Transactions of the American Fisheries Society 133:932–949, 2004

Fallback, Reascension, and Adjusted Fishway Escapement Estimates for Adult Chinook Salmon and Steelhead at Columbia and Snake River Dams

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Abstract.—During their upstream spawning migration in the Columbia River basin, some adult salmonids *Oncorhynchus* spp. ascend and then fall back over main-stem hydroelectric dams. Fallback can result in fish injury or death, migration delays, and biases in fishway counts, the primary index for escapement and the basis for production estimates and harvest quotas. We used radiotelemetry to calculate fallback percentages and rates, reascension percentages, biases in fishway escapement estimates due to fallback, and occurrence of behaviorally motivated fallback (correcting overshoot of natal sites) by spring–summer and fall Chinook salmon *O. tshawytscha* and steelhead *O. mykiss*. The study area included eight Columbia River and Snake River dams evaluated from 1996 to 2001. For all years combined, about 22% of spring–summer Chinook salmon, 15% of fall Chinook salmon, and 21% of steelhead fell back at least once at a dam. Fallback percentages for spring–summer Chinook salmon were generally highest at Bonneville and the Dalles dams and decreased at progressively upstream dams. Fallback rates for spring–summer Chinook salmon were positively correlated with river discharge. Fallback percentages for steelhead and fall Chinook salmon were less variable between years but were more variable between dams than those of spring–summer Chinook salmon. Reascension percentages at dams ranged widely between runs and sites and were negatively related to the number of fish that entered tributaries downstream from the fallback location. Fall Chinook salmon were the most likely to enter a downstream tributary after falling back, though this behavior was also observed in spring–summer Chinook salmon and steelhead. For all years and at all dams, fallback produced positive fishway count biases ranging from 1% to 16% for spring–summer Chinook salmon, 1% to 38% for fall Chinook salmon, and 1% to 12% for steelhead.

Adult salmonids *Oncorhynchus* spp. migrating upriver and exiting the fishways of Columbia and Snake River dams will occasionally pass back downstream over the dam via spillways, turbine intakes, navigation locks, debris sluiceways, or juvenile fish collection devices, an event referred to as fallback. Migrating anadromous fish are both positively rheotactic and shoreline oriented during migration (Groot and Margolis 1991). When exiting fishways and confronting the impounded water of a dam forebay, migrants may be attracted to water passing through spillways, sluiceways, and turbine intakes or may orient with the upstream face of the dam and enter these areas. Additionally, a salmon or steelhead *O. mykiss* that migrates upstream beyond its natal stream or hatchery and passes an upstream dam may fall back in an effort to return; this temporary straying or ‘‘overshooting’’ behavior has been described for many salmonids (Ricker 1972).

Fallback has been documented at all Columbia and Snake River hydrosystem dams, and attempts have been made to quantify its effects on upriver migrants (Liscom et al. 1977; Bjornn and Peery 1992). Although not all fish that fall back suffer mortality or injury, death and injury do occur (Wagner and Hilsen 1992), and salmon and steelhead that fall back at dams are less likely to reach spawning tributaries and hatcheries than those that do not fall back (Boggs et al. 2004). Fallback has been associated with significant migration delays through the Columbia River hydrosystem (Monan and Liscom 1975, 1979). Keefer et al. (in press) reported significant delays of several days to several weeks for radio-tagged Chinook salmon *O. tshawytscha* and steelhead that fell back.

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Received July 25, 2003; accepted January 7, 2004

Fish that fall back at and subsequently reascend dams can be counted more than once, which leads to a positive bias in fish counts and escapement calculations. Counts at dams are also used to estimate adult salmon and steelhead run sizes and to calculate interdam conversion rates (estimates of between-dam survival; Dauble and Mueller 2000), as well as to evaluate the effects of changes in dam operations, such as spill patterns and turbine discharges. Biases in counts at Columbia and Snake River dams can exceed 10% of the total fish run (Bjornn et al. 2000b; Boggs et al. 2004) and have serious management implications. For instance, several evolutionarily significant steelhead and Chinook salmon populations in the Columbia and Snake rivers are federally listed as threatened or endangered species (Busby et al. 1996; Meyers et al. 1998), and fish counts at dams are used to make decisions affecting those stocks, such as setting harvest quotas and the timing and length of commercial, tribal, and sportfishing seasons.

Prior to the advent of large-scale radiotelemetry research, characterization of the frequency and implications of fallback in the hydrosystem was constrained by small sample sizes and unknown final fates of fish. Bjornn et al. (1998, 2002) radio-tagged about 6,000 adult spring–summer Chinook salmon and steelhead from 1991 to 1994 to study passage at dams and through reservoirs in the lower Snake River. Concurrently, Blankenship and Mendel (1994) studied radio-tagged adult fall Chinook salmon passage through the lower Snake River, and Stuehrenberg et al. (1995) studied adult Chinook salmon behavior at selected mid-Columbia River dams. These studies (and others) established baseline information on adult fallback at main-stem Columbia and Snake River dams.

Advances in radiotelemetry have facilitated increasingly large-scale monitoring of individual adult fish. In 1996, we began radio-tagging adult salmonids at Bonneville Dam, the most downstream Columbia River site where large numbers of adult fish can be efficiently collected. During five study years (1996, 1997, 1998, 2000, and 2001), we tagged and released more than 12,000 adult Chinook salmon and steelhead at or downstream from the dam and monitored them as they migrated upstream through the hydrosystem. Our objectives were to calculate the proportions of radio-tagged spring–summer Chinook salmon, fall Chinook salmon, and steelhead that fell back at each of the eight lower Columbia River and lower Snake River dams, to calculate fish reascension rates after fallback, and to determine fishway count adjustment factors for each dam and year. We also determined final known locations and probable fates for fish that fell back and estimated the proportion of fish that fell back in order to return to downstream tributaries.

Methods

Study area and fish tagging.—The study area included the lower Columbia and Snake rivers and their major tributaries (Figure 1). The U.S. Army Corps of Engineers (USACE) dams where fallback behavior was monitored included Bonneville, the Dalles, John Day, and McNary dams on the lower Columbia River and Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams on the lower Snake River. Major tributaries between Bonneville and Lower Granite dams were monitored in all years of the study; several tributaries downstream from Bonneville Dam were monitored in 1996 and 1998.

Adult salmon and steelhead were trapped in the adult fish facility (AFF) adjacent to the Washington-shore fishway at Bonneville Dam as they migrated upstream to natal streams or hatcheries. In the five study years, radio transmitters were placed in 12,361 fish: 5,168 spring–summer Chinook salmon, 3,142 fall Chinook salmon, and 4,051 steelhead (Table 1). Spring–summer Chinook salmon (predominantly stream-type life history) were tagged in all years from April to early or late July, and fall Chinook salmon (ocean-type life history) were tagged from early August (2000, 2001) or September (1998) through October. Steelhead were tagged from early to mid-June through October (1996, 1997, 2000, 2001). Chinook salmon run designations were based on the established separation between spring, summer, and fall-run fish at Bonneville Dam (USACE 2001). For our analyses, radio-tagged fish kept their designation regardless of the date of passage at upstream sites.

On each day of radio-tagging, a weir in the Washington-shore fishway was lowered into place in the morning to divert fish from the main fishway into the AFF via a short section of ladder. Diverted adults entered a collection pool with two false weirs at the top of chutes that led to either a channel back to the main ladder or to an anesthetic tank. Fish selected for tagging were directed to the anesthetic tank by activating hydraulic gates in the chutes. We tagged fish as they arrived at the trap, but tagging was not random because only fish passing the Washington-shore ladder were sampled, the proportion sampled each day varied, and no fish were sampled at night. In addition, to accommo-

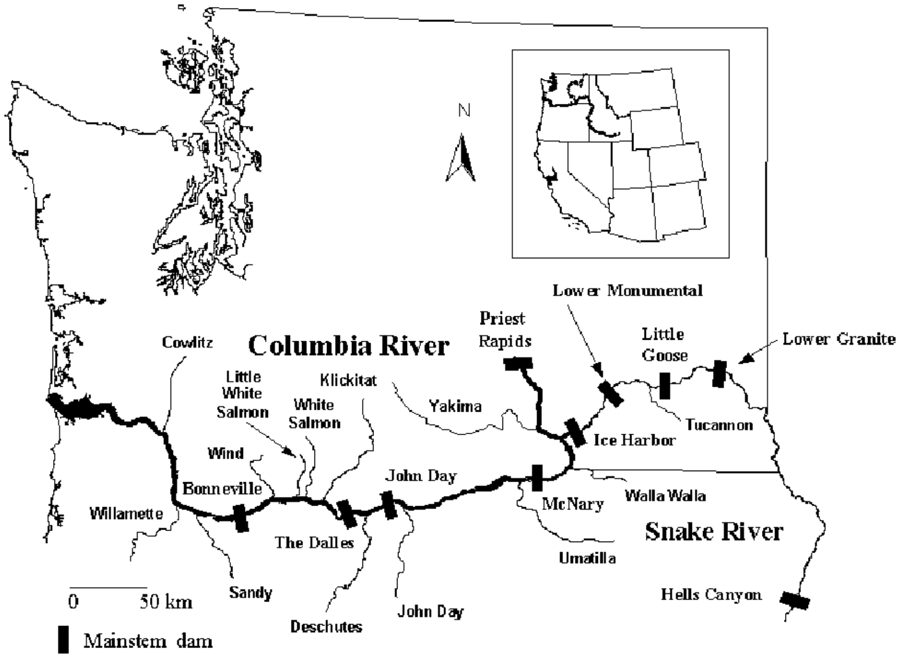

FIGURE 1.—Map of the lower Columbia and lower Snake rivers, with the locations of main-stem dams and major tributaries in Washington, Oregon, and Idaho. Adult Chinook salmon and steelhead were fitted with radio transmitters at Bonneville Dam.

date transmitter size, we rejected ‘‘jack’’ (precocious adult, by size) Chinook salmon and steelhead with fork lengths less than 50 cm.

We attempted to tag fish in proportion to their abundance based on long-term averages of run size at Bonneville Dam. However, run timing varied each year, causing some deviations that could not be compensated for by in-season adjustments to tagging schedules. Because we tagged fish throughout each run, we tended to under-sample during migration peaks and over-sample during passage nadirs. Departures from representative sampling occurred in July 1996 and in the second half of July in 1997 and 1998, when no spring–summer Chinook salmon were tagged, and in August 1998, when high water temperatures precluded the tagging of fall Chinook salmon. We intentionally radio-tagged more late-migrating (B-group) steelhead than early-migrating (A-group) steelhead to increase samples of fish returning to the Snake River.

During fall Chinook salmon tagging, we primarily selected for upriver-bright fish, which spawn mostly in the Columbia River’s Hanford Reach or in the Snake, Yakima, John Day, or Deschutes rivers, rather than the darker-colored, sexually mature Tule Chinook salmon, which return to Bonneville reservoir hatcheries. In 2000 and 2001, we also selected for fish with passive integrated transponder (PIT) tags that identified where fish were tagged as juveniles. We used an automated PIT tag detection system (McCutcheon et al. 1994) to identify PIT-tagged fish before they were diverted into the anesthetic tank.

TABLE 1.—Number of adult Chinook salmon and steelhead fitted with radio transmitters at Bonneville Dam from 1996 to 2001.

Fish	1996	1997	1998	2000	2001	Total
Spring-summer Chinook salmon	853	1,014	957	1,132	1,212	5,168
Fall Chinook salmon			1,032	1,118	992	3,142
Steelhead	765	975		1,160	1,151	4,051
Total	1,618	1,989	1,989	3,410	3,355	12,361

Anesthetization, fish handling, and radio-tag insertion methods were the same in all years (Keefer et al. 2004). We primarily used 3-V and 7-V transmitters, but we also used small numbers of radio-data storage transmitters (RDST) and combination acoustic/radio transmitters (CART) (Lotek Wireless, Inc., Newmarket, Ontario); all transmitters had a repeat rate of 5 s. Each transmitter was sterilized and dipped in glycerin before intragastric insertion (Mellas and Haynes 1985). Three-volt tags weighed 11 g in air (4.3 × 1.4 cm), 7-V tags were 29 g (8.3 × 1.6 cm), RDST tags were 34 g (9.0 × 2.0 cm), and CART tags were 28 g (6.0 × 1.6 cm). Lithium batteries powered the transmitters, and all but the CART tags had a rated operating life of 8–10 months; CART tags had an operating life of 15 months.

We inserted a unique secondary visual implant tag into the clear tissue posterior to the eye of each fish in all years except 2001, when PIT tags with a coded wire component were used instead. After tagging, fish were moved to a 2,275-L transport tank, where they were held (<3 h) until release.

All fish radio-tagged from 1996 to 1998 were released about 9.5 km downstream from Bonneville Dam at sites on both sides of the Columbia River. In 2000, 91% of spring Chinook salmon, 74% of summer Chinook salmon, 67% of fall Chinook salmon, and 73% of steelhead were released at the downstream sites, and the remaining fish were released in the Bonneville Dam forebay within 1 km of the dam. In 2001, 57–72% of each stock was released at the downstream sites. Fish released in the Bonneville forebay were not used in Bonneville Dam fallback analyses, but were included in fallback summaries at upstream dams.

Telemetry monitoring.—We used fixed radiotelemetry sites to assess radio-tagged fish movements and fallback in all years. Aerial Yagi antennas connected to SRX scanning receivers (Lotek Wireless, Inc.) were used to monitor dam forebay and tailrace areas and the mouths of major tributaries, and underwater antennas made of coaxial cable were used to monitor movements in and around dam fishway entrances, inside fishways, and at fishway exits. Digital spectrum processors added to SRX receivers could simultaneously monitor several frequencies and antennas at sites with underwater antennas. Trucks and boats equipped with aerial antennas were used to track fish in areas not monitored by fixed-site receivers, including main-stem reservoirs, unimpounded reaches, and accessible tributaries. Mobile-tracking efforts were most extensive in the lower Columbia River reservoirs and tributaries and in Snake River tributaries.

Data analysis.—Fallbacks by radio-tagged fish were determined exclusively from telemetry records. To qualify as undergoing a fallback event, a fish had to be recorded as exiting from the top of a fishway at a dam (or to be conclusively detected at a telemetry site upstream from a dam) and subsequently recorded at a telemetry site downstream from that dam. Given the large number of monitoring sites, most fallback events were easily identified.

The fallback percentage, or the proportion of each run that fell back at a dam, was calculated by dividing the number of unique, radio-tagged fish that fell back at a dam by the number of unique, radio-tagged fish known to have passed the dam. The fallback rate, which included multiple fallback events by individual fish at a dam, was the total number of fallback events divided by the number of unique, radio-tagged fish known to have passed the dam. The reascension percentage was the proportion of unique fish that fell back, subsequently reascended the dam where the fallback occurred, and were last located upstream from that dam. Last-known locations of fish that fell back were determined from the telemetry records of fixed-site receivers at dams and the mouths of tributaries, from mobile tracking records, and from recaptures of tagged fish in fisheries, hatcheries, and spawning-ground surveys. All transmitters used in this study were inscribed with return and reward information, and tags that were found or that were recovered in fisheries were eligible for rewards of US$10 to $100 when returned to us. Information from returned tags was helpful in determining last-known locations for some radio-tagged fish.

Steelhead that fell back over dams after entering spawning areas during historic spawning periods (e.g., March–May) were considered postspawners (kelts) and were not included in any fallback calculations. Fallbacks by Chinook salmon that occurred after likely spawning periods (e.g., November–December) were similarly excluded.

We estimated errors in fishway counts (e.g., USACE 2001) at Columbia and Snake River dams by calculating count adjustment factors (AFs) based on passage, fallback, and reascension rates of radio-tagged fish at each dam. Adjustment factors were calculated by the formula

$$\mathrm{AF} = (\mathrm{LP}_U + \mathrm{NLP}_U - \mathrm{FB}_U + R_U)/\mathrm{TLP}$$

where LP_U is the number of unique, radio-tagged fish known to have passed the dam via the fish ladders (assumes that unrecorded fish passed the dam via fish ladders). NLP_U is the number known to have passed via the navigation lock (only Bonneville and McNary locks monitored). FB_U is the number of unique fish that fell back at the dam one or more times. R_U is the number of unique fish that fell back one or more times, reascended the dam, and ultimately stayed upstream from the dam after the final reascension, and TLP is the total number of times unique, radio-tagged fish were known to have passed the dam via fish ladders (includes initial passage and all reascension events).

Count adjustments were based on the assumption that radio-tagged fish were good surrogates for the remainder of each run and were calculated by pooling data for the entire passage period at each dam. Pooling data could bias adjustments by masking temporal variability in fallback and reascension rates. To address potential biases, we calculated additional adjustments based on stratified sampling during consecutive 5-d blocks, weighted by the number of fish passing the dam during each block. The weighted adjustment factors were typically within 2% of pooled adjustment factors (Bjornn et al. 2000a; 2000b), and so only pooled values are reported here.

We tested the influence of dam, run, and year on fallback percentages and rates by use of two separate multivariate analysis of variance (MANOVA) models. The MANOVAs were followed by univariate analyses of variance (ANOVAs), as well as Tukey's tests for pairwise comparisons (Zar 1999). The main effects of run, dam, and the run × dam interaction were tested using observations across years as the replicates. The effect of year was tested within each run using observations at each dam as the replicates. The run × year interaction could not be tested because not all runs were sampled in all years. Fallback percentages and rates were log-transformed to improve normality. Fall Chinook salmon fallback percentages and rates at Little Goose and Lower Granite dams were excluded from the analysis due to high variability and small sample sizes.

We used linear regression to evaluate the relationship between mean Columbia and Snake River discharge and fallback rates for spring–summer Chinook salmon. Mean discharge at each dam from April through July, the period that included the annual snowmelt event and spilling at the dams, was used as the independent variable. We did not perform similar regressions for fall Chinook salmon or steelhead because the majority of those runs passed dams after river discharge declined to near-baseline levels and therefore the range in flow was insufficient for detection of differences.

Results

Fallback and Reascension

For all years combined, at least 22% of spring–summer Chinook salmon, 21% of steelhead, and 15% of fall Chinook salmon with radio transmitters that passed a dam fell back over a dam one or more times during their upstream migration in the Columbia and Snake rivers. The ranges in annual fallback percentages were 11–32% for spring–summer Chinook salmon, 18–25% for steelhead, and 12–18% for fall Chinook salmon.

The mean percentages of spring–summer Chinook salmon that fell back at lower Columbia River dams during the five study years were 11.3% (range, 4.1–14.6%) at Bonneville Dam, 10.9% (range, 5.5–14.4%) at the Dalles Dam, 8.3% (range, 3.0–11.9%) at John Day Dam, and 6.4% (range, 1.4–9.3%) at McNary Dam (Table 2). Spring–summer Chinook salmon fallback rates, which incorporated multiple fallback events by individual fish, were 1.5–5.3% higher than fallback percentages for each year at Bonneville and the Dalles dams, and 0.3–2.7% higher than percentages at John Day and McNary dams. Mean fallback percentages for fall Chinook salmon at Columbia River dams were 4.1% (range, 3.5–4.8%) at Bonneville Dam, 8.5% (range, 6.9–10.2%) at the Dalles Dam, 3.0% (range, 2.6–3.7%) at John Day Dam, and 2.5% (range, 2.0–3.5%) at McNary Dam (Table 2). Fall Chinook salmon fallback rates exceeded fallback percentages by 0.7–2.1% for each year at Bonneville and the Dalles dams and by 0.0–0.4% at John Day and McNary dams.

Mean percentages of steelhead that fell back at Columbia River dams were 6.3% (range, 4.3–9.1%) at Bonneville Dam, 6.3% (range, 6.0–6.6%) at the Dalles Dam, 6.9% (range, 4.3–10.1%) at John Day Dam, and 8.8% (range, 7.1–10.7%) at McNary Dam (Table 2). Steelhead fallback rates at lower Columbia River dams were 0.2–2.7% higher than fallback percentages in each year.

Fallback percentages and rates for spring–summer Chinook salmon and steelhead were generally lower at Snake River dams than at lower Columbia River dams. However, relatively large proportions of fall Chinook salmon fell back at

TABLE 2.—Percentages of radio-tagged adult Chinook salmon and steelhead that fell back at lower Columbia River dams and fallback rates at each dam, 1996–2001. NP_U is the number of fish known to pass the dam. FB_U is the number of unique fish that fell back, and FB_T is the total number of fallback events; fallback percent is calculated as FB_U/NP_U, and fallback rate is calculated as FB_T/NP_U.

Year and dam	Fallback percent	Fallback rate	NP_U	FB_U	FB_T
Spring–summer Chinook salmon					
Bonneville Dam					
1996	13.8	16.4	809	112	133
1997	14.6	19.9	950	139	189
1998	11.2	15.8	932	104	147
2000	13.0	16.8	951	124	160
2001	4.1	7.0	773	32	54
The Dalles Dam					
1996	13.3	18.3	497	66	91
1997	14.4	18.6	714	103	133
1998	11.5	14.3	763	88	109
2000	9.6	12.2	844	81	103
2001	5.5	7.0	1,032	57	72
John Day Dam					
1996	11.9	14.1	377	45	53
1997	9.9	12.6	629	62	79
1998	10.6	11.6	639	68	74
2000	6.0	6.5	681	41	44
2001	3.0	3.3	969	29	32
McNary Dam					
1996	9.3	10.3	301	28	31
1997	8.0	10.6	587	47	62
1998	9.2	10.9	576	53	63
2000	4.3	5.4	626	27	34
2001	1.4	1.7	908	13	15
Fall Chinook salmon					
Bonneville Dam					
1998	3.5	4.2	913	32	38
2000	3.9	5.2	659	26	34
2001	4.8	6.9	521	25	36
The Dalles Dam					
1998	10.2	11.6	629	64	73
2000	8.5	9.6	738	63	71
2001	6.9	8.4	713	49	60
John Day Dam					
1998	3.7	3.7	483	18	18
2000	2.6	2.6	570	15	15
2001	2.6	2.8	580	15	16
McNary Dam					
1998	2.1	2.1	428	9	9
2000	2.0	2.0	456	9	9
2001	3.5	3.9	482	17	19
Steelhead					
Bonneville Dam					
1996	4.9	5.3	720	35	38
1997	9.1	9.9	916	83	91
2000	6.9	7.4	811	56	60
2001	4.3	4.5	775	33	35
The Dalles Dam					
1996	6.0	6.9	580	35	40
1997	6.6	7.6	683	45	52
2000	6.3	7.2	871	55	63
2001	6.1	8.8	963	59	85
John Day Dam					
1996	10.1	11.2	457	46	51
1997	7.9	9.0	554	44	50
2000	4.3	4.5	748	32	34
2001	5.3	5.6	869	46	49
McNary Dam					
1996	7.4	8.6	394	29	34
1997	10.7	12.9	487	52	63
2000	9.8	10.2	645	63	66
2001	7.1	7.6	790	56	60

Snake River dams, though sample sizes were small. Mean fallback percentages for spring–summer Chinook salmon and steelhead at Snake River dams ranged from 2.8% to 7.0%, and annual values were less than 10% at all dams in all years (Table 3). Mean fall Chinook salmon fallback percentages were 7.2% at Ice Harbor Dam, 6.2% at Lower Monumental Dam, 22.1% at Little Goose Dam, and 23.2% at Lower Granite Dam.

Dam, year, and the run × dam interaction had significant effects on fallback percentage and rate (MANOVA, $P < 0.001$); the effect of run was not significant. Individual ANOVAs for each run indicated that dam had a significant effect on fallback rates for all runs ($P < 0.05$); year affected fallback rates of spring–summer Chinook salmon and steelhead ($P < 0.01$). Pairwise comparison of dams revealed that spring–summer Chinook salmon fallback rates at Bonneville Dam were significantly higher than rates at McNary Dam and at all Snake River dams ($P < 0.05$); rates at the Dalles Dam were significantly higher than those at Lower Monumental, Little Goose, and Lower Granite dams ($P < 0.01$). Fallback rates of spring–summer Chinook salmon at John Day Dam were significantly higher than rates at Lower Monumental Dam ($P < 0.01$). Steelhead fallback rates at Bonneville, The Dalles, and John Day dams were significantly higher than rates at Lower Monumental Dam ($P < 0.05$). Fall Chinook salmon fell back at significantly higher rates at the Dalles Dam than at John Day and McNary dams ($P < 0.05$). Pairwise comparisons of years indicated that spring–summer Chinook salmon fallback rates in 2001 were significantly lower than in all other study

TABLE 3.—Percentages of radio-tagged adult Chinook salmon and steelhead that fell back at lower Snake River dams and fallback rates at each dam, 1996–2001. NP_U is the number of fish known to pass the dam. FB_U is the number of unique fish that fell back, and FB_T is the total number of fallback events; fallback percent is calculated as FB_U/NP_U, and fallback rate is calculated as FB_T/NP_U.

Year and dam	Fallback percent	Fallback rate	NP_U	FB_U	FB_T
Spring-summer Chinook salmon					
Ice Harbor Dam					
1996	7.5	8.3	120	9	10
1997	9.1	10.4	318	29	33
1998	7.4	7.4	256	19	19
2000	9.6	13.7	249	24	34
2001	1.4	1.4	555	8	8
Lower Monumental Dam					
1997	5.1	5.8	311	16	18
1998	4.0	4.0	252	10	10
2000	4.5	4.5	246	11	11
2001	0.9	0.9	551	5	5
Little Goose Dam					
1997	8.9	8.9	302	27	27
1998	5.6	6.0	249	14	15
2000	3.7	3.7	241	9	9
2001	1.5	1.5	543	8	8
Lower Granite Dam					
1996	1.0	1.0	101	1	1
1997	5.8	5.8	292	17	17
1998	4.3	4.8	230	10	11
2000	2.9	2.9	238	7	7
2001	0.6	0.6	538	3	3
Fall Chinook salmon					
Ice Harbor Dam					
1998	6.9	6.9	29	2	2
2000	3.0	3.0	33	1	1
2001	11.8	11.8	93	11	11
Lower Monumental Dam					
1998	3.6	3.6	28	1	1
2000	9.1	9.1	33	3	3
2001	5.9	5.9	85	5	5
Little Goose Dam					
1998	20.0	30.0	20	4	6
2000	35.5	58.1	31	11	18
2001	10.8	12.2	74	8	9
Lower Granite Dam					
1998	25.0	37.5	8	2	3
2000	40.0	56.0	25	10	14
2001	4.8	6.5	62	3	4
Steelhead					
Ice Harbor Dam					
1996	5.6	6.3	319	18	20
1997	4.9	5.4	387	19	21
2000	4.7	5.1	486	23	25
2001	3.9	4.7	489	19	23
Lower Monumental Dam					
1997	4.0	4.8	375	15	18
2000	1.7	1.7	471	8	8
2001	2.8	3.0	472	13	14
Little Goose Dam					
1997	8.4	9.0	335	28	30
2000	5.3	5.3	450	24	24
2001	5.2	5.2	445	23	23
Lower Granite Dam					
1996	8.4	9.2	262	22	24
1997	5.9	6.9	306	18	21
2000	3.7	3.7	407	15	15
2001	2.7	2.9	445	12	13

[a] Lower Monumental and Little Goose dams were not monitored in 1996.

years ($P < 0.001$). Steelhead fallback rates in 2000 and 2001 were significantly lower than in 1997 ($P < 0.05$). The ANOVAs and pairwise comparisons of fallback percentages for all runs showed results similar to those of fallback rates and are therefore not reported.

The percentages of fallback fish that reascended a dam and remained upstream were widely variable among dams and between runs (Table 4). Mean reascension percentages for spring–summer Chinook salmon were highest at Bonneville Dam (86.5%) and Lower Granite Dam (71.7%) and were between 52% and 65% at all other dams. Mean steelhead reascension percentages were highest at Bonneville Dam (83.2%) and the Dalles Dam (77.3%) and were between 46% and 65% at all other dams. In contrast, mean reascension percentages for fall Chinook salmon were less than 15% at John Day, Ice Harbor, and Lower Monumental dams, 27–29% at the Dalles, McNary, and Little Goose dams, 49.2% at Bonneville Dam, and 60.0% at Lower Granite Dam.

Overshoot Fallbacks

Many salmon and steelhead that fell back at dams entered tributaries or were recaptured at hatcheries downstream from the fallback location. Some, though not all, of these fallbacks were probably behaviorally motivated, or overshoot, fallbacks. Percentages of spring–summer Chinook salmon that entered downstream tributaries or hatcheries after falling back at Columbia River dams ranged from a mean of 18.0% at the Dalles Dam to 31.6% at McNary Dam over the five study years (Table 5). Tributaries downstream from Bonneville Dam were monitored in 1996 and 1998 only; 4.5% (1996) and 2.9% (1998) of spring–summer Chinook salmon that fell back at Bon-

TABLE 4.—Percentages of radio-tagged adult Chinook salmon and steelhead that reascended fishways at Columbia and Snake River dams after falling back and that remained upstream. Dam codes are as follows: Bonneville (BO), The Dalles (TD), John Day (JD), McNary (MN), Ice Harbor (IH), Lower Monumental (LM), Little Goose (GO), and Lower Granite (GR).

	Columbia River dams				Snake River dams			
Year	BO	TD	JD	MN	IH	LM[a]	GO[a]	GR
				Spring–summer Chinook salmon				
1996	89.3	54.5	57.8	32.1	77.8			100.0
1997	92.1	68.9	61.3	48.9	69.0	62.5	77.8	70.6
1998	82.7	61.4	63.2	58.5	52.6	40.0	42.9	50.0
2000	92.7	72.8	68.3	77.8	79.2	45.5	44.4	71.4
2001	75.8	64.9	58.6	61.5	25.0	60.0	55.5	66.7
				Fall Chinook salmon				
1998	37.5	25.0	5.6	33.3	0	0	25.0	50.0
2000	50.0	34.9	6.7	22.2	0	0	18.2	30.0
2001	60.0	26.5	13.3	29.4	18.2	40.0	37.5	100.0
				Steelhead				
1996	85.7	77.1	45.7	41.4	38.9			36.4
1997	77.1	75.6	75.0	46.2	52.6	26.7	42.9	38.9
2000	91.1	80.0	62.5	47.6	52.2	50.0	43.5	66.7
2001	78.8	76.3	78.3	64.3	47.4	92.3	87.0	50.0

[a] LM and GO were not monitored in 1996.

neville Dam were last located in downstream drainages. Spring–summer Chinook salmon that fell back at Snake River dams entered downstream tributaries or hatcheries in mean percentages ranging from 11.2% at Lower Granite Dam to 28.8% at Ice Harbor Dam (Table 5).

Fall Chinook salmon that fell back at Columbia and Snake River dams were more likely to enter downstream tributaries or hatcheries than spring–summer Chinook salmon. Mean percentages of fall Chinook salmon that entered tributaries downstream from Columbia River dams after falling back ranged from 40.8% at the Dalles Dam to 47.8% at John Day Dam; in 1998, 31.1% of fall Chinook salmon that fell back at Bonneville Dam entered monitored tributaries or hatcheries downstream from the dam (Table 5). Mean overshoot percentages at Snake River dams ranged from 26.7% at Lower Granite Dam to 93.9% at Ice Harbor Dam (Table 5).

TABLE 5.—Percentages of radio-tagged adult Chinook salmon and steelhead that fell back at Columbia and Snake River dams and that later entered tributaries or hatcheries downstream from the fallback location (possible overshoot fallbacks). Tributaries and hatcheries downstream from Bonneville Dam were monitored in 1996 and 1998 only. See Table 4 for dam code definitions.

	Columbia River dams				Snake River dams			
Year	BO	TD	JD	MN	IH	LM	GO	GR
				Spring–summer Chinook salmon				
1996	4.5	27.3	22.4	46.4	22.2			0
1997		19.4	25.8	23.4	17.2	18.8	18.5	17.6
1998	2.9	19.3	22.1	24.5	21.1	10.0	14.3	10.0
2000		13.6	17.1	40.7	20.8	45.5	55.6	28.6
2001		10.5	13.8	23.1	62.5	20.0	12.5	0
				Fall Chinook salmon				
1998	31.3	45.3	50.0	66.6	100.0	100.0	75.0	50.0
2000		44.4	53.3	33.3	100.0	33.3	45.5	30.0
2001		32.7	40.0	41.2	81.8	60.0	62.5	0
				Steelhead				
1996	5.7	11.4	26.1	24.1	22.2			4.5
1997		0	6.8	26.9	26.3	20.0	25.0	22.2
2000		7.3	18.8	31.7	13.0	12.5	4.3	0
2001		5.1	13.0	17.9	21.1	0	4.3	16.7

TABLE 6.—Percentages of spring–summer Chinook salmon (all years combined) that fell back at dams and that were last recorded in tributaries or hatcheries, reported recaptured in main-stem fisheries, or last recorded at main-stem sites but whose fates were unknown. Percentages in bold italic type represent fish that entered tributaries downstream from the fallback site, except for those that fell back at Snake River dams and subsequently passed Priest Rapids Dam on the upper Columbia River. See Table 4 for dam code definitions.

	Columbia River dams				Snake River dams			
Last location	BO	TD	JD	MN	IH	LM	GO	GR
Fallback fish (*N*)	512	395	245	168	89	42	58	38
				Tributaries or hatcheries				
Below BO	***1.8***	***1.0***	***1.2***					
BO pool	15.8	***17.2***	***7.3***	***4.2***	***1.1***	***2.4***		
TD pool	9.2	7.6	***12.5***	***6.5***	***2.2***	***2.4***	***1.7***	
JD pool	3.1	2.3	4.5	***20.2***	***11.2***	***11.9***	***6.9***	***5.3***
MN pool[a]	4.5	1.0	6.5	8.9	***7.9***	***2.4***	***1.7***	***2.6***
Lower Snake River[b]	0.6	1.3	1.2	1.8	5.6		***19.0***	***7.9***
Above GR[c]	28.3	36.7	35.9	29.8	53.9	52.4	53.4	65.8
Above Priest Rapids[c]	7.8	8.1	8.6	7.1	2.2	4.8		
Total	71.1	75.2	76.9	78.6	84.3	76.2	84.5	81.6
				Main stem				
Recaptured	5.7	4.1	3.7	4.2				
Unknown	23.2	20.8	18.8	17.3	15.7	23.8	15.5	18.4

[a] Includes the Walla Walla and Yakima rivers and the Ringold and Priest Rapids hatcheries.

[b] Includes the Tucannon River and the Lyons Ferry Hatchery.

[c] Includes all sites upstream from GR or Priest Rapids Dam.

Overshoot fallbacks by steelhead at Columbia River dams ranged from a mean of 6.0% at the Dalles Dam to 25.2% at McNary Dam; 5.7% of steelhead that fell back at Bonneville Dam in 1996 entered downstream tributaries or hatcheries (Table 5). At Snake River dams, fallback steelhead entered downstream tributaries in mean percentages ranging from 10.8% at Lower Monumental Dam to 20.7% at Ice Harbor Dam (Table 5).

Last-Known Locations of Fallback Fish

Percentages of fallback spring–summer Chinook salmon that eventually entered tributaries or hatcheries upstream or downstream from the fallback location were relatively consistent (71.1–84.5%) for all dams, with a mean of 75.5% at Columbia River dams and a mean of 81.7% at Snake River dams. Between 3.7% and 5.7% (mean, 4.4%) of the spring–summer Chinook salmon that fell back at Columbia River dams were reported as recaptured in main-stem fisheries (Table 6). Percentages of fallback spring–summer Chinook salmon that were last located in the main-stem rivers ranged from 15.5% to 23.8%, with means of 20.0% and 18.4% for fallback fish at Columbia River dams and Snake River dams, respectively; the fates of these fish were unknown (Table 6). Between 47.0% and 74.3% (mean, 58.7%) of fall Chinook salmon that fell back at Columbia River dams were last located in tributaries or hatcheries (Table 7); percentages ranged from 53.3% to 100% (mean, 77.4%) for fall Chinook salmon that fell back at Snake River dams, where sample sizes were small. Between 3.6% and 14.6% (mean, 9.1%) of fall Chinook salmon that fell back at Columbia River dams were reported as recaptured in fisheries. Of the fall Chinook salmon that fell back, the percentages that were last located at main-stem sites and whose fates were unknown ranged from 17.1% to 49.4% (mean, 32.2%) for Columbia River dams and from 0% to 46.7% (mean, 22.7%) for Snake River dams.

Percentages of steelhead that entered tributaries or hatcheries after falling back ranged from 46.8% to 68.5% (mean, 59.6%) at Columbia River dams and from 50.0% to 63.5% (mean, 57.4%) at Snake River dams (Table 8). From 8.9% to 16.9% (mean, 11.9%) of steelhead that fell back at Columbia River dams and from 1.3% to 9.5% (mean, 6.0%) of those that fell back at Snake River dams were reported as recaptured in main-stem fisheries. Percentages of fallback steelhead that were last located at main-stem sites ranged from 22.6% to 36.2% (mean, 28.4%) for Columbia River dams and from 27.0% to 44.4% (mean, 36.6%) for Snake River dams.

Fishway Escapement Adjustments

Fishway escapement (count) adjustments were most precise for Bonneville and McNary dams,

TABLE 7.—Percentages of fall Chinook salmon (all years combined) that fell back at dams and that were last recorded in tributaries, reported recaptured in main-stem fisheries, or last recorded at main-stem sites but whose fates were unknown. Percentages in bold italic type represent fish that entered tributaries downstream from the fallback site, except for those that fell back at Snake River dams and subsequently passed Priest Rapids Dam on the upper Columbia River. See Table 4 for dam code definitions.

	Columbia River dams				Snake River dams			
Last location	BO	TD	JD	MN	IH	LM	GO	GR
Fallback fish (*N*)	83	177	48	35	14	9	23	15
Tributaries or hatcheries								
Below BO	***12.0***	***0.6***						
BO pool	19.3	***40.7***	***18.8***	***8.6***				
TD pool	3.6	4.0	***29.2***	***17.1***				
JD pool	2.4	1.1		***20.0***	***21.4***	***11.1***		
MN pool[a]	6.0	10.2	4.2	17.1	***57.1***	***33.3***	***8.7***	
Lower Snake River[b]	1.2	0.6		2.9			***39.1***	***26.7***
Above GR[c]	1.2	1.7	2.1	8.6	14.3	29.2	26.1	26.7
Above Priest Rapids[c]	1.2	0.6			7.1	11.1	4.3	
Total	47.0	59.3	54.2	74.3	100.0	77.8	78.3	53.3
Main stem								
Recaptured	3.6	9.6	14.6	8.6				
Unknown	49.4	31.1	31.3	17.1	0.0	22.2	21.7	46.7

[a] Includes the Walla Walla and Yakima rivers and the Ringold and Priest Rapids hatcheries.
[b] Includes the Tucannon River and the Lyons Ferry Hatchery.
[c] Includes all sites upstream from GR or Priest Rapids Dam.

where we monitored all passage routes, including navigation locks, from 1996 to 2001. Mean adjustment factors for Bonneville Dam counts were 0.874 (range, 0.839–0.934) for spring–summer Chinook salmon, 0.986 (range, 0.961–0.999) for fall Chinook salmon, and 0.969 (range, 0.939–0.992) for steelhead (Table 9). Mean adjustments for McNary Dam counts were 0.935 (range, 0.904–0.988) for spring–summer Chinook salmon, 0.981 (range, 0.961–0.988) for fall Chinook salmon, and 0.913 (range, 0.880–0.932) for steelhead.

We did not monitor navigation lock passage at

TABLE 8.—Percentages of steelhead (all years combined) that fell back at dams and that were last recorded in tributaries, reported recaptured in main-stem fisheries, or last recorded at main-stem sites but whose fates were unknown. Percentages in bold italic type represent fish that entered tributaries downstream from the fallback site, except for those that fell back at Snake River dams and subsequently passed Priest Rapids Dam on the upper Columbia River. See Table 4 for dam code definitions.

Last location	Columbia River dams				Snake River dams			
	BO	TD	JD	MN	IH	LM	GO	GR
Fallback fish (*N*)	207	194	168	200	79	36	74	67
Tributaries or hatcheries								
Below BO	***1.4***							
BO pool	7.7	***5.7***	***2.4***	***0.0***				
TD pool	5.3	9.8	***14.3***	***4.0***	***1.3***			
JD pool	5.3	6.7	8.9	***21.5***	***3.8***			
MN pool[a]	2.9	2.6	4.2	4.0	***13.9***	***11.1***	***1.4***	
Lower Snake River[b]	1.0	0.5		0.5	3.8		***9.5***	***9.0***
Above GR[c]	19.8	29.9	33.3	32.0	35.4	38.9	51.4	46.3
Above Priest Rapids[c]	3.1	2.6	5.4	3.0				
Total	46.8	58.2	68.5	65.0	59.5	50.0	63.5	56.7
Main stem								
Recaptured	16.9	12.9	8.9	9.0	1.3	5.6	9.5	7.5
Unknown	36.2	28.9	22.6	26.0	39.2	44.4	27.0	35.8

[a] Includes the Walla Walla and Yakima rivers and the Ringold and Priest Rapids hatcheries.
[b] Includes the Tucannon River and the Lyons Ferry Hatchery.
[c] Includes all sites upstream from GR or Priest Rapids Dam.

TABLE 9.—Fish-count adjustment factors (AFs), U.S. Army Corps of Engineers (USACE) estimated fishway escapement, adjusted escapement, and escapement bias for spring–summer Chinook salmon, fall Chinook salmon, and steelhead at Columbia River dams, 1996–2001.

Year and dam	AF	USACE escapement	Adjusted escapement	Bias
Spring–summer Chinook salmon				
Bonneville Dam				
1996	0.863	67,527	58,276	9,251
1997	0.839	141,393	119,087	22,852
1998	0.871	59,775	52,064	7,711
2000	0.860	208,918	179,669	29,249
2001	0.934	467,523	436,666	30,857
The Dalles Dam				
1996	0.845	36,900	31,181	5,719
1997	0.837	89,566	74,966	14,600
1998	0.870	40,687	35,398	5,289
2000	0.930	127,260	118,352	8,908
2001	0.924	375,374	346,846	28,528
John Day Dam				
1996	0.864	30,481	26,336	4,145
1997	0.882	82,761	72,995	9,766
1998	0.892	38,046	33,937	4,109
2000	0.879	109,576	96,317	13,259
2001	0.968	328,363	317,855	10,508
McNary Dam				
1996	0.904	32,934	29,772	3,162
1997	0.910	78,766	71,677	7,089
1998	0.907	35,641	32,326	3,315
2000	0.966	85,191	82,295	2,896
2001	0.988	326,603	322,684	3,919
Fall Chinook salmon				
Bonneville Dam				
1998	0.999	189,085	188,896	189
2000	0.998	192,793	192,407	386
2001	0.961	400,205	384,597	15,608
The Dalles Dam				
1998	0.941	92,932	82,524	10,408
2000	0.913	124,967	114,095	10,872
2001	0.919	181,316	166,629	14,687
John Day Dam				
1998	0.963	78,237	75,342	2,895
2000	0.974	102,903	100,228	2,675
2001	0.973	124,747	121,379	3,368
McNary Dam				
1998	0.984	63,791	62,770	1,021
2000	0.998	67,572	67,437	135
2001	0.961	110,517	106,207	4,310
Steelhead				
Bonneville Dam				
1996	0.992	205,213	203,571	1,642
1997	0.939	258,385	242,624	15,761
2000	0.965	351,370	339,072	12,298
2001	0.978	633,073	619,145	13,928
The Dalles Dam				
1996	0.937	162,447	152,213	10,234
1997	0.926	164,657	152,472	12,185
2000	0.930	205,241	188,616	16,625
2001	0.919	503,327	462,558	40,769
John Day Dam				
1996	0.895	156,924	140,447	16,477
1997	0.916	159,442	146,049	13,393
2000	0.957	220,328	210,854	9,474
2001	0.943	483,409	455,855	27,554
McNary Dam				
1996	0.925	124,177	114,864	9,313
1997	0.880	129,817	114,239	15,578
2000	0.913	130,332	118,993	11,339
2001	0.932	398,784	371,667	27,117

the Dalles or John Day dams, but telemetry records at fishway sites indicated that few (estimated to be <2%) fish passed those dams via the locks. Mean adjustment factors at the Dalles Dam, uncorrected for passage through the lock, were 0.881 for spring–summer Chinook salmon, 0.924 for fall Chinook salmon, and 0.928 for steelhead (Table 9). Mean adjustments for John Day Dam were 0.897 for spring–summer Chinook salmon, 0.970 for fall Chinook salmon, and 0.950 for steelhead (Table 9).

Mean adjustment factors at lower Snake River dams were between 0.928 and 0.972 at all dams and for all runs, except that mean adjustments for fall Chinook salmon were 0.794 at Little Goose Dam and 0.747 at Lower Granite Dam (Table 10).

Positive bias estimates, or overcounts, at lower Columbia River dams ranged from 2,896 to 30,857 for spring–summer Chinook salmon, from 135 to 15,608 for fall Chinook salmon, and from 1,642 to 40,769 for steelhead (Table 9). Overcounts at Snake River dams ranged from 75 to 4,857 for spring–summer Chinook salmon, from 110 to 1,568 for fall Chinook salmon, and from 2,140 to 13,050 for steelhead (Table 10). Numerically, the largest positive biases tended to occur in 2001, a year with very large adult returns; biases were also quite high at some dams in 1997, the study year with the highest flow and spill levels.

Influence of River Flow and Dam Spill on Fallback

Columbia River discharge during the five study years varied widely and included one of the lowest-discharge years on record (2001), two high-discharge years (1997, 1996), and two near-average years (1998, 2000). Mean daily discharge at Bonneville Dam from April through July averaged 6,768 m^3/s for the period 1972–2001.

TABLE 10.—Fish-count adjustment factors (AFs), U.S. Army Corps of Engineers (USACE) estimated fishway escapement, adjusted escapement, and escapement bias for spring–summer Chinook salmon, fall Chinook salmon, and steelhead at Snake River dams, 1996–2001.

Year and dam	AF	USACE escapement	Adjusted escapement	Bias
Spring–summer Chinook salmon				
Ice Harbor Dam				
1996	0.929	11,757	10,922	835
1997	0.904	50,594	45,737	4,857
1998	0.929	17,907	16,636	1,271
2000	0.891	43,391	38,661	4,730
2001	0.986	186,443	183,833	2,610
Lower Monumental Dam				
1997	0.944	47,632	44,965	2,667
1998	0.961	14,888	14,307	581
2000	0.956	40,200	38,431	1,769
2001	0.991	200,107	198,306	1,801
Little Goose Dam				
1997	0.916	47,246	43,277	3,969
1998	0.941	14,810	13,936	874
2000	0.963	38,533	37,107	1,426
2001	0.985	191,036	188,170	2,866
Lower Granite Dam				
1996	0.989	6,814	6,739	75
1997	0.950	44,564	42,336	2,228
1998	0.953	14,209	13.541	668
2000	0.971	37,761	36,666	1,095
2001	0.995	185,693	185,765	928
Fall Chinook salmon				
Ice Harbor Dam				
1998	0.931	4,220	3,929	291
2000	0.970	6,652	6,452	200
2001	0.884	13,516	11,948	1,568
Lower Monumental Dam				
1998	0.964	3,046	2,936	110
2000	0.909	5,447	4,651	496
2001	0.943	13,297	12,539	758
Little Goose Dam				
1998	0.739	2,032	1,502	530
2000	0.769	3,588	2,759	829
2001	0.873	10,550	9,210	1,340
Lower Granite Dam				
1998	0.667	1,908	1,273	635
2000	0.620	3,694	2,290	1,404
2001	0.954	8,915	8,505	410
Steelhead				
Ice Harbor Dam				
1996	0.940	97,250	91,415	5,835
1997	0.947	102,900	97,446	5,454
2000	0.952	131,426	125,118	6,308
2001	0.954	283,694	270,644	13,050
Lower Monumental Dam				
1997	0.953	85,602	81,579	4,023
2000	0.981	112,616	110,476	2,140
2001	0.967	252,923	244,577	8,346

TABLE 10.—Continued.

Year and dam	AF	USACE escapement	Adjusted escapement	Bias
Little Goose Dam				
1997	0.914	74,219	67,836	6,383
2000	0.949	101,030	95,877	5,153
2001	0.951	232,669	221,268	11,401
Lower Granite Dam				
1996	0.912	85,129	77,638	7,491
1997	0.936	91,957	86,062	5,895
2000	0.966	113,211	109,362	3,849
2001	0.960	262,568	252,065	10,503

April–July means at Bonneville Dam were 9,289 m^3/s (137% of the 1972–2001 average) in 1996, 10,988 m^3/s (162%) in 1997, 7,250 m^3/s (107%) in 1998, 6,655 m^3/s (98%) in 2000, and 3,483 m^3/s (51%) in 2001. Peak discharge occurred in late May or early June of the first three study years, in late April of 2000, and in mid-May of 2001. Mean discharge at the dam typically dropped to between 3,000 and 4,000 m^3/s by early September in all years, but was approximately 5,000 m^3/s in fall 1997. Between-year differences in discharge at other Columbia River and Snake River dams were proportionally similar to those at Bonneville Dam.

Daily flow and spill (April–July) were strongly correlated at all dams in 1996, 1997, and 1998, with a mean correlation coefficient (r) of 0.92 (range, 0.82–0.99). In 2000, strong correlations between flow and spill existed at McNary Dam and at Snake River dams (mean $r^2 = 0.86$; range, 0.78–0.93). Correlations in 2000 were weaker for Bonneville, the Dalles, and John Day dams (mean $r^2 = 0.39$; range, 0.16–0.61), where spill was being manipulated as part of a large-scale experiment. In 2001, near-record low river flows resulted in zero spill at Snake River dams and greatly reduced spill duration and volume at Columbia River dams.

Annual fallback rates of spring–summer Chinook salmon for the five study years were positively correlated with mean daily flow (April–July) at all Columbia and Snake River dams (Figure 2). Linear regression models of mean daily flow (m^3/s) and fallback rates were significant for Bonneville ($r^2 = 0.82$, $P = 0.033$), the Dalles ($r^2 = 0.95$, $P = 0.005$), John Day ($r^2 = 0.79$, $P = 0.044$), and Little Goose dams ($r^2 = 0.99$, $P < 0.001$) and nearly significant for McNary Dam ($r^2 = 0.73$, $P = 0.07$). Models were nonsignificant for Ice Harbor ($r^2 = 0.26$, $P = 0.38$), Lower Monumental ($r^2 = 0.75$, $P = 0.13$), and Lower Granite dams (r^2

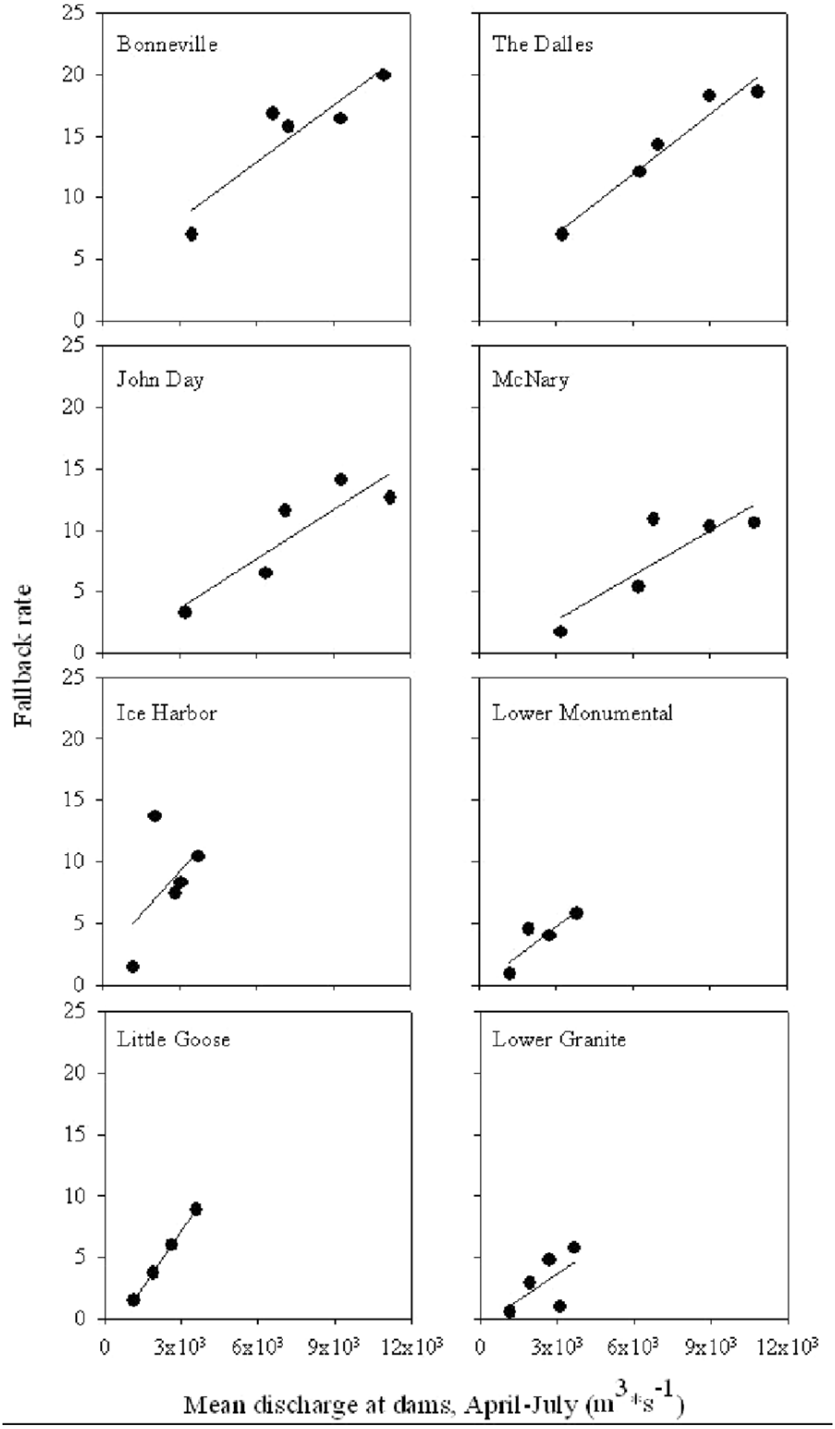

FIGURE 2.—Linear regressions between annual fallback rates of spring–summer Chinook salmon at dams on the lower Columbia River (Bonneville, the Dalles, John Day, and McNary) and the lower Snake River (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite) and mean April–July river discharge at each dam (1996–2001). The fallback rate (expressed as a percentage) was calculated as the total number of fallback events divided by the number of unique, radio-tagged fish known to have passed the dam.

= 0.40, P = 0.25). Model slopes ranged from 0.0012 at McNary Dam to 0.0031 at Little Goose Dam.

In 2000 and 2001, our telemetry antenna arrays at Bonneville Dam provided sufficient resolution to determine specific routes of fallback. During the 2000 spring–summer Chinook salmon run, spill occurred from early April through August, and we determined that 140 of 160 total fallback events likely occurred via the spillway. More than 80% of all steelhead fallbacks in 2000 occurred during spill, but only 39% of all radio-tagged steelhead passed the dam during this period. While spill was occurring, fallback routes for steelhead were exclusively via the spillway. In 2001, more than 70% of the spring–summer Chinook salmon fallback events that occurred during the limited periods of spill occurred through the spillway.

Discussion

The proportion of upriver-migrating salmon and steelhead that fall back at Columbia and Snake River dams varies widely, depending on the run, species, and hydroelectric project involved as well as on the river conditions at the time of migration. In terms of salmon and steelhead fallback behavior, each dam on the Columbia and Snake rivers is unique (1) structurally, (2) operationally, as a combination of river inflow, dam spill, and turbine discharge at any given time, and (3) geographically, in its location relative to natal spawning tributaries and hatcheries. These factors and the timing, size, and composition of anadromous fish runs appear to influence fallback behavior at dams. For example, a large return run to the Umatilla or John Day rivers could result in high fallback percentages at McNary Dam—the project just upstream from those tributaries—due to increased overshoot fallback behavior.

With a few exceptions, the percentages of spring–summer Chinook salmon that fell back were highest at Bonneville Dam and decreased at progressively upstream dams, and years characterized by high river flows (1996 and 1997) had higher percentages of fallback fish. Spring–summer Chinook salmon migration overlaps with peak river discharge, and fallback by this run appears to be most influenced by flow levels and associated forced spill at dams. As the spring–summer Chinook salmon migration proceeds upriver and snowmelt runoff ebbs in midsummer, portions of the run are exposed to decreasing river flow and spill, the dams become smaller and less complex, and the number of proximate tributaries fish can overshoot become fewer; all of these factors would be expected to decrease overall fallback percentages at upstream dams. Most steelhead enter the lower Columbia River in summer and fall, when discharge is low (Robards and Quinn 2002), and many steelhead pass dams between September and November after spill conditions have typically ceased. Lower flow and reduced- or zero-spill conditions may account for the lower between-year variation in fallback percentages we observed for steelhead and fall Chinook salmon as compared to spring–summer Chinook salmon. Fall Chinook salmon also migrate after peak river flows, and the majority of this run passes dams after spill has ceased. Fall Chinook salmon fallback percentages were more variable at Snake River dams, but sample sizes were small.

Fall Chinook salmon were the most likely to enter a downstream tributary or hatchery after falling back. Based on final records at downstream tributaries or hatcheries, about 45% of the fall Chinook salmon that fell back at the Dalles, John Day, and McNary dams possibly did so in order to return to downstream natal spawning sites. For all years combined, 11 of 14 (79%) fall Chinook salmon that fell back at Ice Harbor Dam were later located in the Umatilla or Yakima rivers or in the Hanford Reach of the Columbia River, and most fall Chinook salmon that fell back at Little Goose and Lower Granite dams returned downstream to these same spawning areas or to Lyons Ferry Hatchery. Overshoot fallback behavior was also apparent, but to a lesser degree, in spring–summer Chinook salmon and steelhead. Eighteen percent to 30% of spring–summer Chinook salmon and 6–26% of steelhead that fell back at the Dalles, John Day, and McNary dams entered tributaries downstream from these projects, including the Klickitat, Deschutes, John Day, and Umatilla rivers. Not all of these fish were necessarily homing to the drainages or hatcheries where they were last located; rather, some had probably strayed into these areas either temporarily or permanently. Permanent straying rates (spawning at nonnatal sites) have not been well documented for most Columbia River basin stocks, but estimates for fall Chinook salmon have ranged from less than 2% (Quinn and Fresh 1984) to more than 25% (Quinn et al. 1991). Temporary straying rates (entry into nonnatal spawning areas before resuming migration) are likely higher than permanent straying rates, particularly for steelhead and fall Chinook salmon that seek thermal refugia during summer (Goniea 2002; High 2002). In 2001, many of the spring–

summer Chinook salmon and steelhead we radiotagged at Bonneville Dam were PIT-tagged as juveniles, thereby providing information on adult destinations. Telemetry records for these fish indicated that less than 2% of spring–summer Chinook salmon and about 7% of steelhead were last detected in major tributaries other than their natal spawning areas. Because steelhead migration is protracted, it is likely that some of these fish had strayed temporarily into lower reaches of nonnatal drainages and were harvested before they resumed migration. These low estimates of straying rates suggest that most of the fish falling back at dams and entering downstream tributaries are homing to those drainages.

We were able to determine a last location for most fallback fish, but about 20% of spring–summer Chinook salmon, 27% of fall Chinook salmon, and 32% of steelhead that fell back were not recorded in tributaries or reported as recaptured at hatcheries or in fisheries. These fish might have suffered fallback- or migration-related mortality, entered tributaries undetected, or spawned at main-stem sites; they could also have been captured in fisheries and not reported to us. It is possible that some fallback fish with unknown final fates regurgitated transmitters in deep water, where radio signals are attenuated (Eiler 1990). Steelhead in this study had the highest detected transmitter regurgitation rates, perhaps because their migration was more protracted than those of the Chinook salmon runs (Keefer et al. 2004). Some fall Chinook salmon with unknown fates might have spawned at main-stem sites, though we suspect this number is low. Limited fall Chinook salmon spawning has been documented in tailrace sites at Snake River dams (Dauble et al. 1999), but few redds have been found, and this behavior has proven difficult to verify with radiotelemetry (Mendel and Milks 1995).

In all years of this study, Chinook salmon and steelhead that fell back at Bonneville Dam escaped to tributaries or hatcheries at lower rates than fish that did not fall back (Bjornn et al. 2000a; Boggs et al. 2004), and research into the relationship between fallback and escapement is ongoing. The lower escapement rates we observed for fish that fell back at Bonneville Dam suggest that fallback could cause reduced adult survival due to physical trauma, migration delay, increased vulnerability to fisheries, or greater exposure to marginal environmental conditions (e.g., gas-supersaturated tailrace waters; Backman and Evans 2002). It is also possible that fish that fall back are less physically fit than fish that ascend successfully. Fallback and reascension behavior at dams is likely bioenergetically expensive and could exhaust energy reserves, as occurs with delay at dams (Geist et al. 2000) and other difficult passage areas (Hinch et al. 1996) or with long migrations (Bernatchez and Dodson 1987).

Our results indicate that high river flows and associated high spill volumes increase the percentages of fish that fall back at a dam. Fallback rates of spring–summer Chinook salmon in particular were strongly correlated with mean seasonal river flow at Columbia and Snake River dams. This influence was evident in 2001, when near-record low river flows resulted in only 70 d of spill at Bonneville Dam (10-year mean = 136 d), and fallback percentages at the dam were roughly one-third of those observed in the other four study years. Another period of zero spill occurred in April 1998, during which 7 of 152 (4.6%) spring–summer Chinook salmon that passed Bonneville Dam fell back. During the remainder of the spring–summer Chinook salmon migration in 1998, spill occurred at rates up to 4,248 m^3/s, and 139 of 898 (15.5%) spring–summer Chinook salmon fell back. Reischel and Bjornn (2003) also reported significant positive correlations between fallback by Chinook salmon or sockeye salmon *O. nerka* and spill volume at Bonneville Dam in 1997 and 1998; most fallback events occurred via the dam spillway. Ongoing research into the relationship between fallback, river flow, and dam spill includes experimental manipulation of spill volume at Bonneville, the Dalles, and John Day dams in 2002 and 2003.

Proportions of salmon and steelhead runs that fall back may also be influenced by dam operations other than spill, including activities that attract upstream migrants to (or deter them from) different fishways. For example, increasing the discharge of turbines or spill bays near the entrances to a fishway can affect the total proportion of the fish run attracted to that fishway (Bjornn and Peery 1992). At Bonneville Dam, fish that pass via the Bradford Island, Oregon, fishway have historically fallen back at much higher rates than those that pass the Washington-shore fishway (Bjornn and Peery 1992). When the proportion of fish passing via the Bradford Island fishway increases, total dam fallback proportions also increase because many fish exiting this fishway follow the Bradford Island shoreline directly into the spillway forebay (Reischel and Bjornn 2003).

Fallback and reascension at dams can significantly reduce the accuracy of fishway counts (Blankenship and Mendel 1994; Dauble and Mueller 2000). Low precision in fish counts has raised concerns that the use of count data for escapement estimates or harvest management could harm stocks listed for protection under the U.S. Endangered Species Act, such as threatened Snake River fall and spring–summer Chinook salmon or endangered upper Columbia River spring Chinook salmon (Dauble and Mueller 2000). The largest biases we detected were for fall Chinook salmon at Little Goose (23%) and Lower Granite dams (38%) in 2000. Biases in spring–summer Chinook salmon counts at Bonneville Dam ranged from almost 7% in 2001 to 16% in 1997. Biases between 5% and 15% were common for all runs at most other dams. Because we did not tag fall Chinook salmon in August 1998 or summer Chinook salmon in July 1996, count adjustments for those runs may be less accurate than for other species in other years.

The count adjustments that we calculated from pooled telemetry data should be considered approximate because navigation lock passage was not monitored at most dams, fallback and reascension rates varied through time, and radio-tagged samples were small for some groups (e.g., fall Chinook salmon at Snake River dams) and also varied through time. However, adjustment factors should be reasonably accurate: we found that pooled estimates minimized the impact of within-year variability in adjustment calculations and were similar to stratified, weighted count adjustments for Bonneville and the Dalles dams, where fallback rates were highest and most variable (Bjornn et al. 2000a, 2000b). Pooled adjustments would be least appropriate for comparisons of temporally separated subbasin stocks within a run, as such stocks could be exposed to divergent river environments and have differing fallback responses. More fine-scale adjustments (e.g., weekly) should be used for evaluating the impacts of fallback on specific stocks or to assess management activities at dams.

Radiotelemetry has been the most reliable method for obtaining salmonid fallback and reascension estimates. Recent innovations in PIT tag technology, namely the increase in detection range that allows for detector deployment in fishways and near counting windows, could provide fallback data for addressing count biases. However, PIT tag technology cannot identify fish that fall back and do not reascend, and because PIT tag detectors lack the resolution of radiotelemetry, they cannot determine specific routes of fallback.

Dam operation, river environment, and adult salmon and steelhead migration behaviors all appear to contribute to fallback at Columbia and Snake River hydroelectric dams. The consequences of fallback in terms of direct or delayed mortality, escapement to spawning sites, spawning success, or permanent interbasin straying have not been fully examined. Managers of anadromous Columbia River basin fisheries and operators of hydroelectric projects should focus on strategies to reduce unintentional fallback and work to facilitate benign downstream passage for adult fish, including overshooting prespawn migrants and postspawn out-migrants, such as steelhead kelts.

Acknowledgments

Many people provided their time and assistance during the course of this study. We thank C. Caudill, K. Tolotti, S. Lee, M. Jepson, R. Ringe, T. Dick, M. Feeley, M. Heinrich, B. Hastings, and P. Keniry, who helped with field operations and with collection and processing of telemetry data at the University of Idaho. A. Matter, S. McCarthy, M. Moser, and B. Burke, National Marine Fisheries Service, helped with data management and analysis. Funding for this study was provided by the USACE and was administered by M. Langeslay and B. Dach.

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