration upstream. This base rate of fallback is probably 5% or less, but may be as high as 10% during the spring with low spill.

The proportion of the fallback fish that we need to be concerned about are those fish that migrate into the spillway forebay and fallback. The changes that can be made to reduce the proportion of fish that fall back are of two types: (1) reduce the spill so that fish do not accidentally fall back through the spillway if they happen to enter the spillway forebay, and (2) reduce the number of fish that enter the spillway forebay. Both changes have tradeoffs and problems. Flow and spill cannot always be controlled, and passage via the spillway is the preferred way to pass smolts at the dam. Reducing the number of adult migrants that enter the spillway forebay is possible, but it will probably require that a new exit for the Bradford Island fishway be located on or near the Oregon shoreline rather than the present exit on Bradford Island.

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Appendix A

Spill treatment and block groupings used in fallback analysis.

Treatment 1 = low spill. Treatment 2 = high spill.

Exits from either fishway.

Treatment	Day	Date	Exits	Block
1	1	07-Apr	9	1
1	2	11-Apr	24	1
1	3	13-Apr	15	2
2	1	13-Apr	4	1
1	4	14-Apr	6	3
1	5	15-Apr	6	3
1	6	16-Apr	6	3
1	7	17-Apr	32	4
1	8	18-Apr	15	5
2	2	18-Apr	16	1
2	3	19-Apr	18	2
2	4	20-Apr	9	2
1	9	20-Apr	9	6
1	10	21-Apr	22	7
2	5	22-Apr	19	3
2	6	23-Apr	15	4
2	7	24-Apr	14	5
2	8	25-Apr	27	6
2	9	26-Apr	7	6
1	11	26-Apr	15	8
1	12	27-Apr	19	9
1	13	28-Apr	23	10
2	10	29-Apr	19	7
2	11	30-Apr	31	8
2	12	01-May	21	9
2	13	02-May	26	10
2	14	03-May	17	11
2	15	04-May	12	12
1	14	05-May	19	11
1	15	06-May	14	12
1	16	07-May	8	12
2	16	07-May	15	13
2	17	09-May	12	14
2	18	10-May	5	14
1	18	12-May	6	13
1	19	13-May	5	13
2	19	14-May	9	15
2	20	15-May	10	15
2	21	16-May	6	15
1	20	17-May	4	14
1	21	18-May	4	14
1	22	19-May	10	14
2	22	20-May	1	16
2	23	21-May	6	16
2	24	22-May	11	16
1	23	23-May	3	15
1	24	24-May	5	15
1	25	25-May	7	15
2	25	25-May	5	17

Exits from Bradford Island fishway only.

Treatment	Day	Date	Exits	Block
1	1	07-Apr	7	1
1	2	11-Apr	21	1
1	3	13-Apr	12	2
2	1	14-Apr	2	1
1	4	14-Apr	5	3
1	5	15-Apr	3	3
1	7	17-Apr	23	3
1	8	18-Apr	12	4
2	2	18-Apr	10	1
2	3	19-Apr	6	2
2	4	20-Apr	6	2
1	9	20-Apr	4	5
1	10	21-Apr	13	5
2	5	22-Apr	11	3
2	6	23-Apr	7	4
2	7	24-Apr	6	4
2	8	25-Apr	20	5
2	9	26-Apr	4	5
1	11	26-Apr	10	6
1	12	27-Apr	15	7
1	13	28-Apr	20	8
2	10	29-Apr	12	6
2	11	30-Apr	25	7
2	12	01-May	7	8
2	13	02-May	9	8
2	14	03-May	9	9
2	15	04-May	4	9
1	14	05-May	10	9
1	15	06-May	3	10
1	16	07-May	3	10
2	16	08-May	1	10
2	17	09-May	7	10
2	18	10-May	5	10
1	18	12-May	2	10
1	19	13-May	4	10
2	19	14-May	4	11
2	20	15-May	6	11
2	21	16-May	1	11
1	20	17-May	2	11
1	21	18-May	2	11
1	22	19-May	4	11
2	22	20-May	1	12
2	23	21-May	2	12
2	24	22-May	5	12
1	23	23-May	1	1
1	24	24-May	1	11
2	25	25-May	3	12
2	26	27-May	3	12
2	27	28-May	5	12

2	26	27-May	4	17
2	27	28-May	7	17
1	26	29-May	2	16
1	27	30-May	7	16
1	28	31-May	6	17
1	29	01-Jun	5	17
1	30	02-Jun	5	18
1	31	03-Jun	6	18
2	29	04-Jun	11	18
2	30	05-Jun	6	19
2	31	06-Jun	4	19
2	32	07-Jun	8	20
2	33	08-Jun	6	20
2	34	09-Jun	2	20
1	32	10-Jun	4	19
1	33	11-Jun	6	19
1	34	12-Jun	1	19
1	35	13-Jun	4	20
1	36	14-Jun	7	20
1	37	15-Jun	4	20
2	35	16-Jun	9	21
2	36	17-Jun	5	21
2	37	18-Jun	6	22
2	38	19-Jun	8	22
2	39	20-Jun	6	23
2	40	21-Jun	9	23
1	38	22-Jun	8	21
1	39	23-Jun	5	21
1	40	24-Jun	3	22
1	41	25-Jun	6	22
1	42	26-Jun	6	23
1	43	27-Jun	8	23
2	41	28-Jun	5	24
2	42	29-Jun	5	24
2	43	30-Jun	6	24
1	44	01-Jul	5	24
1	45	02-Jul	5	24
1	46	03-Jul	5	24
2	44	04-Jul	7	25
2	45	05-Jul	4	25
2	46	06-Jul	6	25
1	47	07-Jul	5	25
1	48	08-Jul	5	25
1	49	09-Jul	7	25
2	47	10-Jul	7	26
2	48	11-Jul	8	26
2	49	12-Jul	2	27
2	50	13-Jul	11	27
2	51	14-Jul	9	28
2	52	15-Jul	5	28
1	50	16-Jul	13	26
1	51	17-Jul	9	27

1	26	29-May	1	12
1	27	30-May	7	12
1	28	31-May	4	12
1	29	01-Jun	2	13
1	30	02-Jun	2	13
1	31	03-Jun	5	13
2	29	04-Jun	8	13
2	30	05-Jun	5	13
2	31	06-Jun	2	13
2	32	07-Jun	5	14
2	33	08-Jun	5	14
2	34	09-Jun	1	14
1	32	10-Jun	3	14
1	33	11-Jun	6	14
1	34	12-Jun	1	14
1	35	13-Jun	3	14
1	36	14-Jun	3	14
1	37	15-Jun	1	14
2	35	16-Jun	6	15
2	36	17-Jun	3	15
2	37	18-Jun	4	15
2	38	19-Jun	6	16
2	39	20-Jun	5	16
2	40	21-Jun	4	16
1	38	22-Jun	4	15
1	39	23-Jun	4	15
1	40	24-Jun	3	15
1	41	25-Jun	3	16
1	42	26-Jun	5	16
1	43	27-Jun	6	16
2	41	28-Jun	2	17
2	42	29-Jun	4	17
2	43	30-Jun	4	17
1	45	02-Jul	4	17
1	46	03-Jul	4	17
2	44	04-Jul	5	18
2	45	05-Jul	3	18
2	46	06-Jul	4	18
1	47	07-Jul	4	17
1	48	08-Jul	5	18
1	49	09-Jul	6	18
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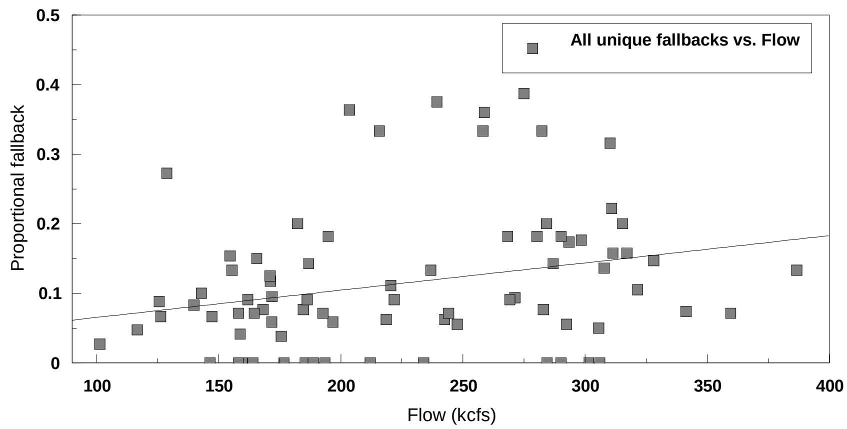
2	48	11-Jul	5	19
2	49	12-Jul	1	19
2	50	13-Jul	8	20
2	51	14-Jul	4	20
2	52	15-Jul	3	20
1	50	16-Jul	6	19
1	51	17-Jul	7	19
1	52	18-Jul	2	19
1	53	19-Jul	1	20
1	54	20-Jul	10	20

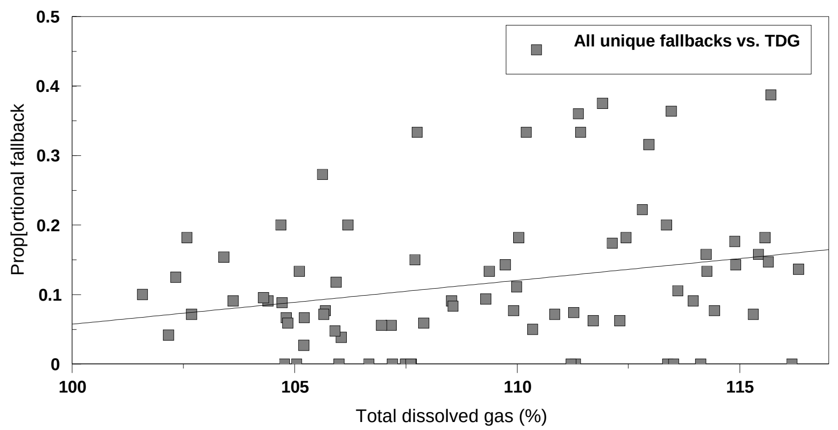
1	52	18-Jul	4	27
1	53	19-Jul	9	28
1	54	20-Jul	17	28
1	55	21-Jul	9	29
2	53	22-Jul	6	29
2	54	23-Jul	13	29
2	55	24-Jul	6	29
1	56	24-Jul	1	29
1	57	25-Jul	14	30
1	58	26-Jul	14	31
1	59	27-Jul	6	31
2	56	28-Jul	7	30
2	57	29-Jul	13	30
1	60	30-Jul	4	31
2	58	30-Jul	5	31
2	59	31-Jul	14	31
2	60	01-Aug	15	32
2	61	02-Aug	11	33
1	61	03-Aug	9	32
1	62	04-Aug	18	32
1	63	05-Aug	15	33
2	62	06-Aug	11	34
2	63	07-Aug	12	35
2	64	08-Aug	9	35
1	64	09-Aug	17	34
1	65	09-Aug	18	35
1	66	11-Aug	10	35
2	65	12-Aug	9	36
2	66	13-Aug	17	36
2	67	14-Aug	16	37
1	67	15-Aug	14	36
1	68	16-Aug	10	36
1	69	17-Aug	19	37
1	70	18-Aug	14	37
1	71	19-Aug	12	38
1	72	20-Aug	22	38
2	68	20-Aug	15	38
1	73	21-Aug	21	39
2	69	22-Aug	3	39
2	70	23-Aug	9	39
1	74	24-Aug	16	40
1	75	25-Aug	17	40
1	76	26-Aug	4	40
2	71	26-Aug	10	40
1	77	27-Aug	19	41
1	78	28-Aug	32	42
1	79	29-Aug	29	43
1	80	30-Aug	16	44
1	81	31-Aug	21	45

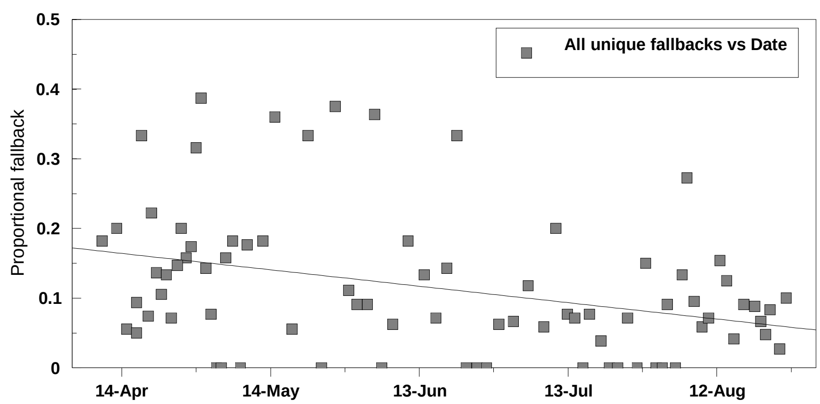
1	55	21-Jul	1	20
2	53	22-Jul	2	21
2	54	23-Jul	4	21
2	55	24-Jul	3	21
1	57	25-Jul	5	21
1	58	26-Jul	8	21
2	56	28-Jul	4	21
2	57	29-Jul	7	21
2	58	30-Jul	2	21
1	60	30-Jul	2	21
2	59	31-Jul	5	22
2	60	01-Aug	10	22
2	61	02-Aug	9	22
1	61	03-Aug	2	22
1	62	04-Aug	8	22
1	63	05-Aug	6	22
2	62	06-Aug	8	23
2	63	07-Aug	6	23
2	64	08-Aug	6	23
1	64	09-Aug	4	23
1	65	09-Aug	8	23
1	66	11-Aug	3	23
2	65	12-Aug	5	24
2	66	13-Aug	10	25
2	67	14-Aug	8	24
1	67	15-Aug	9	24
1	68	16-Aug	3	24
1	69	17-Aug	12	25
1	70	18-Aug	7	25
1	71	19-Aug	9	25
1	72	20-Aug	15	26
1	73	21-Aug	15	26
2	68	20-Aug	12	26
2	70	23-Aug	8	27
1	74	24-Aug	11	27
1	75	25-Aug	14	27
2	71	26-Aug	9	27
1	76	26-Aug	3	28
1	77	27-Aug	13	28
1	78	28-Aug	28	29
1	79	29-Aug	23	30
1	80	30-Aug	11	31
1	81	31-Aug	14	32

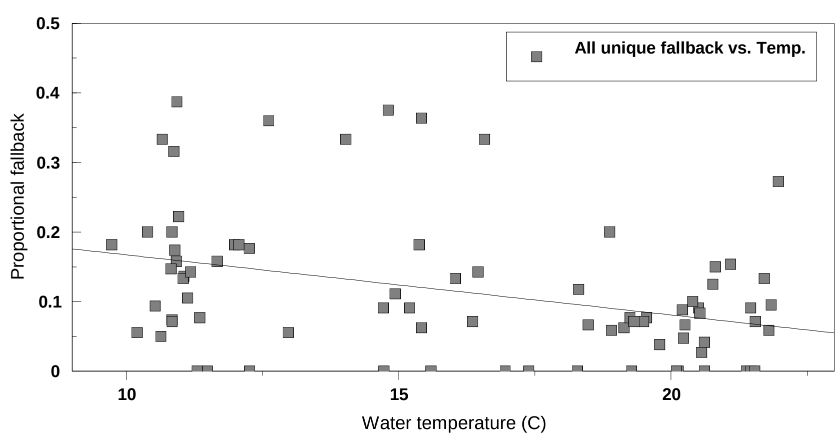
Appendix B

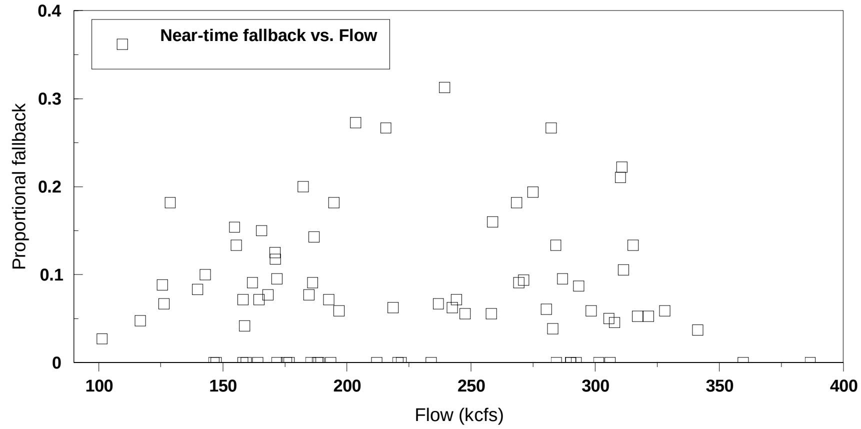
Figures of fallback rates versus mean river flow, total dissolved gas levels, water temperature, and date.

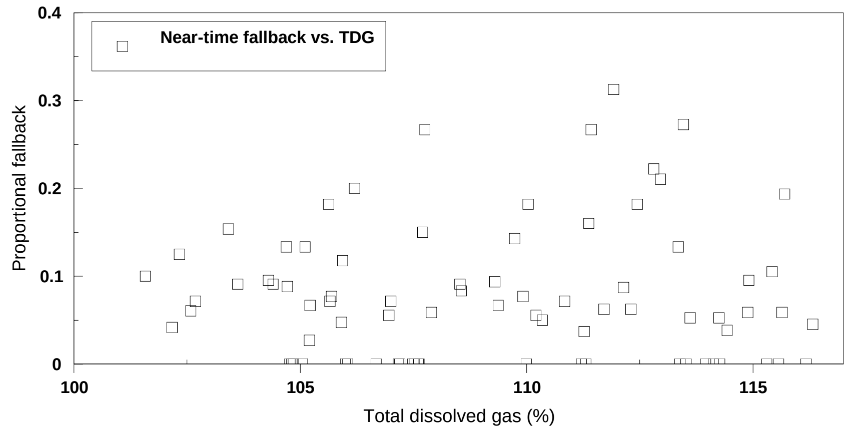

All unique fallbacks vs. Flow
Proportional fallback
Flow (kcfs)
0.5
0.4
0.3
0.2
0.1
0
100
150
200
250
300
350
400

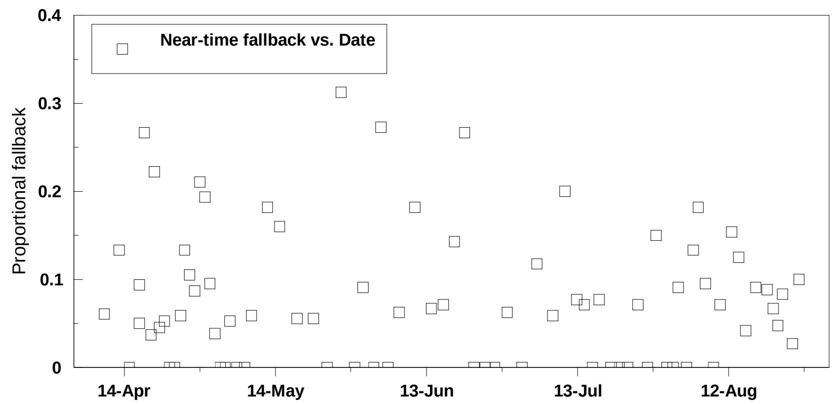

All unique fallbacks vs. TDG
Prop[ortional fallback
Total dissolved gas (%)
0.5
0.4
0.3
0.2
0.1
0
100
105
110
115

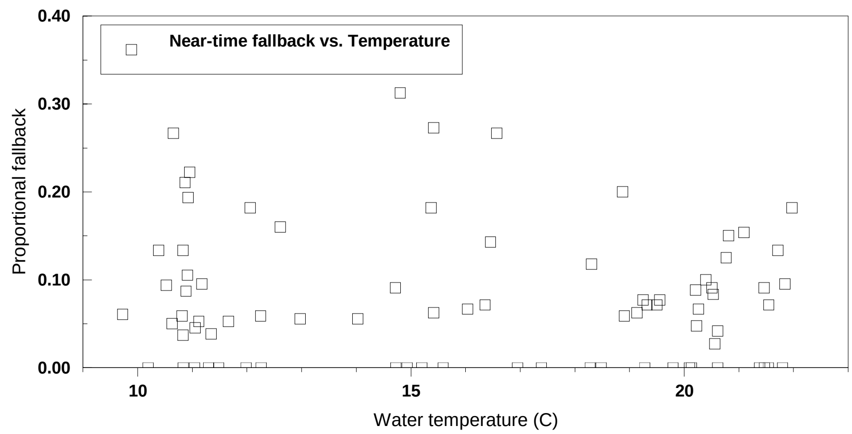

All unique fallbacks vs Date
Proportional fallback
0.5
0.4
0.3
0.2
0.1
0
14-Apr
14-May
13-Jun
13-Jul
12-Aug

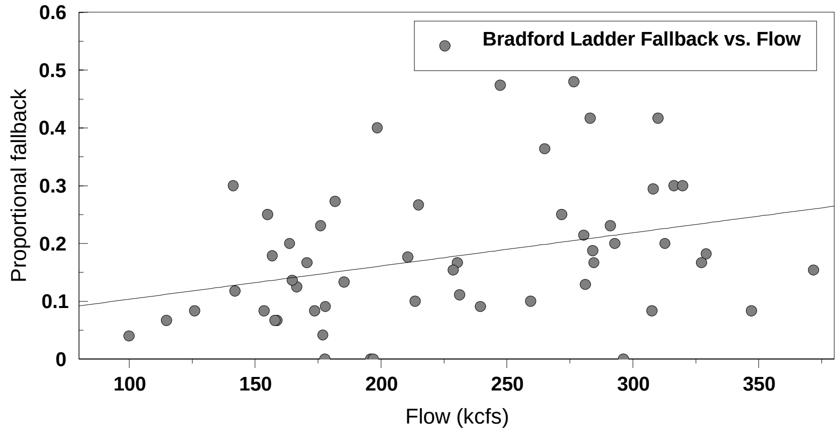

All unique fallback vs. Temp.
Proportional fallback
Water temperature (C)
0.5
0.4
0.3
0.2
0.1
0
10
15
20

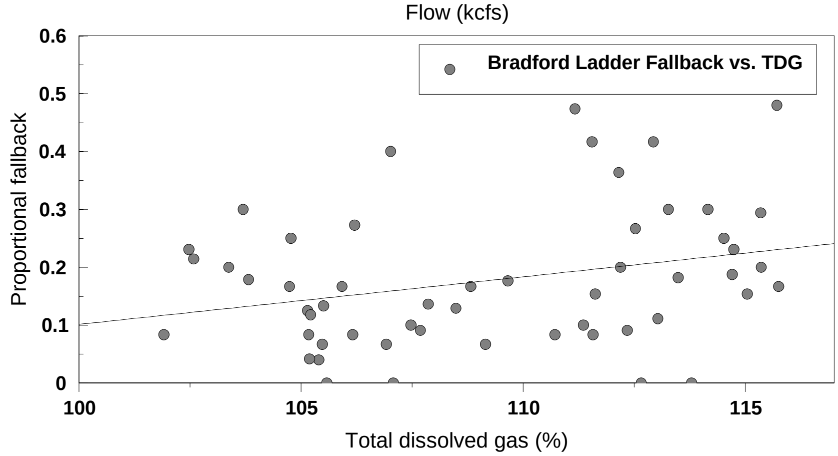

Near-time fallback vs. Flow
Proportional fallback
Flow (kcfs)

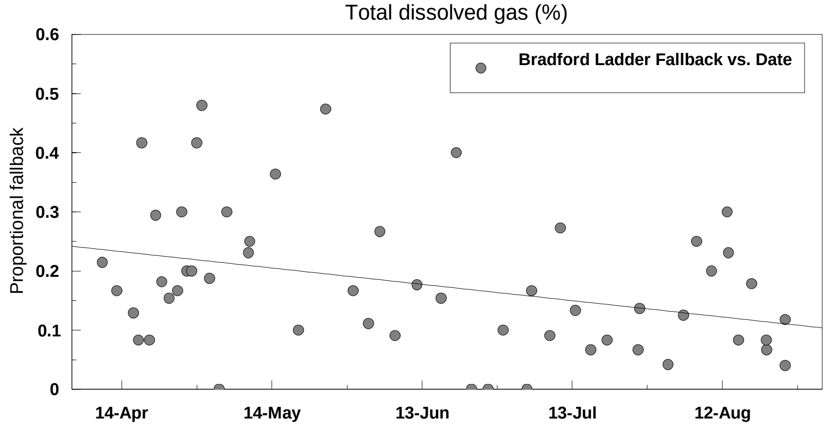

Near-time fallback vs. TDG
Proportional fallback
Total dissolved gas (%)

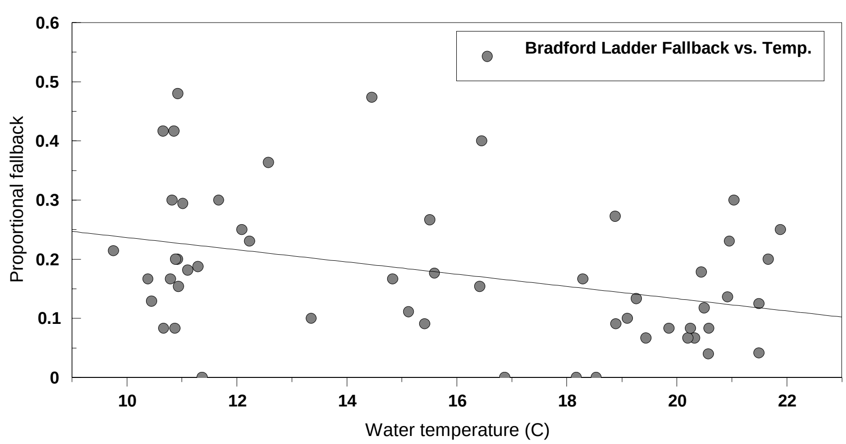

Near-time fallback vs. Date
Proportional fallback
14-Apr
14-May
13-Jun
13-Jul
12-Aug

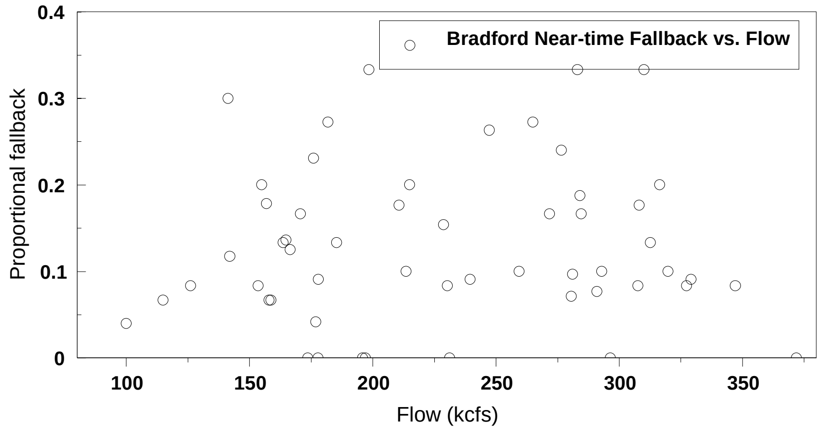

Near-time fallback vs. Temperature
Proportional fallback
Water temperature (C)

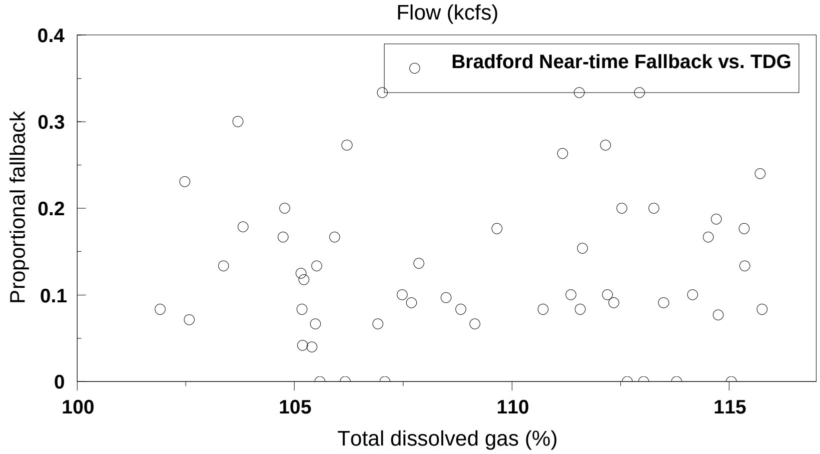

Bradford Ladder Fallback vs. Flow
Proportional fallback
0
0.1
0.2
0.3
0.4
0.5
0.6
100
150
200
250
300
350
Flow (kcfs)

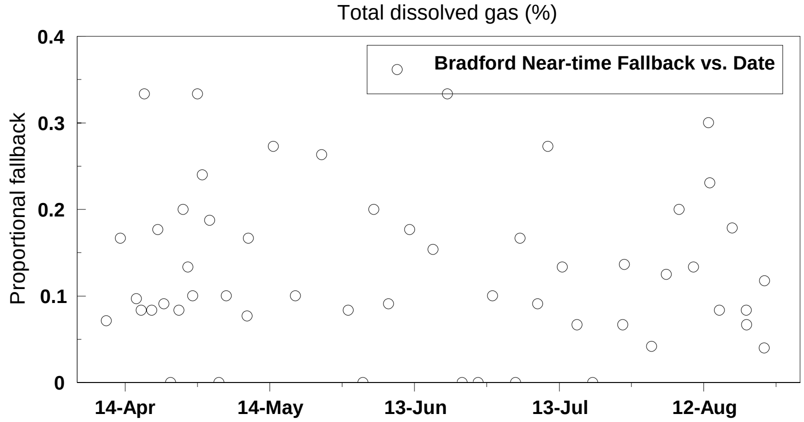

Bradford Ladder Fallback vs. TDG
Proportional fallback
0
0.1
0.2
0.3
0.4
0.5
0.6
100
105
110
115
Total dissolved gas (%)

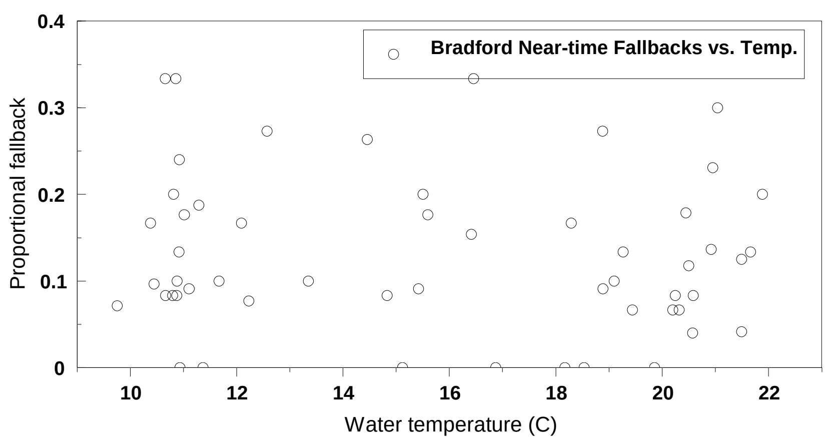

Bradford Ladder Fallback vs. Date
Proportional fallback
0
0.1
0.2
0.3
0.4
0.5
0.6
14-Apr
14-May
13-Jun
13-Jul
12-Aug


Bradford Ladder Fallback vs. Temp.
Proportional fallback
0
0.1
0.2
0.3
0.4
0.5
0.6
10
12
14
16
18
20
22
Water temperature (C)


Bradford Near-time Fallback vs. Flow
Proportional fallback
Flow (kcfs)
0.4
0.3
0.2
0.1
0
100
150
200
250
300
350


Bradford Near-time Fallback vs. TDG
Proportional fallback
Total dissolved gas (%)
0.4
0.3
0.2
0.1
0
100
105
110
115


Bradford Near-time Fallback vs. Date
Proportional fallback
0.4
0.3
0.2
0.1
0
14-Apr
14-May
13-Jun
13-Jul
12-Aug


Bradford Near-time Fallbacks vs. Temp.
Proportional fallback
Water temperature (C)
0.4
0.3
0.2
0.1
0
10
12
14
16
18
20
22