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FALLBACK, REASCENSION AND ADJUSTED FISHWAY ESCAPEMENT ESTIMATES FOR ADULT CHINOOK SALMON AND STEELHEAD AT COLUMBIA AND SNAKE RIVER DAMS, 1996-2003.

by

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Preface

Studies of adult salmon and steelhead *Oncorhynchus* spp. migrations past dams, through reservoirs, and into tributaries began in 1990 with planning, purchase, and installation of radio telemetry equipment for studies at the Snake River dams. Adult spring–summer Chinook salmon (*O. tshawytscha)* and steelhead (*O. mykiss*) were outfitted with transmitters at Ice Harbor Dam in 1991 and 1992, and at John Day Dam in 1993; reports of those studies are available (Bjornn et al. 1992; 1994; 1995; 1998). The focus of adult salmonid passage studies shifted to include the lower Columbia River dams and tributaries starting in 1996. From 1996 to 2003 we radio-tagged various combinations of spring–summer Chinook salmon, fall Chinook salmon, steelhead and sockeye salmon at Bonneville Dam and monitored them as they migrated upstream. In this report we present summary information on adult salmonid fallback percentages and rates, dam reascension rates, incidence of "overshoot" fallback, and adjusted fishway escapement estimates for the eight dams on the lower Columbia and lower Snake rivers from 1996 to 2003. We also summarize and discuss fallback by known-source (PIT-tagged as juveniles) adult salmonids at these dams from 2000 to 2003.

This and related reports from this research project can be downloaded from the website: http://www.cnr.uidaho.edu/uiferl/

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Abstract

During their upstream spawning migration in the Columbia River basin, some adult salmon and steelhead *Oncorhynchus* spp. ascend and then fall back over mainstem hydroelectric dams. Fallback can result in fish injury or death, migration delays and biased fishway counts, the primary index for escapement and the basis for production estimates and harvest quotas. We used radio-telemetry to calculate fallback percentages and rates, reascension rates, biases in fishway escapement estimates due to fallback, and occurrence of behaviorally motivated fallback by fish that passed dams upstream from natal spawning sites. We also evaluated fallback by adult fish tha had been PIT tagged as juveniles (known source). The study area included the four Lower Columbia and the four Lower Snake River dams from 1996 to 2003. Research fish were adult spring–summer and fall Chinook salmon *O. tshawytscha* and steelhead *O. mykiss* collected at Bonneville Dam, the first dam Columbia River stocks encounter after leaving the ocean.

With all years combined, about 19% of spring–summer Chinook salmon, 13% of fall Chinook salmon and 24% 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 more variable between dams than for 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 (overshoot fallback). Fall Chinook salmon were the most likely to overshoot fallback, though this behavior was also observed with spring–summer Chinook salmon and steelhead. In all years and at all dams, fallback produced positive biases in fishway counts, ranging from 1-16% for spring–summer Chinook salmon, 1-38% for fall Chinook salmon and 1-12% for steelhead.

Analysis of fallback by known-source (PIT tagged as juveniles) spring–summer Chinook salmon and steelhead indicated that fish transported by barge as juveniles from Snake River dams fell back in significantly higher percentages than Chinook salmon and steelhead returning to the Wind River, the Yakima River, Mid Columbia tributaries and non-transported Chinook salmon returning to the Snake River drainage. Known-source steelhead exhibited a similar pattern with transported Snake River fish falling back in significantly higher percentages than steelhead returning to Mid Columbia tributaries or hatcheries or non-transported Snake River fish.

About 79% of spring–summer Chinook that fell back at Columbia and Snake River dams were later detected in spawning tributaries or recaptured at hatcheries and 20% were unaccounted for in the hydrosystem. Fall Chinook and steelhead that fell back escaped to tributaries and hatcheries at lower rates than spring–summer Chinook (65% and 57%, respectively) with 9% of fall Chinook and 12% or steelhead being unaccounted for in the hydrosystem.

Introduction

The study described herein was undertaken because of concerns of the U.S. Army Corps of Engineers (USACE), state and federal fish agencies and tribes, those expressed in section 603 of the Northwest Power Planning Council (NPPC) 1987 Columbia River Basin Fish and Wildlife Program, and later reflected in the Biological Opinions issued in 1995, 1998, and 2000 for operation of the Federal Columbia River Power System. These agencies and opinions recommended studies to ensure that adult salmon and steelhead passage past dams and through reservoirs was as efficient as possible. Results presented here specifically relate to questions of fallback, reascention and associated bias in fishway escapement estimates as outlined in the 2000 Biological Opinion, Action 107 (National Marine Fisheries Service [NMFS] 2000). Study plans were developed in consultation with USACE personnel, and with biologists in other federal, state, and tribal agencies. Research was conducted by the Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) and National Marine Fisheries Service (NMFS – NOAA Fisheries). Logistical support, cooperation, and funding came from USACE, Bonneville Power Administration (BPA), and the U.S. Geological Survey.

Adult salmon and steelhead 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 orient with the upstream face of the dam and enter these areas. Additionally, salmon or steelhead that migrate upstream beyond their natal stream or hatchery and pass an upstream dam may fall back in an effort to return; this temporary straying or “overshoot” 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 (reviewed in Bjornn and Peery 1992). While not all fish that fall back die or are injured, 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. 2004a; Keefer et al. 2004c). Fallback has been associated with migration delays through the Columbia hydrosystem (e.g. Monan and Liscom 1975, 1979), and significant delays of several days to several weeks were recorded for radio-tagged Chinook salmon and steelhead that fell back in this study (Keefer et al. 2004a).

Fish that fall back and subsequently reascend at dams can pass counting stations more than once, which leads to a positive bias in fish counts and escapement calculations. Counts at dams are also used to estimate run size and to calculate inter-dam conversion rates (dam-to-dam reach 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. 2000a; Boggs et al.2004a) and have important management implications. For instance, several evolutionarily significant steelhead and Chinook salmon populations in the Columbia and Snake rivers are listed as threatened or endangered species (Busby et al. 1996; Meyers et al. 1998) and fish counts at dams are used in making decisions affecting these stocks, including setting harvest quotas and the timing and length of commercial, tribal and sport fishing seasons.

Prior to the advent of large-scale radio telemetry research, characterizing the frequency and implications of fallback in the hydrosystem was constrained by small sample sizes and unknown final fates of fish (Bjornn and Peery 1992). From 1991 to 1994, Bjornn et al. (1998, 2002) radio-tagged about 6,000 adult spring–summer Chinook salmon and steelhead to study their passage at dams and through reservoirs in the lower Snake River, and those samples included fish released at John Day Dam in some years. 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) helped establish baseline estimates of adult fallback at mainstem Snake River dams and at some Columbia River dams.

Advances in radio telemetry 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. Over seven years (1996, 1997, 1998, 2000, 2001, 2002 and 2003) we tagged and released more than 18,000 adult 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 percentages of radio-tagged spring–summer and fall Chinook salmon and steelhead that fell back at each of the eight lower Columbia and lower Snake River dams, fish reascension rates after fall back, and 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 percentages 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). 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, as were several tributaries downstream from Bonneville Dam in 1996 and 1998. Additional sites were monitored at and upstream from Priest Rapids Dam and in Snake River tributaries; data from these locations were generally not used for fallback analyses, except to identify final fish fates.

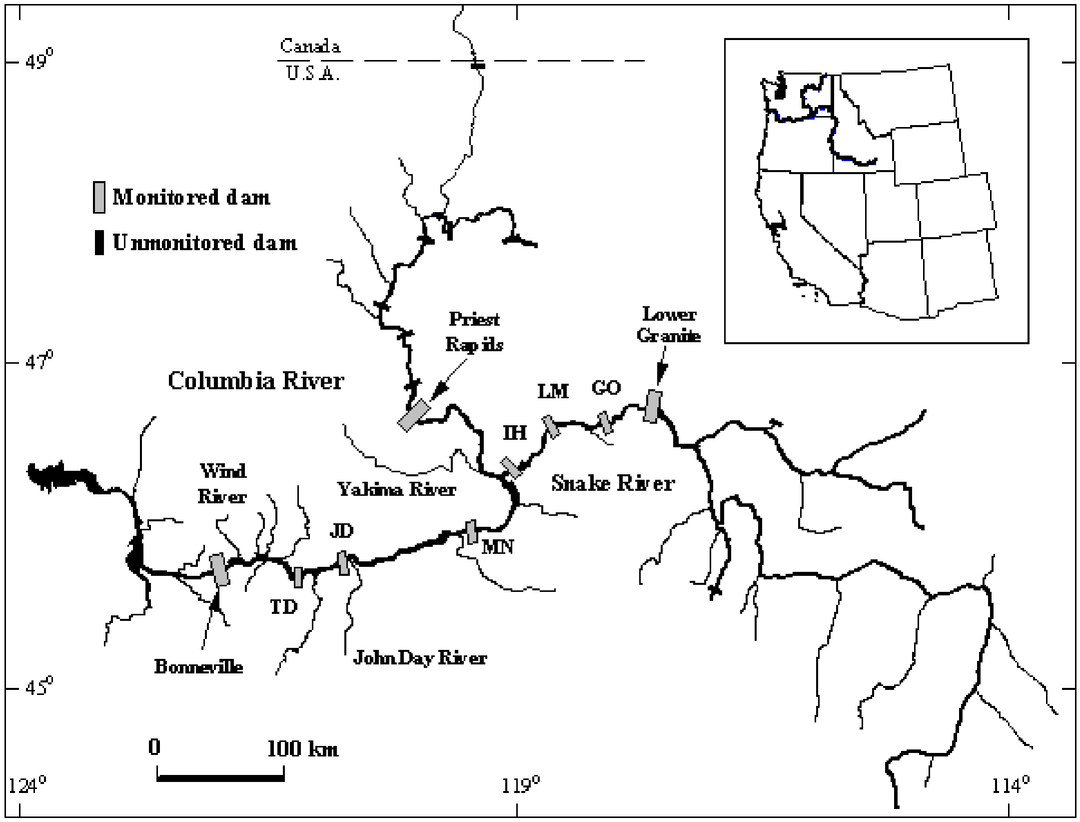

Figure 1. The Columbia and Snake rivers, showing dams monitored with radiotelemetry. For this study, the hydrosystem was bounded by Bonneville, Lower Granite, and Priest Rapids dams. Other monitored dams: The Dalles (TD), John Day (JD), McNary (MN), Ice Harbor (IH), Lower Monumental (LM), and Little Goose (GO). All major Columbia River tributaries upstream from Bonneville Dam were monitored with radio antennas.

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 seven study years, radio transmitters were placed in 18,380 fish: 7,568 spring–summer Chinook salmon, 4,873 fall Chinook salmon and 5,939 steelhead (Table 1). Spring–summer Chinook salmon (primarily stream-type life history) were tagged in all years from April to early or late July and fall Chinook salmon (primarily ocean-type life history) were tagged from early August (2000, 2001, 2002, 2003) or September (1998) through October. Steelhead were tagged from early to mid-June through October (1996, 1997, 2000, 2001, 2002, 2003). Chinook salmon run designations were based on the established separation between spring, summer, and fall-run fish at Bonneville Dam (e.g. USACE 2001). For our analyses, radio-tagged fish kept their initial designation regardless of date of passage at upstream sites.

Each day fish were tagged, 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 not randomly 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, we rejected "jack" (precocious males, by size) Chinook salmon and steelhead with fork lengths less than 50 cm to accommodate transmitter size.

Table 1. Number of adult salmon and steelhead outfitted with radio-transmitters at Bonneville Dam from 1996 to 2003.

Year	Sp-Su Chinook	Fall Chinook	Steelhead	**Total**
1996	853	-	765	**1,618**
1997	1,014	-	975	**1,989**
1998	957	1,032	-	**1,989**
2000	1,132	1,118	1,160	**3,410**
2001	1,212	992	1,151	**3,355**
2002	1,217	1,065	1,273	**3,555**
2003	1,183	666	615	**2,464**
Total	**7,568**	**4,873**	**5,939**	**18,380**

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 summer Chinook salmon were tagged, and when high water temperatures precluded tagging fall Chinook salmon in August of 1998. We intentionally radio-tagged more late-migrating (B-group) than early-migrating (A-group) steelhead to increase samples of fish returning to the Snake River.

During fall Chinook tagging, we primarily selected for 'upriver-bright' fish that spawn mostly in the Hanford Reach, Snake, Yakima, John Day or Deschutes rivers and limited our collection of the darker colored, sexually mature 'Tule' fall Chinook salmon. Tules return only a short distance upstream to Bonneville reservoir hatcheries (Meyers et al. 1998), and during times of high Tule passage we selected against these fish to ensure adequate sample sizes at upstream projects.

In 2000-2003, tagging methods were modified to include use of an automated system (McCutcheon et al. 1994) that identified fish with passive integrated transponder (PIT) tags as they passed through the AFF trap. PIT tags indicated if and where fish were tagged as juveniles (referred to here as "known-source" fish because their natal sites or river drainages were known), and use of PIT-tagged fish allowed us to make stock-specific harvest, escapement, and unaccounted-for loss estimates (see Keefer et al.

2004c). Only approved groups of PIT-tagged fish were available for radio-tagging, and codes for those fish were imported into the automatic detection system at the trap. We attempted to radio tag as many known-source fish as possible within the 2000-2003 tagging schedules. Known-source fish were radio-tagged as they were trapped, and fish without PIT tags made up the remainders of each daily sample. In 2000, 2001, 2002 and 2003 spring–summer Chinook that had been PIT-tagged as juveniles comprised 6, 70, 37, and 26% of the spring–summer Chinook sample, respectively. Known-source fish made up < 1, 13, 6, and 18% of fall Chinook salmon, and < 1, 61, 46, and 17% of steelhead during the four years, respectively.

Anesthetization, fish handling and radio-tag insertion methods were the same in all years and are described in Keefer et al. 2004b. We primarily used 3 volt and 7 volt transmitters, but also used small numbers of radio-data storage transmitters (RDST) and combination acoustic/radio transmitters (CART) (Lotek Wireless, Inc., Newmarket, Ont); all transmitters had a repeat rate of 5 sec. All transmitters were dipped in glycerin before intragastric insertion (Mellas and Haynes 1985). Three-volt tags weighed 11 g in air (4.3 by 1.4 cm), 7-volt tags were 29 g (8.3 by 1.6 cm), RDST tags were 34 g (9.0 by 2.0 cm) and CART tags were 28 g (6.0 by 1.6 cm). Lithium batteries powered 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 (VI) tag into the clear tissue posterior to the eye of each fish during the 1996-2000 study years. We switched secondary tags in 2000 to PIT tags inserted into the abdominal cavities of those fish that had not been PIT-tagged as juveniles; only original PIT tags were used as secondary markers for fish with juvenile PIT tags. After tagging, fish were moved to a 2275 L transport tank where they were held (< 3 h) until release.

All fish radio-tagged from 1996, 1997, 1998, and 2003 were released about 9.5 km downstream from Bonneville Dam at sites on both banks of the Columbia River. In 2000, 91% of spring Chinook, 74% of summer Chinook, 67% of fall Chinook salmon and 73% of steelhead were released at the downstream sites and the remainders were released in the Bonneville Dam forebay within 1 km of the dam. In 2001 and 2002, 57 to 72% and 71 to 74% of each run, respectively, 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. For a description of fallback behavior at Bonneville Dam by fish released in the Bonneville Dam forebay, see Boggs et al. 2004b.

Telemetry Monitoring

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

Data Analysis

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

Fallback percentage, the percentage 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. Fallback rate, which included multiple fallback events by individual fish at a dam, was the total number of fallback events at a dam divided by the number of unique radio-tagged fish known to have passed the dam. Reascension proportion was the proportion of unique fish that fell back at a dam that 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 telemetry records from fixed site receivers at dams and the mouths of tributaries, from mobile tracking records, and from recaptures of tagged fish in fisheries, hatcheries and from spawning ground surveys. All transmitters used in this study were inscribed with return and reward information and found tags or those recovered from fish captured in fisheries were eligible for rewards of US$10 to $100. 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 through May) were considered post-spawn (kelts) and not included in any fallback calculations. Fallbacks by Chinook salmon that occurred after likely spawning were similarly excluded.

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

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

LP_K was the number of unique fish with transmitters known to have passed the dam via the fishways (assumes that unrecorded fish passed dam via fishways), NLP_K was the number of unique fish with transmitters known to have passed the dam via the navigation lock (only Bonneville and McNary locks monitored), FB_{UF} was the number of unique fish that fell back at the dam one or more times, R_{UF} was the number of unique fish that reascended the dam and stayed upstream from the dam regardless of the number of fallbacks, and TLP_K was the total number of times unique fish with transmitters were known to have passed the dam via fishways (includes initial passage and all reascention).

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 both fallback and reascension rates. To address potential biases, we calculated additional adjustments using stratified sampling methods during consecutive 5-d blocks weighted by the number of fish passing the dam during each block. In earlier multi-year studies, the weighted adjustment factors were typically within 2% of pooled adjustment factors (Bjornn et al. 2000a; 2000b; 2000c) and so only pooled values are reported here.

We tested the influence of dam, run and year on fallback percentages and rates using two separate MANOVA models followed by univariate ANOVAs with pairwise comparisons performed using a Tukey test (Zar 1999). The effects of run and dam and the interaction of these two factors on fallback were tested using observations across years as the replicates. The effect of year was tested by using observations at each dam, within runs, as the replicates. The interaction of run and year could not be tested because not all runs were sampled in all years. Fallback percentages and rates were log transformed to improve normality, and fall Chinook salmon fallback percentages and rates at Little Goose and Lower Granite dams were excluded due to high variability and small sample sizes for this analysis.

Stock specific fallback was evaluated using the known-source component of radio-tagged spring–summer Chinook salmon and steelhead. Spring–summer Chinook were divided into several groups based on where they were PIT-tagged as juveniles: 1) fish from the Wind River (Carson National Fish Hatchery), 2) fish from Mid Columbia River tributaries or dams upstream of McNary Dam (excluding the Snake River), 3) fish from the Yakima River drainage, 4) fish from the Snake River and its tributaries that were not transported, and 5) fish that had been collected and barged from Snake River dams. Steelhead were divided into the Mid Columbia and the two Snake River groups only. Contingency tables and a Pearson Chi-square statistic were used to compare the fallback percentages of each group at each of the Lower Columbia River dams.

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, a period including the annual snowmelt event and spilling at the dams, was used as the independent variable. Similar regressions were not performed for fall Chinook salmon or steelhead because the majority of those runs passed dams after river discharge declined to near base levels, summer spill had ended, and the range in flow was insufficient to detect differences.

Results

Fallback and Reascension

With all years combined, at least 19% of spring–summer Chinook salmon, 24% of steelhead and 13% of fall Chinook salmon with radio transmitters that passed a dam fell back over at least one dam one or more times during their upstream migration in the lower Columbia and Snake rivers. The range in annual fallback percentages was 11 to 32% for spring–summer Chinook salmon, 18 to 27% for steelhead and 12 to 18% for fall Chinook salmon.

The mean percentage of spring–summer Chinook salmon that fell back at lower Columbia River dams during the seven study years was 9.6% (*range* 4.1-14.6%) at Bonneville Dam, 9.5% (*range* 5.4-14.4%) at The Dalles Dam, 7.3% (*range* 3.0-11.9%) at John Day Dam, and 5.6% (*range* 1.4-9.3%) at McNary Dam (Table 2). Spring–summer Chinook fallback rates, which included multiple fallback events by individual fish, were 0.8 to 5.3% higher than fallback percentages each year at Bonneville and The Dalles dams, and 0.3 to 2.7% higher than percentages at John Day and McNary dams. Mean fallback percentages for fall Chinook at Columbia River dams were 4.0% (*range* 3.5-4.8%) at Bonneville Dam, 8.8% (*range* 6.9-10.2%) at The Dalles Dam, 2.5% (*range* 1.7-3.7%) at John Day Dam and 2.8% (*range* 2.0-3.5%) at McNary Dam (Table 2). Fall Chinook fallback rates were higher than fallback percentages by 0.7 to 2.1% each year at Bonneville and The Dalles dams and 0 to 0.4% higher at John Day and McNary dams.

Mean percentages of steelhead that fell back at Columbia River dams were 5.8% (*range* 3.6-9.1%) at Bonneville Dam, 7.1% (*range* 6.0-10.5%) at The Dalles Dam, 6.9% (*range* 4.3-10.1%) at John Day Dam and 7.9% (*range* 4.9-10.7%) at McNary Dam (Table 2). Steelhead fallback rates at lower Columbia River dams were higher than fallback percentages by 0.2 to 3.1% except at The Dalles Dam in 2003 when the fallback rate exceeded the fallback percentage by 7.0%.

Fallback percentages and rates for spring–summer Chinook salmon and steelhead were generally lower at Snake River dams than at lower Columbia River dams (Table 3). In contrast, relatively large percentages of fall Chinook salmon fell back at Snake River dams, though sample sizes were small. Mean fallback percentages for spring–summer Chinook and steelhead at Snake River dams ranged from 2.4% to 6.4% and were less than 10% at all dams in all years (Table 3). Mean fall Chinook fallback percentages were 9.8% at Ice Harbor Dam, 4.3% at Lower Monumental Dam, 16.0% at Little Goose Dam and 16.7% at Lower Granite Dam.

Table 2. Percentages of radio-tagged Chinook salmon and steelhead that fell back at lower Columbia River dams and fallback rates at each dam during 1996-2003. NP_K = number of fish known to pass dam, FB_U = number of unique fish that fell back, FB_T = total fallback events, Fallback Percent = FB_U/ NP_K, Fallback Rate = FB_T/NP_K.

	Fallback					Fallback				
Year	Percent	Rate	NP_K	FB_U	FB_T	Percent	Rate	NP_K	FB_U	FB_T
	Bonneville Dam					The Dalles Dam				
	Spring–Summer Chinook									
1996	13.8	16.4	809	112	133	13.3	18.3	497	66	91
1997	14.6	19.9	950	139	189	14.4	18.6	714	103	133
1998	11.2	15.8	932	104	147	11.5	14.3	763	88	109
2000	13.0	16.8	951	124	160	9.6	12.2	844	81	103
2001	4.1	7.0	773	32	54	5.5	7.0	1,032	57	72
2002	6.1	6.9	881	54	61	5.4	6.9	981	53	68
2003	4.7	6.2	1,089	51	67	6.6	8.1	849	56	69
	Fall Chinook									
1998	3.5	4.2	913	32	38	10.2	11.6	629	64	73
2000	3.9	5.2	659	26	34	8.5	9.6	738	63	71
2001	4.8	6.9	521	25	36	6.9	8.4	713	49	60
2002	3.8	4.6	676	26	31	8.9	10.2	744	66	76
2003	4.0	4.8	583	23	28	9.3	10.8	453	42	49
	Steelhead									
1996	4.9	5.3	720	35	38	6.0	6.9	580	35	40
1997	9.1	9.9	916	83	91	6.6	7.6	683	45	52
2000	6.9	7.4	811	56	60	6.3	7.2	871	55	63
2001	4.3	4.5	775	33	35	6.1	8.8	963	59	85
2002	3.6	4.4	909	33	40	7.1	10.2	1,136	81	116
2003	5.9	8.3	564	33	47	10.5	17.5	506	47	78

Table 2 continued.

Year	Fallback Percent	Fallback Rate	NP_K	FB_U	FB_T	Fallback Percent	Fallback Rate	NP_K	FB_U	FB_T
	John Day Dam					McNary Dam				
	Spring–Summer Chinook									
1996	11.9	14.1	377	45	53	9.3	10.3	301	28	31
1997	9.9	12.6	629	62	79	8.0	10.6	587	47	62
1998	10.6	11.6	639	68	74	9.2	10.9	576	53	63
2000	6.0	6.5	681	41	44	4.3	5.4	626	27	34
2001	3.0	3.3	969	29	32	1.4	1.7	908	13	15
2002	4.9	5.7	837	41	48	4.7	5.8	770	36	45
2003	4.5	4.9	719	32	35	2.3	3.1	656	15	20
	Fall Chinook									
1998	3.7	3.7	483	18	18	2.1	2.1	428	9	9
2000	2.6	2.6	570	15	15	2.0	2.0	456	9	9
2001	2.6	2.8	580	15	16	3.5	3.9	482	17	19
2002	1.8	1.8	570	10	10	3.5	3.5	479	17	17
2003	1.7	1.7	350	6	6	2.7	4.1	293	8	12
	Steelhead									
1996	10.1	11.2	457	46	51	7.4	8.6	394	29	34
1997	7.9	9.0	554	44	50	10.7	12.9	487	52	63
2000	4.3	4.5	748	32	34	9.8	10.2	645	63	66
2001	5.3	5.6	869	46	49	7.1	7.6	790	56	60
2002	4.6	5.0	920	42	46	4.9	5.8	831	41	48
2003	9.1	10.4	395	36	41	7.2	7.5	333	24	25

Table 3. Percentages of radio-tagged Chinook salmon and steelhead that fell back at lower Snake River dams and fallback rates at each dam during 1996-2003. NP_K = number of fish known to pass dam, FB_U = number of unique fish that fell back, FB_T = total fallback events, Fallback Percent = FB_U/ NP_K, Fallback Rate = FB_T/NP_K.

	Fallback					Fallback				
Year	Percent	Rate	NP_K	FB_U	FB_T	Percent	Rate	NP_K	FB_U	FB_T
	Ice Harbor Dam					Lower Monumental Dam[a]				
	Spring–Summer Chinook									
1996	7.5	8.3	120	9	10	-	-	-	-	-
1997	9.1	10.4	318	29	33	5.1	5.8	311	16	18
1998	7.4	7.4	256	19	19	4.0	4.0	252	10	10
2000	9.6	13.7	249	24	34	4.5	4.5	246	11	11
2001	1.4	1.4	555	8	8	0.9	0.9	551	5	5
2002	4.5	5.6	376	17	21	3.7	3.7	374	10	10
2003	5.2	6.4	327	17	21	2.5	2.8	323	8	9
	Fall Chinook									
1998	6.9	6.9	29	2	2	3.6	3.6	28	1	1
2000	3.0	3.0	33	1	1	9.1	9.1	33	3	3
2001	11.8	11.8	93	11	11	5.9	5.9	85	5	5
2002	10.9	10.9	73	8	8	3.1	3.1	65	2	2
2003	16.2	16.2	37	6	6	-	-	33	0	0
	Steelhead									
1996	5.6	6.3	319	18	20	-	-	-	-	-
1997	4.9	5.4	387	19	21	4.0	4.8	375	15	18
2000	4.7	5.1	486	23	25	1.7	1.7	471	8	8
2001	3.9	4.7	489	19	23	2.8	3.0	472	13	14
2002	4.5	5.4	652	29	35	4.2	4.6	637	27	29
2003	5.1	5.8	275	14	16	2.6	2.6	271	7	7

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

Table 3 continued

Year	Fallback Percent	Fallback Rate	NP_K	FB_U	FB_T	Fallback Percent	Fallback Rate	NP_K	FB_U	FB_T
	Little Goose Dam[a]					Lower Granite Dam				
	Spring–Summer Chinook									
1996	-	-	-	-	-	1.0	1.0	101	1	1
1997	8.9	8.9	302	27	27	5.8	5.8	292	17	17
1998	5.6	6.0	249	14	15	4.3	4.8	230	10	11
2000	3.7	3.7	241	9	9	2.9	2.9	238	7	7
2001	1.5	1.5	543	8	8	0.6	0.6	538	3	3
2002	3.7	3.7	370	10	10	3.1	3.1	360	11	11
2003	2.8	3.5	318	9	11	2.3	2.3	309	7	7
	Fall Chinook									
1998	20.0	30.0	20	4	6	25.0	37.5	8	2	3
2000	35.5	58.1	31	11	18	40.0	56.0	25	10	14
2001	10.8	12.2	74	8	9	4.8	6.5	62	3	4
2002	6.9	6.9	58	4	4	6.8	11.4	44	3	5
2003	6.9	6.9	29	2	2	7.1	7.1	28	2	2
	Steelhead									
1996	-	-	-	-	-	8.4	9.2	262	22	24
1997	8.4	9.0	335	28	30	5.9	6.9	306	18	21
2000	5.3	5.3	450	24	24	3.7	3.7	407	15	15
2001	5.2	5.2	445	23	23	2.7	2.9	445	12	13
2002	5.3	5.5	606	32	33	4.6	4.8	522	24	25
2003	6.0	6.4	266	16	17	2.4	2.8	254	6	7

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

Dam, year, and the dam × run interaction had a significant effect on fallback percentage and rate (MANOVA, $P < 0.001$); the effect of run was not significant. Individual ANOVA for each run indicated dam had significant effect on fallback rates for all runs ($P < 0.05$); year affected fallback rates of spring–summer Chinook and steelhead ($P < 0.05$). Pairwise comparison of dams revealed spring–summer Chinook fallback rates at Bonneville Dam were significantly ($P < 0.05$) higher than rates at McNary Dam and all Snake River dams, rates at The Dalles Dam were significantly ($P < 0.01$) higher than at

Lower Monumental, Little Goose and Lower Granite dams, and rates at John Day Dam were significantly higher than at Lower Monumental Dam ($P < 0.01$). Steelhead fallback rates at Bonneville, The Dalles and John Day, McNary and Little Goose dams were significantly ($P < 0.05$) higher than rates at Lower Monumental Dam and fallback rates at McNary and The Dalles dams were significantly ($P < 0.05$) higher than rates at Lower Granite Dam. Fall Chinook fell back at significantly ($P < 0.05$) higher rates at Bonneville and The Dalles dams than at John Day Dam, and rates at The Dalles and Ice Harbor dams were significantly ($P < 0.01$) higher than at McNary Dam. Pairwise comparisons of years indicated spring–summer Chinook fallback rates in 2001 were significantly ($P < 0.001$) lower than in all other study years and 2003 had significantly

($P < 0.01$) lower fallback rates than 1997 and 1998. Spring–summer Chinook fallback rates in 1997 were significantly ($P < 0.001$) higher than in 2002. Steelhead fallback rates in 2000 and 2001 were marginally significantly ($P < 0.08$) lower than in 1997. ANOVA and pairwise comparisons of fallback percentages for all runs showed similar results as fallback rates and are not reported.

The proportions of fallback fish that reascended at dams 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 (85.0%) and Lower Granite (76.2%) dams and were between 47 and 66% at all other dams. Mean steelhead reascension percentages were highest at Bonneville (76.4%) and The Dalles (70.1%) dams and were between 44 and 63% at all other dams. In contrast, mean reascension percentages for fall Chinook salmon were less than 15% at Lower Monumental Dam, between 22 to 38% at The Dalles, John Day, McNary, Ice Harbor and Little Goose dams, 49.4% at Bonneville Dam, and 50.8% at Lower Granite Dam.

"Overshoot" Fallbacks

Many Chinook 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 likely behaviorally motivated, or "overshoot" fallbacks. Others may have been temporary or permanent strays from other basins. Percentages of spring–summer Chinook salmon that entered downstream tributaries or hatcheries after falling back at lower Columbia River dams ranged from a mean of 14.4% at The Dalles Dam to 34.8% at McNary Dam over the seven study years (Table 5). Tributaries downstream from Bonneville Dam were monitored in 1996 and 1998 only, and 4.5% (1996) and 2.9% (1998) of spring–summer Chinook salmon that fell back at Bonneville 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 10.1% at Lower Granite Dam to 24.7% at Ice Harbor Dam (Table 5).

Table 4. Percentages of radio-tagged salmon and steelhead that reascended fishways at Columbia and Snake River dams after falling back.

	Columbia River Dams				Snake River Dams			
Spp/Year	BO	TD	JD	MN	IH	LM[a]	GO[a]	GR
Spring–Summer Chinook								
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
2002	83.3	77.4	80.5	38.9	76.5	60.0	70.0	90.0
2003	80.4	64.3	62.5	46.7	82.4	62.5	66.7	85.7
Fall Chinook								
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
2002	43.2	30.3	30.0	11.8	0	0	0	0
2003	21.7	14.3	14.3	16.7	66.7	0	100.0	50.0
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
2002	72.7	76.5	59.5	36.6	37.9	37.3	56.3	68.2
2003	54.5	36.2	61.1	29.2	71.4	71.4	68.8	66.7

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

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. At lower Columbia River dams, mean percentages of fall Chinook salmon that entered tributaries downstream after falling back ranged from 42.2% at The Dalles Dam to 50.1% at John Day Dam; in 1998, 31.3% of fall Chinook salmon that fell back at Bonneville dam entered monitored tributaries or hatcheries downstream from the dam. Mean fall Chinook salmon overshoot percentages at Snake River dams ranged from 16.0% at Lower Granite to 78.0% at Ice Harbor Dam (Table 5).

Overshoot fallbacks by steelhead at Columbia River dams ranged from a mean of 4.5% at The Dalles Dam to 29.1% at McNary Dam; 5.7% of steelhead that fell back at Bonneville Dam entered downstream tributaries or hatcheries in 1996. At Snake River dams, fallback steelhead entered downstream tributaries in mean percentages ranging from 8.6% at Lower Granite Dam to 18.5% at Ice Harbor Dam (Table 5).

Table 5. Percentages of adult salmon and steelhead that fell back at Columbia River or Snake River dams that were known to have entered tributaries or hatcheries downstream from the fallback location (possible "overshoot" fallbacks). Tributaries downstream from Bonneville Dam monitored in 1996 and 1998 only.

	Columbia River Dams				**Snake River Dams**			
Spp/Year	BO	TD	JD	MN	IH	LM	GO	GR
Spring–Summer Chinook								
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
2002	-	1.9	4.9	38.9	11.8	20.0	10.0	0
2003	-	10.7	3.1	46.7	17.6	25.0	33.3	14.3
Fall Chinook								
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
2002	-	40.9	50.0	64.7	75.0	0	33.3	0
2003	-	47.6	57.1	33.3	33.3	0	0	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
2002	-	1.2	11.9	19.5	6.9	14.8	12.5	8.3
2003	-	2.1	2.8	54.2	21.4	28.6	12.5	0

Fallback by Known-Source Spring and Summer Chinook Salmon

At all dams, four-year mean fallback percentages for the five groups of known-source spring–summer Chinook salmon were less than 2% for the Yakima River and Mid Columbia groups, ranged from 0.5% to 3.4% for the non-transported Snake River group and ranged from 3.4% to 13.8% for transported Snake River salmon. The Wind River group had the smallest sample size (49 fish) and fell back at Bonneville Dam at a mean of 10.2%. Sample sizes for other dam-group combinations ranged from 155 to 427 salmon (Table 6). At all dams, Chi tests indicated significant differences in fallback percentages among stocks ($P < 0.001$) with the transported Snake River group deviating the greatest amount from expected frequencies. Additionally, the Wind River group fell back at higher than expected frequencies at Bonneville Dam.

Table 6. Annual (2000-2003) percentages (*n*) of known-source spring–summer Chinook salmon that fell back at lower Columbia River dams.

		Fallback percentage (*n*)			
Stock	Year	Bonneville	The Dalles	John Day	McNary
Wind River	2000	0 (1)	-	-	-
	2001	-	-	-	-
	2002	8.6 (35)	-	-	-
	2003	15.4 (13)	-	-	-
	Total	**10.2 (49)**	**-**	**-**	**-**
Yakima River	2000	-	-	-	-
	2001	0 (82)	0 (109)	0 (109)	0 (109)
	2002	4.6 (65)	1.1 (91)	2.3 (86)	0 (84)
	2003	0 (8)	0 (8)	0 (8)	0 (8)
	Total	**1.9 (155)**	**0.5 (208)**	**1.0 (203)**	**0 (201)**
Mid Columbia	2000	2.7 (37)	5.4 (37)	3.0 (33)	0 (33)
	2001	0 (96)	0 (127)	0.8 (127)	0 (127)
	2002	1.4 (73)	2.1 (94)	1.1 (92)	2.2 (90)
	2003	1.1 (180)	2.4 (169)	2.0 (152)	0.7 (143)
	Total	**1.0 (386)**	**1.9 (427)**	**1.5 (404)**	**0.8 (393)**
Snake R., no transport	2000	15.4 (13)	9.1 (11)	0 (11)	0 (11)
	2001	1.1 (182)	0.8 (236)	1.3 (236)	0.4 (236)
	2002	6.0 (116)	0.8 (119)	2.6 (115)	0.9 (112)
	2003	2.3 (44)	0 (43)	0 (38)	0 (38)
	Total	**3.4 (355)**	**1.0 (409)**	**1.5 (400)**	**0.5 (397)**
Snake R., transport	2000	28.6 (14)	27.3 (11)	18.2 (11)	10.0 (10)
	2001	9.7 (103)	13.5 (148)	6.1 (148)	3.4 (148)
	2002	17.0 (47)	17.0 (41)	10.0 (40)	5.3 (38)
	2003	4.5 (41)	7.7 (39)	2.6 (39)	0 (37)
	Total	**11.7 (205)**	**13.8 (239)**	**6.7 (238)**	**3.4 (233)**

Four-year mean fallback percentages for known-source fall Chinook from the Snake River ranged from 3.9% at Bonneville Dam to 1.0% at John Day and McNary dams (Table 7). There were no fallbacks by known-source fall Chinook except in 2001. Approximately 10% of known-source fall Chinook were barged as juveniles.

Table 7. Annual (2000-2003) percentages (*n*) of known-source Snake River[1] fall Chinook salmon that fell back at lower Columbia River dams.

		Fallback percentage (*n*)			
Stock	Year	Bonneville	The Dalles	John Day	McNary
Snake River	2000	0 (6)	0 (7)	0 (7)	0 (6)
	2001	11.5 (26)	3.7 (54)	2.0 (51)	2.0 (49)
	2002	0 (34)	0 (33)	0 (31)	0 (26)
	2003	0 (11)	0 (11)	0 (10)	0 (10)
	Total	**3.9 (77)**	**1.9 (105)**	**1.0 (99)**	**1.0 (99)**

[1] Approximately 10% were barged as juveniles

Known-source steelhead fell back in percentages similar to spring–summer Chinook salmon with four-year mean fallback proportions for the Mid Columbia and non-transported Snake River groups ranging from 0.9% to 3.0% at the four dams. Transported Snake River steelhead four-year mean rates ranged from 5.8% to 11.7% (Table 8). Again, Chi tests indicated significant differences in fallback percentages among stocks ($P < 0.001$) with the transported Snake River group deviating the greatest amount from expected frequencies.

Table 8. Annual (2000-2003) percentages (*n*) of known-source steelhead that fell back at lower Columbia River dams.

		Fallback percentage (*n*)			
Stock	Year	Bonneville	The Dalles	John Day	McNary
Mid Columbia	2000	0 (2)	0 (1)	0 (1)	0 (1)
	2001	1.1 (183)	2.8 (284)	2.3 (257)	1.7 (235)
	2002	1.2 (82)	3.4 (117)	0 (107)	1.0 (104)
	2003	-	-	-	-
	Total	**1.1 (267)**	**3.0 (402)**	**1.6 (365)**	**1.5 (340)**
Snake R., no transport	2000	0 (6)	0 (7)	0 (7)	0 (7)
	2001	2.5 (120)	1.9 (154)	1.4 (144)	0.7 (142)
	2002	1.7 (180)	2.2 (179)	1.8 (164)	1.3 (157)
	2003	0 (33)	0 (30)	0 (29)	0 (28)
	Total	**1.8 (339)**	**1.9 (370)**	**1.5 (344)**	**0.9 (334)**
Snake R., transport	2000	0 (1)	0 (1)	0 (1)	-
	2001	7.3 (110)	11.8 (161)	11.9 (151)	10.6 (132)
	2002	2.3 (175)	8.1 (197)	2.8 (180)	3.0 (166)
	2003	13.6 (59)	26.0 (50)	20.5 (44)	8.6 (35)
	Total	**5.8 (345)**	**11.7 (409)**	**8.5 (376)**	**6.6 (333)**

Last Known Locations of Fallback Fish

Percentages of fallback spring–summer Chinook that eventually entered tributaries or hatcheries up or downstream from the fallback location were relatively consistent (71.3-86.2%) for all dams with a mean of 74.7% at Columbia River dams and 82.3% at Snake River dams. Between 3.7 and 5.5% (*mean* 4.6%) of the spring–summer Chinook salmon that fell back at Columbia River dams were reported recaptured in mainstem fisheries. Percentages of fallback spring–summer Chinook salmon that were last located in the mainstem rivers (unknown fate, or unaccounted for) ranged from 13.8 to 25.0%, with means of 20.7% and 17.7% for fish that fell back at Columbia and Snake River dams, respectively (Table 9).

Table 9. Percentages of spring–summer Chinook salmon (all years combined) that fell back at dams that were last recorded in tributaries or hatcheries, reported recaptured in mainstem fisheries or last recorded at mainstem sites but whose fate was unknown. Percentages above line entered tributaries downstream from the fallback site, except for fish that fell back at Snake River dams and subsequently passed Priest Rapids Dam in the upper Columbia River.

	Columbia River Dams				Snake River Dams			
	BO	TD	JD	MN	IH	LM	GO	GR
Fallback fish (N)	617	504	318	219	123	60	77	55
In Tributaries or Hatcheries (%)								
Below Bonneville	1.5	0.8	0.9					
Bonneville Pool	15.9	14.9	6.0	3.2	0.8	1.7		
The Dalles Pool	8.3	6.3	10.1	5.0	1.6	1.7	1.3	
John Day Pool	2.8	2.2	5.0	25.6	11.4	13.3	7.8	3.6
McNary Pool[1]	4.2	1.0	6.3	7.8	5.7	1.7	1.3	1.8
Lower Snake[2]	0.5	1.0	0.9	1.9	4.1		15.6	5.5
Above L. Granite[3]	30.6	39.3	37.7	26.9	60.2	51.7	55.8	70.9
Above P. Rapids[3]	7.6	7.7	9.4	7.8	2.4	5.0	2.6	1.8
Total	71.3	73.2	76.3	78.1	86.2	75.0	84.4	83.6
In Mainstem (%)								
Recapture	5.5	5.2	3.8	3.7				
Unknown	23.2	21.6	19.8	18.3	13.8	25.0	15.6	16.4

[1] Includes Walla Walla and Yakima rivers and Ringold and Priest Rapids hatcheries
[2] Includes Tucannon River and Lyons Ferry Hatchery
[3] Includes all sites upstream from Lower Granite or Priest Rapids dams

Between 46.2 and 73.3% (*mean* 59.3%) of fall Chinook salmon that fell back at Columbia River dams were last located in tributaries or hatcheries (Table 10); percentages ranged from 55.6 to 89.3% (*mean* 70.9%) for fall Chinook salmon that fell back at Snake River dams, where sample sizes were small. Between 4.5 and 14.1% (*mean* 9.4%) of fall Chinook salmon that fell back at Columbia River dams were reported recaptured in mainstem fisheries. Fall Chinook salmon that fell back and were last located at mainstem sites (unknown fate) ranged from 18.3 to 49.2% (*mean* 31.3%) for Columbia River dams and from 10.7 to 44.4% (*mean* 22.7%) for Snake River dams. Fall Chinook salmon that returned to the Hanford Reach were considered successful migrants.

Table 10. Percentages of fall Chinook salmon (all years combined) that fell back at dams that were last recorded in tributaries, reported recaptured in mainstem fisheries or last recorded at mainstem sites but whose fate was unknown. Percentages above line entered tributaries downstream from the fallback site, except for fish that fell back at Snake River dams and subsequently passed Priest Rapids Dam on the upper Columbia River. Fall Chinook that returned to the Hanford Reach of the Columbia River were considered successful migrants.

	Columbia River Dams				Snake River Dams			
	BO	TD	JD	MN	IH	LM	GO	GR
Fallback fish (N)	132	285	64	60	28	11	28	18
In Tributaries or Hatcheries (%)								
Below Bonneville	15.9	1.8	1.6					
Bonneville Pool	17.4	40.4	23.4	8.3	3.6			
The Dalles Pool	3.0	4.6	25.0	11.7				
John Day Pool	1.5	0.7		26.7	21.4	9.1		
McNary Pool[1]	5.3	8.4	4.7	20.0	42.9	27.3	7.1	
Lower Snake[2]	0.8	0.4		1.7	3.6		35.7	22.2
Above L. Granite[3]	1.5	1.8	3.1	5.0	10.7	18.2	28.6	33.3
Above P. Rapids[3]	0.8	0.4	1.6		7.1	9.1	3.6	
Total	46.2	58.2	59.4	73.3	89.3	63.6	75.0	55.6
In Mainstem (%)								
Recapture	4.5	10.5	14.1	8.3	0.0	0.0	0.0	0.0
Unknown	49.2	31.2	26.6	18.3	10.7	36.4	25.0	44.4

[1] Includes Walla Walla and Yakima rivers and Ringold and Priest Rapids hatcheries
[2] Includes Tucannon River and Lyons Ferry Hatchery
[3] Includes all sites upstream from Lower Granite or Priest Rapids dams

Percentages of steelhead that entered tributaries or hatcheries after falling back ranged from 44.3 to 65.4% (*mean* 57.3%) at Columbia River dams and from 45.7 to 67.2 % (*mean* 57.7%) at Snake River dams (Table 11). Between 8.5 and 14.7% (*mean* 11.5%) of steelhead that fell back at Columbia River dams and from 3.3 to 6.6% (*mean* 5.1%) of those that fell back at Snake River dams were reported recaptured in mainstem fisheries. Percentages of fallback steelhead with unknown fate at mainstem sites ranged from 26.0 to 41.0% (*mean* 31.2%) for Columbia River dams and 26.2 to 50.0% (*mean* 37.2%) for Snake River dams.

Table 11. Percentages of steelhead (all years combined) that fell back at dams that were last recorded in tributaries, reported recaptured in mainstem fisheries or last recorded at mainstem sites but whose fate was unknown. Percentages above line entered tributaries downstream from the fallback site, except for fish that fell back at Snake River dams and subsequently passed Priest Rapids Dam on the upper Columbia River.

	Columbia River Dams				Snake River Dams			
	BO	TD	JD	MN	IH	LM	GO	GR
Fallback fish (N)	273	322	246	265	122	70	122	97
In Tributaries or Hatcheries (%)								
Below Bonneville	1.1							
Bonneville Pool	7.7	3.4	1.6					
The Dalles Pool	4.8	9.0	12.2	3.8	0.8			
John Day Pool	6.2	8.7	12.2	23.8	5.7	2.9	0.8	
McNary Pool[1]	2.2	1.6	3.3	4.5	9.8	7.1	1.6	1.0
Lower Snake[2]	1.1	0.6		0.4	3.3	1.4	9.8	8.2
Above L. Granite[3]	19.0	30.1	32.5	28.7	35.2	34.3	54.9	53.6
Above P. Rapids[3]	2.2	2.2	3.7	2.6				
Total	44.3	55.6	65.4	63.8	54.9	45.7	67.2	62.9
In Mainstem (%)								
Recapture	14.7	13.7	8.5	9.1	3.3	4.3	6.6	6.2
Unknown	41.0	30.7	26.0	27.2	41.8	50.0	26.2	30.9

[1] Includes Walla Walla and Yakima rivers and Ringold and Priest Rapids hatcheries
[2] Includes Tucannon River and Lyons Ferry Hatchery
[3] Includes all sites upstream from Lower Granite or Priest Rapids dams

Fishway Escapement Adjustments

Fishway escapement (count) adjustments were most precise for Bonneville and McNary dams, where we monitored all passage routes including through navigation locks from 1997-2003. Mean adjustment factors for counts at Bonneville Dam were 0.892 (*range* 0.839-0.943) for spring–summer Chinook, 0.974 (*range* 0.954-0.999) for fall Chinook and 0.959 (*range* 0.923-0.992) for steelhead (Table 12). Mean adjustments at McNary Dam were 0.941 (*range* 0.904-0.988), 0.974 (*range* 0.961-0.998) and 0.920 (*range* 0.880-0.946) for the three runs, respectively.

We did not monitor navigation lock passage at The Dalles or John Day dams, but telemetry records at fishway and upstream sites indicated that few (estimated < 2%) fish passed those dams via the locks. Mean adjustment factors at The Dalles Dam, uncorrected for passage through the lock, were 0.894 for spring–summer Chinook, 0.914 for fall Chinook salmon and 0.905 for steelhead; means at John Day Dam were 0.912 for spring–summer Chinook salmon, 0.975 for fall Chinook salmon and 0.928 for steelhead (Table 12).

Mean adjustment factors at lower Snake River dams were between 0.933 and 0.973 at all dams for all spring–summer Chinook salmon and steelhead runs; mean adjustments for fall Chinook salmon were 0.906 at Ice Harbor Dam, 0.957 at Lower Monumental Dam, 0.846 at Little Goose Dam and 0.812 at Lower Granite Dam (Table 13).

Positive bias estimates, or overcounts, at lower Columbia River dams ranged from about 3,000 to more than 30,000 spring–summer Chinook salmon, from a few hundred to nearly 33,000 fall Chinook salmon and from about 1,600 to more than 48,000 steelhead (Table 10). Approximate over-counts at Snake River dams were between 75 and 5,900 for spring–summer Chinook salmon, 100 and 3,000 for fall Chinook salmon and 2,100 and 13,000 for steelhead (Table 11). Numerically, the largest positive biases tended to be in 2001 and 2003, years 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 and high fallback rates.

Influence of River Flow and Dam Spill on Fallback

Columbia River discharge during the seven study years varied widely and included one of the lowest-discharge years on record (2001), two high-discharge years (1997, 1996) and four near-average years (1998, 2000, 2002, 2003). Mean daily discharge at Bonneville Dam from April through July averaged 6,768 $m^3 \cdot s^{-1}$ from 1972 to 2001. April-July means were 9,289 $m^3 \cdot s^{-1}$ (137% of the 1972-2001 average) in 1996, 10,988 $m^3 \cdot s^{-1}$ (162%) in 1997, 7,250 $m^3 \cdot s^{-1}$ (107%) in 1998, 6,655 $m^3 \cdot s^{-1}$ (98%) in 2000, 3,483 $m^3 \cdot s^{-1}$ (51%) in 2001, 7,253 $m^3 \cdot s^{-1}$ (107%) in 2002, and 6,366 $m^3 \cdot s^{-1}$ (94%) in 2003. Peak discharge occurred in late May or early June in 1996, 1997, 1998 and 2003, in late April 2000 and in mid-May 2001; two peaks occurred in 2002, one in mid-April and a second in early June. Mean discharge typically drops to between 3,000 and 4,000 $m^3 \cdot s^{-1}$ by early September in all years, but was ~5,000 $m^3 \cdot s^{-1}$ in fall 1997. Between-year differences in discharge at other Columbia and Snake River dams were proportionally similar to those at Bonneville Dam.

Daily flow and spill from April through July were strongly correlated at all dams in 1996, 1997 and 1998 with a mean correlation coefficient 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 correlation coefficient was 0.86, *range* 0.78-0.93), and correlations were weaker at Bonneville, The Dalles and John Day dams (mean correlation coefficient was 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 no spill at Snake River dams and greatly reduced duration and volume of spill at Columbia River dams. In 2002, the mean flow-spill correlation was 0.84 (*range* 0.69-0.97) at Columbia River dams and was 0.65 (*range* 0.50-0.82) at Snake River dams. In 2003, correlations were higher at Snake River dams (*mean* = 0.86, *range* 0.73-0.94) and lower at Columbia River dams (*mean* = 0.69, *range* 0.43-0.93).

Table 12. Fish count adjustment factors (AF) with USACE estimated fishway escapement, adjusted estimated escapement and escapement bias for spring-summer Chinook, fall Chinook and steelhead at Columbia River dams in 1996-1998 and 2000-2001. USACE escapement estimates are based on 16 h counts from April through October and precocious males (jacks) are excluded.

Year	AF	USACE escapement	Adjusted escapement	Bias	AF	USACE escapement	Adjusted escapement	Bias
		Bonneville Dam				The Dalles Dam		
				Spring–Summer Chinook				
1996	0.863	67,527	58,276	9,251	0.845	36,900	31,181	5,719
1997	0.839	141,939	119,087	22,852	0.837	89,566	74,966	14,600
1998	0.871	59,775	52,064	7,711	0.870	40,687	35,398	5,289
2000	0.860	208,918	179,669	29,249	0.930	127,260	118,352	8,908
2001	0.934	467,523	436,666	30,857	0.924	375,374	346,846	28,528
2002	0.935	396,249	370,493	25,756	0.931	292,603	272,413	20,190
2003	0.943	306,818	289,329	17,489	0.923	231,212	213,409	17,803
				Fall Chinook				
1998	0.999	189,085	188,896	189	0.941	92,932	82,524	10,408
2000	0.998	192,793	192,407	386	0.913	124,967	114,095	10,872
2001	0.961	400,205	384,597	15,608	0.919	181,316	166,629	14,687
2002	0.957	472,309	452,000	20,309	0.901	245,938	221,590	24,348
2003	0.954	607,670	579,717	27,953	0.895	313,697	280,759	32,938
				Steelhead				
1996	0.992	205,213	203,571	1,642	0.937	162,447	152,213	10,234
1997	0.939	258,385	242,624	15,761	0.926	164,657	152,472	12,185
2000	0.965	351,370	339,072	12,298	0.930	205,241	188,616	16,625
2001	0.978	633,073	619,145	13,928	0.919	503,327	462,558	40,769
2002	0.958	480,309	460,136	20,173	0.898	387,920	348,352	39,568
2003	0.923	361,412	333,583	27,829	0.822	273,172	224,547	48,625
		John Day Dam				McNary Dam		
				Spring–Summer Chinook				
1996	0.864	30,481	26,336	4,145	0.904	32,934	29,772	3,162
1997	0.882	82,761	72,995	9,766	0.910	78,766	71,677	7,089
1998	0.892	38,046	33,937	4,109	0.907	35,641	32,326	3,315
2000	0.879	109,576	96,317	13,259	0.966	85,191	82,295	2,896
2001	0.968	328,363	317,855	10,508	0.988	326,603	322,684	3,919
2002	0.946	243,064	229,939	13,125	0.943	235,541	222,115	13,426
2003	0.954	195,307	186,323	8,984	0.970	186,512	180,917	5,595
				Fall Chinook				
1998	0.963	78,237	75,342	2,895	0.984	63,791	62,770	1,021
2000	0.974	102,903	100,228	2,675	0.998	67,572	67,437	135
2001	0.973	124,747	121,379	3,368	0.961	110,517	106,207	4,310
2002	0.983	164,920	162,116	2,804	0.963	141,682	136,440	5,242
2003	0.980	215,501	211,191	4,310	0.966	178,951	172,867	6,084
				Steelhead				
1996	0.895	156,924	140,447	16,477	0.925	124,177	114,864	9,313
1997	0.916	159,442	146,049	13,393	0.880	129,817	114,239	15,578
2000	0.957	220,328	210,854	9,474	0.913	130,332	118,993	11,339
2001	0.943	483,409	455,855	27,554	0.932	398,784	371,667	27,117
2002	0.954	390,300	372,346	17,954	0.946	286,805	271,318	15,487
2003	0.903	286,176	258,417	27,759	0.924	230,418	212,906	17,512

Table 13. Fish count adjustment factors (AF) with USACE estimated fishway escapement, adjusted estimated escapement and escapement bias for spring-summer Chinook, fall Chinook and steelhead at Snake River dams in 1996-1998 and 2000-2003. USACE escapement estimates are based on 16 h counts from April through October and precocious males (jacks) are excluded.

Year	AF	USACE escapement	Adjusted escapement	Bias	AF	USACE escapement	Adjusted escapement	Bias
		Ice Harbor Dam				Lower Monumental Dam		
				Spring–Summer Chinook				
1996	0.929	11,757	10,922	835	--	--	--	--
1997	0.904	50,594	45,737	4,857	0.944	47,632	44,965	2,667
1998	0.929	17,907	16,636	1,271	0.961	14,888	14,307	581
2000	0.891	43,391	38,661	4,730	0.956	40,200	38,431	1,769
2001	0.986	186,443	183,833	2,610	0.991	200,107	198,306	1,801
2002	0.947	111,596	105,681	5,915	0.974	99,781	97,187	2,594
2003	0.942	98,704	92,979	5,725	0.973	89,126	86,720	2,406
				Fall Chinook				
1998	0.931	4,220	3,929	291	0.964	3,046	2,936	110
2000	0.970	6,652	6,452	200	0.909	5,447	4,951	496
2001	0.884	13,516	11,948	1,568	0.943	13,297	12,539	758
2002	0.890	15,248	13,571	1,677	0.969	15,193	14,722	471
2003	0.854	20,998	17,932	3,066	1.000	13,641	13,641	0
				Steelhead				
1996	0.940	97,250	91,415	5,835	--	--	--	--
1997	0.947	102,900	97,446	5,454	0.953	85,602	81,579	4,023
2000	0.952	131,426	125,118	6,308	0.981	112,616	110,476	2,140
2001	0.954	283,694	270,644	13,050	0.967	252,923	244,577	8,346
2002	0.949	202,173	191,862	10,311	0.955	212,639	203,070	9,569
2003	0.948	186,474	176,777	9,697	0.978	172,596	168,799	3,797
		Little Goose Dam				Lower Granite Dam		
				Spring–Summer Chinook				
1996	--	--	--	--	0.989	6,814	6,739	75
1997	0.916	47,246	43,277	3,969	0.950	44,564	42,336	2,228
1998	0.941	14,810	13,936	874	0.953	14,209	13,541	668
2000	0.963	38,533	37,107	1,426	0.971	37,761	36,666	1,095
2001	0.985	191,036	188,170	2,866	0.995	185,693	184,765	928
2002	0.973	97,794	95,154	2,640	0.969	96,870	93,867	3,003
2003	0.972	83,107	80,780	2,327	0.984	86,695	85,308	1,387
				Fall Chinook				
1998	0.739	2,032	1,502	530	0.667	1,908	1,273	635
2000	0.769	3,588	2,759	829	0.620	3,694	2,290	1,404
2001	0.873	10,550	9,210	1,340	0.954	8,915	8,505	410
2002	0.915	12,905	11,808	1,097	0.857	12,215	10,468	1,747
2003	0.935	13,950	13,043	907	0.964	11,595	11,178	417
				Steelhead				
1996	--	--	--	--	0.912	85,129	77,638	7,491
1997	0.914	74,219	67,836	6,383	0.936	91,957	86,062	5,895
2000	0.949	101,030	95,877	5,153	0.966	113,211	109,362	3,849
2001	0.951	232,669	221,268	11,401	0.960	262,568	252,065	10,503
2002	0.949	203,494	193,116	10,378	0.965	218,718	211,063	7,655
2003	0.939	161,026	151,203	9,823	0.977	180,072	175,930	4,142

Annual fallback rates of spring–summer Chinook salmon for the seven study years were positively correlated with mean daily flow (from April to July) at all Columbia and Snake River dams (Figure 2). Linear regression models of mean daily flow ($m^3 \cdot s^{-1}$) and fallback rates were significant for The Dalles ($r^2 = 0.70$, $P = 0.018$), John Day ($r^2 = 0.72$, $P = 0.015$), McNary ($r^2 = 0.69$, $P = 0.020$), Lower Monumental ($r^2 = 0.74$, $P = 0.028$), and Little Goose ($r^2 = 0.99$, $P < 0.001$) dams and nearly so for Bonneville Dam ($r^2 = 0.52$, $P = 0.067$). The lower correlation for Bonneville Dam was likely a result of a shift in Powerhouse priority at that dam starting in 2001. The shift resulted in more flow directed to Powerhouse 2, and consequently more fish passed the dam via the Washington-shore ladder, where fallback rates have historically been lower than for fish that pass via the Bradford Island ladder (see Table 12). The two points that fall below the regression line for Bonneville Dam in Figure 2 were for the 2002 and 2003 migrations and reflect the response to the priority change. Fallback rate-flow models were non-significant for Ice Harbor ($r^2 = 0.20$, $P = 0.21$) and Lower Granite ($r^2 = 0.39$, $P = 0.13$) dams.

Fallback Routes at Bonneville Dam

From 2000 to 2003, our telemetry antenna arrays at Bonneville Dam provided sufficient resolution to determine specific routes of fallback. During three of these four years, more than 80% of spring–summer Chinook fallbacks were determined to have occurred via the spillway. The exception to this was 2001 when low river flows truncated amounts and periods of spill and only 32% of fallbacks were through the spillway with 34% and 17% occurring via the ice and trash spillway and the navigation lock, respectively. In the years other than 2001, between 6% and 12% of fallbacks occurred through the ice and trash sluiceway and between 2% and 4% occurred through the navigation lock.

Fall Chinook salmon fallback routes during these years were quite different than those of spring–summer Chinook, likely due to dam operations during their time of migration. Between 41% and 75% of all fall Chinook fallbacks likely occurred via the navigation lock with 4% to 15% occurring via the ice and trash sluiceway and 0 to 15% occurring via the spillway.

Steelhead fallback routes at Bonneville Dam were more variable between years than Chinook routes and we were unable to determine routes for a higher percentage of fallbacks likely due to their timing; many steelhead fallbacks occurred during winter months when our receivers were down for routine maintenance. During the four years, between 9% and 60% of all steelhead fallbacks were by undetermined routes. Nearly 84% of steelhead fallbacks occurred via the spillway in 2000 though after powerhouse priority had shifted to Powerhouse 2 in 2001, this percentage dropped to between 7 and 25% for the remaining three years. The ice and trash sluiceway and navigation lock accounted for between 2% and 11% and for between 7% and 37% of all fallback routes, respectively.

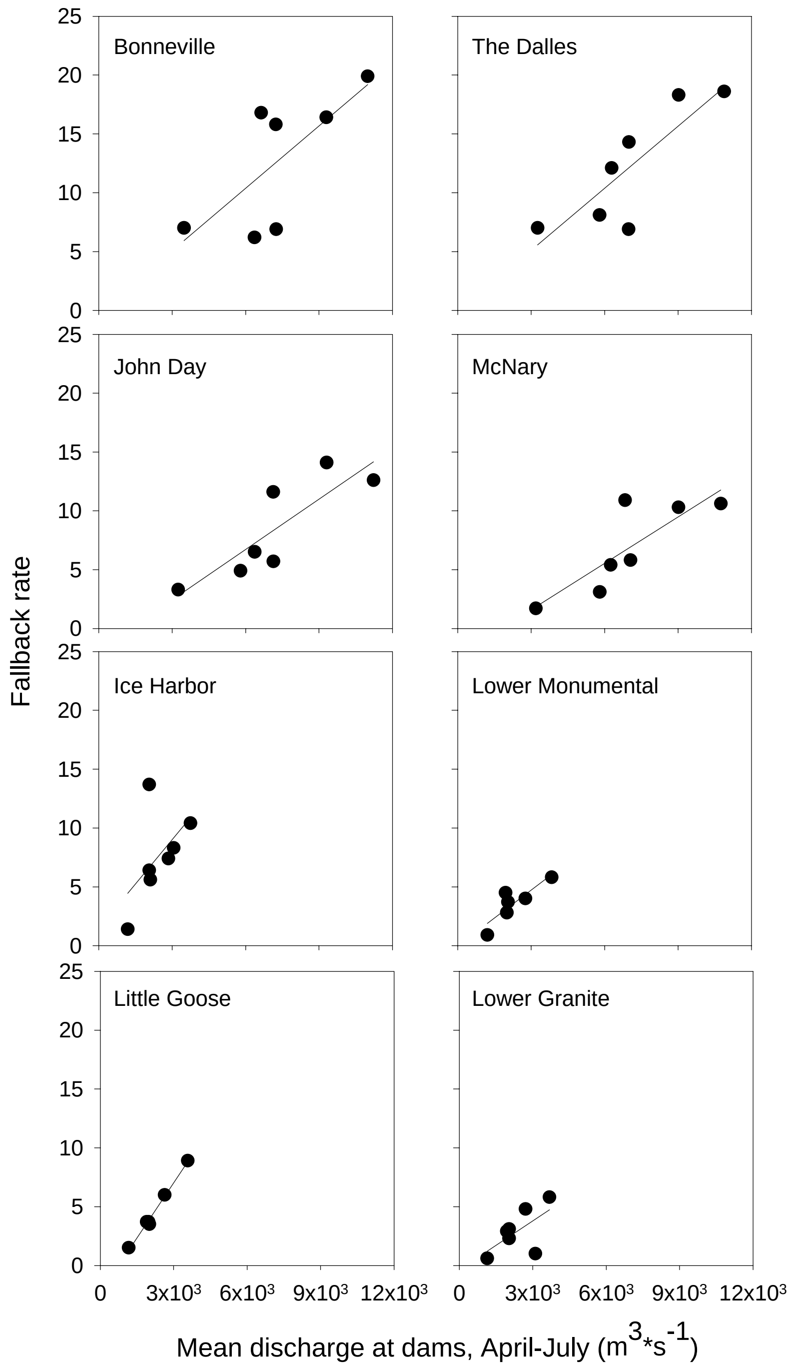

Figure 2. Linear regressions between annual fallback rates of spring–summer Chinook salmon at dams on the lower Columbia River (Bonneville, The Dalles, John Day, and McNary) and the lower Snake River (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite) and mean April-July river discharge at each dam (1996-2003). 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.

Fishway Specific Fallback at Bonneville Dam

The Bradford Island and the Washington shore fishways at Bonneville Dam had significantly different fallback rates in thirteen of eighteen species-year combinations. Fallback rates for the two fishways were not significantly different during the 2001 spring–summer Chinook run, the 2002 and 2003 steelhead run and the 2001 and 2002 fall Chinook run. In all species-run combinations but two, the fallback rate for fish passing the Bradford Island fishway was higher than that for fish passing the Washington shore fishway (Table 14). Differences in spring–summer Chinook fallback rates between the two fishways averaged 15.8% from 1996 to 2000 and 2.4% from 2001 to 2003. Differences in steelhead fallback rates averaged 10.2% from 1996 to 2000 and 1.6% from 2001 to 2003.

Table 14. Fishway specific fallback rates for the Bradford Island (BI) fishway and the Washington shore (WA) fishway at Bonneville Dam for all runs of spring–summer Chinook salmon (CK), steelhead (SH), and fall Chinook salmon (FC) from 1996 to 2003 with Chi-square comparison of respective fallback rates.

	Unique fish To pass BI	Fallback events	BI fishway fallback rate	Unique fish To pass WA	Fallback events	WA fishway fallback rate
1996 CK	429	109	25.4*	416	23	5.5*
1997 CK	486	134	27.8*	522	53	10.2*
1998 CK	533	105	19.7*	441	40	9.1*
2000 CK	559	128	22.9*	376	29	7.7*
2001 CK	338	17	5.0	427	33	7.7
2002 CK	375	35	9.3**	496	25	5.0**
2003 CK	398	38	9.8*	681	28	4.1*
1996 SH	367	32	8.7*	334	6	1.8*
1997 SH	492	74	15.0*	412	14	3.4*
2000 SH	382	52	13.6*	402	6	1.5*
2001 SH	308	24	7.8*	449	11	2.4*
2002 SH	381	16	4.2	487	20	4.1
2003 SH	233	18	7.7	318	27	8.5
1998 FC	410	18	4.4*	478	13	2.7*
2000 FC	385	22	5.7**	245	4	1.6**
2001 FC	206	13	6.3	303	14	4.6
2002 FC	283	13	4.6	385	10	2.6
2003 FC	211	16	7.6*	365	10	2.7*

* Chi-square P<0.01, ** Chi-square P<0.05

Average fallback rates for fall Chinook at the two fishways during these two time periods were the same at 2.9%. The proportion of radio-tagged fish to pass Bonneville Dam using the two fishways also shifted during these two time periods with radio-tagged spring–summer and fall Chinook and steelhead passing the two fishways at approximately a 1:1 ratio from 1996 to 2000. From 2001 to 2003, the ratio of Bradford Island passages to Washington shore passages changed to approximately 2:3 (Table 14). The changes in the difference of average fallback rates and of the ratio of fishway use coincide with shifts in priority between the two Bonneville Dam powerhouses during these time frames. Previous to 2001, the powerhouse located adjacent to the Bradford Island fishway (Powerhouse I) discharged higher volumes of water than the fishway located adjacent to the Washington shore fishway (Powerhouse II). During and after 2001, this was reversed with Powerhouse II discharging the majority of flow.

Discussion

The percentage of upriver-migrating salmon and steelhead that fall back at lower Columbia and Snake River dams varies widely depending on the run, species and project involved and river conditions when fish are migrating. In terms of salmon and steelhead fallback behavior, each dam on the Columbia and Snake rivers is unique; physically as a structure, operationally as a combination of river inflow, dam spill and turbine discharges at any given time, and geographically in its location relative to the natal spawning tributaries and hatcheries to which fish are returning. 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—through increased overshoot fallback.

With a few exceptions, percentages of spring–summer Chinook that fell back were highest at Bonneville Dam and decreased at progressively upstream dams, with years characterized by high river flows (1996 and 1997) having higher percentages of fallback fish. Spring–summer Chinook 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 mid summer, portions of the run are exposed to decreasing river flow and spill, the dams the run is passing become smaller and less complex and the number of proximate tributaries fish could overshoot become fewer, all of which 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 no-spill conditions may account for the lower between-year variation in fallback percentages for steelhead and fall Chinook salmon we observed compared to spring–summer Chinook salmon. Fall Chinook salmon also migrate after peak river flows and the majority of this run pass dams after spill has ceased. Fall Chinook salmon fallback percentages were more variable at Snake River dams, possibly reflecting searching behaviors by Hanford Reach and Lyons Ferry Hatchery stocks, though 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 47% of the fall Chinook that fell back at The Dalles, John Day and McNary dams may have passed natal tributary spawning sites and fell back in an effort to return. With all years combined, 20 of 28 (71%) fall Chinook 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 behavior was also apparent but to a lesser degree by spring–summer Chinook salmon and steelhead. Fourteen to 35% of spring–summer Chinook salmon and 5 to 29% 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. It is likely not all of these fish were destined to return to the drainages or hatcheries where they were last located but had strayed into them either temporarily or permanently. Permanent straying rates (spawning at non-natal sites) have not been well documented for most Columbia 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 (entering non-natal 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; Keefer et al. 2002). From 2000 to 2003, many of the spring–summer Chinook salmon and steelhead we radio-tagged at Bonneville Dam were PIT-tagged as juveniles providing information on adult destinations. Telemetry records for these fish indicated a mean of 2.2% of spring–summer Chinook (*range* 1.6% in 2001 to 4.5% in 2000) and 6.8% of steelhead (*range* 6.1% in 2002 to 9.1% in 2000) were last detected in major tributaries other than their natal spawning area (University of Idaho, *unpublished data*). It is likely some of these fish had strayed temporarily into lower reaches of non-natal drainages and were harvested before they resumed migration. When corrected for fish known harvested in non-natal drainages, the pooled spring–summer Chinook salmon straying rate dropped to 1.4% and pooled steelhead straying rate dropped to 4.7%. These relatively low estimates of total straying rates suggest most of the fish falling back at dams and entering downstream tributaries are destined to return to these drainages.

By selecting returning adult fish that had been PIT tagged as juveniles for radio-tagging, we were able to detect differences is fallback behavior by groups of Columbia Basin salmon and steelhead stocks. Given the small numbers of returning known-source adults, in some cases pooling of sub-basin stocks was necessary to achieve adequate sample sizes. Most of the fallback percentages for Yakima River and Mid Columbia spring–summer Chinook salmon were very low with four-year means for the dam-group combinations not exceeding 2%. This may be due in part to the majority of these stocks being summer Chinook and their peak migration being later in the season after river flow has begun dropping. The Wind River group fell back at Bonneville Dam only, though at relatively high percentages, the majority of these were likely overshoot fallbacks. Fallback percentages for transported Snake River spring–summer Chinook were higher than non-transported spring–summer Chinook in every dam-year combination and four-year mean percentages by dam were from nearly three to thirteen times greater for transported versus non-transported salmon. Considering that these two groups are migrating concurrently, it is not likely these differences are caused by operational or physical disparities. Known-source steelhead behaved similarly with both Mid Columbia and non-transported Snake River groups falling back at low percentages and transported Snake River steelhead fallback percentages being at least three times greater. We hypothesize that the transportation of migrating juveniles somehow disrupts the sequential imprinting necessary for their efficient homing to spawning tributaries. While permanent straying rates are low, it appears many returning adult salmon and steelhead that were transported as juveniles have increased wandering and searching behavior in the lower Columbia River which, in turn, increases their likelihood of falling back.

We were able to determine a last location for most fallback fish, but about 19% of spring–summer Chinook salmon, 30% of fall Chinook salmon and 34% of steelhead that fell back were not recorded in tributaries or reported recaptured at hatcheries or in fisheries. These fish may have been fallback-related or migration-related mortalities, could have been captured in fisheries and not reported to us, may have entered tributaries undetected, or may have spawned at mainstem sites. 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 for Chinook salmon runs (Keefer et al. 2004b). Some fall Chinook salmon with unknown fates may have spawned at mainstem sites, though we suspect this number is low. Limited fall Chinook 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 radio telemetry (Mendel and Milks 1995).

In all years of this study, lower proportions of Chinook salmon and steelhead that fell back at Bonneville Dam escaped to tributaries, hatcheries, or past Lower Granite or Priest Rapids dams than fish that did not fall back (Bjornn et al. 2000b; Boggs et al. 2004a). System-wide, harvest-adjusted escapement estimates averaged 6.5% (*range* 3.0-9.7%) lower for fallback spring–summer Chinook salmon, 19.5% (*range* 11.2-25.9%) lower for fallback fall Chinook salmon, and 13.3% (*range* 7.8-20.2%) lower for fallback steelhead, when compared to fish that did not fall back during migration (Keefer et al. 2004c). Patterns of significantly lower escapement for fallback fish were observed for both known-source stocks and unknown-source random samples. Research into the relationships between fallback and escapement is ongoing, with increased emphasis on spawning success rather than simply escapement beyond the monitored hydrosystem. The lower escapements we observed for fish that fell back suggest that either the physical trauma of the fallback event, migration delay related to fallback (Keefer et al. 2004a), or increased exposure to fisheries or marginal environmental conditions such as gas-supersaturated tailrace waters (Backman and Evans 2002) may reduce adult survival. It is also possible that fish that fall back are less physically fit upon system entry than those that do not fall back, and investigation of this possibility is recommended. In any case, fallback and reascension behavior at dams is almost certainly bioenergetically expensive and may exhaust energy reserves for some fish, much like delay at dams (Geist et al.

2000), long migrations (Bernatchez and Dodson 1987), or difficult passage areas (Hinch et al. 1996).

Our results indicate that high river flow and associated high spill volumes at dams increase the percentages of fish that fall back at dams. 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 days of spill at Bonneville Dam (10 y *mean* = 136 days) and annual fallback percentages at the dam were roughly one third those observed in most other study years. Another period of no spill occurred at Bonneville Dam in April of 1998 during which 7 of 152 (4.6%) spring–summer Chinook salmon that passed the dam fell back. During the remainder of the spring–summer Chinook salmon migration that year, spill occurred (up to 150 kcfs) 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 and sockeye salmon and spill volume at Bonneville Dam in 1997 and 1998, when 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.

Generally speaking, when spill is occurring at a dam the vast majority of fallback events will occur via the spillway. Migrating salmonids are rheotactic and when large volumes of water are being passed through spillbays this route of fallback is likely to predominate. At Bonneville Dam from 2000 to 2003 we were able to determine routes for most fallbacks by Chinook salmon and steelhead. More than 80% of spring–summer Chinook fallbacks occurred via the spillway in all years but 2001, the year of near-record low flows and reduced periods of spill. Spring–summer Chinook migration overlaps with peak river flows and in most years spill is occurring throughout their entire migration period. Only the first part of fall Chinook and steelhead migrations experience spill conditions at dams, these generally exist from April through August. This results in a smaller proportion of total fallback to occur via the spillway. though when the spillway is available as a fallback route it is used disproportionately to other available, albeit smaller scale, routes.

Percentages of salmon and steelhead runs that fall back may also be influenced by dam operations other than spill, including activities that attract (or deter) upstream migrants to 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) and also affect the behavior of migrants in the forebay of the dam after fishway exit (Boggs et al. 2004b). At Bonneville Dam, fish that pass via the Bradford Island fishway have historically fallen back at much higher rates than those that pass the dam's other fishway, located on the Washington shore (Bjornn and Peery 1992). When the proportion of fish passing via the Bradford Island fishway increases, total dam fallback percentages also increase because many fish exiting this fishway follow the Bradford Island shoreline directly into the spillway forebay (Reischel and Bjornn 2003). During the spring–summer Chinook migration of 2000, Bonneville Dam's

Powerhouse I, adjacent to Bradford Island and its fishway, discharged significantly more water than Powerhouse II, located adjacent to the Washington shore fishway. About 60% of radio-tagged spring–summer Chinook and 50% of radio-tagged steelhead passed the Bradford Island fishway during that year. In 2001, powerhouse priority had switched with the majority of turbine discharge occurring through Powerhouse II. As a result, about 45% of radio-tagged Chinook passage and 41% of radio-tagged steelhead passage occurred through the Bradford Island fishway (Boggs et al. 2004a).

Fallback and reascention at dams can significantly reduce the accuracy of fishway counts (Blankenship and Mendel 1993; Dauble and Mueller 2000). Lack of precision in fish counts has raised concerns that the use of count data for escapement estimates or harvest management could harm ESA-listed stocks 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 (38%) dams in 2000. Biases in spring–summer Chinook salmon counts at Bonneville Dam ranged from almost 6% in 2003 to 16% in 1997. Biases between 5 and 15% were common with all runs at most other dams. Because we did not tag fall Chinook in August 1998 or summer Chinook in July 1996, count adjustments for those runs may be less accurate than for other species-years.

The count adjustments we calculated using pooled telemetry data should be considered approximate because passage through navigation locks 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, The Dalles, and John Day dams where fallback rates were highest and most variable (Bjornn et al. 2000a; 2000b; 2000c). It would be inappropriate to apply the pooled estimates provided here, which included all stocks within each annual run, to temporally separated sub-basin stocks within a run (e.g. Keefer et al. 2004d), as each stock could be exposed to divergent river environments and have differing fallback responses. More fine-scale adjustments should be used for evaluating the impacts of fallback on specific stocks or to assess specific management activities at dams.

Radio-telemetry has been the most reliable method for obtaining fallback and reascension estimates. Recent innovations in passive integrated transponder (PIT) tag technology, such as 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 technology cannot identify fish that fall back and do not reascend and, because PIT-tag detectors lack the resolution of radio-telemetry, cannot determine specific routes of fallback (B. Burke, *personal communication*).

In conclusion, dam operation, river environment and adult salmon and steelhead migration behaviors (i.e. searching for natal sites) 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 and permanent inter-basin straying, appear to be costly for some fish, including listed stocks from each run studied. Managers of anadromous Columbia basin fisheries and operators of hydroelectric projects should focus on strategies to reduce unintentional fallback, and also work to facilitate benign downstream passage for adult fish, including "overshoot" pre-spawn migrants and post-spawn out-migrants such as steelhead kelts.

References

Backman, T.W.H., and A.F. Evans. 2002. Gas bubble trauma incidence in adult salmonids in the Columbia River basin. North American Journal of Fisheries Management 22:579-584.

Bernatchez, L. and J.J. Dodson. 1987. Relationship between bioenergetics and behavior in anadromous fish migrations. Canadian Journal of Fisheries and Aquatic Sciences 44:399-407.

Bjornn, T.C., and C.A. Peery. 1992. A review of literature related to movements of adult salmon and steelhead past dams and through reservoirs in the Lower Snake River. U.S. Fish and Wildlife Service and Idaho Cooperative Fish and Wildlife Research Unit. U.S. Army Corps of Engineers, Walla Walla, Washington. www.cnr.uidaho.edu/coop/download.htm

Bjornn, T.C., K.R. Tolotti, J.P. Hunt, P.J. Keniry, R.R. Ringe, and C.A. Peery. 1998. Passage of Chinook salmon through the lower Snake River and distribution into the tributaries. Part I of the final report for: Migration of adult Chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and tributaries. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, for the U.S. Army Corps of Engineers, Walla Walla, Washington. www.cnr.uidaho.edu/coop/download.htm

Bjornn, T.C., M.L. Keefer, C.A. Peery, K.R. Tolotti, R.R. Ringe, and L.C. Stuehrenberg. 2000a. Adult Chinook and sockeye salmon, and steelhead fallback rates at Bonneville Dam, 1996-1998. Technical Report 2000-1. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho for the U.S. Army Corps of Engineers, Portland, Oregon. www.cnr.uidaho.edu/coop/download.htm

Bjornn, T.C., M.L. Keefer, C.A. Peery, M.A. Jepson, K.R. Tolotti, R.R. Ringe, and L.C. Stuehrenberg. 2000b. Adult Chinook and sockeye salmon, and steelhead fallback rates at The Dalles Dam, 1996, 1997, and 1998. Technical Report 2000-2. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho for the U.S. Army Corps of Engineers, Portland, Oregon. www.cnr.uidaho.edu/coop/download.htm

Bjornn, T.C., M.L. Keefer, C.A. Peery, K.R. Tolotti, M.A. Jepson, R.R. Ringe, and L.C. Stuehrenberg. 2000c. Adult Chinook and sockeye salmon, and steelhead fallback rates at John Day Dam, 1996, 1997, and 1998. Technical Report 2000-3. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho for the U.S. Army Corps of Engineers, Portland, Oregon. www.cnr.uidaho.edu/coop/download.htm

Bjornn, T.C., K.R. Tolotti, J.P. Hunt, P.J. Keniry, R.R. Ringe, and C.A. Peery. 2002. Passage of steelhead through the lower Snake River and distribution into the tributaries, 1991-1994. Part 2 of final report for: Migration of adult Chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. www.cnr.uidaho.edu/coop/download.htm

Blankenship, H.L. and G.W. Mendel. 1994. Upstream passage, spawning, and stock identification of fall Chinook salmon in the Snake River, 1992. Bonneville Power Administration, Division of Fish and Wildlife Report DOE/BP-60415-1.

Boggs, C.T., M.L. Keefer and C.A. Peery. 2004a. Adult Chinook salmon and steelhead fallback at Bonneville Dam, 2000-2001. Technical Report 2004-1. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, for the U.S. Army Corps of Engineers, Portland and Walla Walla Districts, Portland, Oregon. www.cnr.uidaho.edu/coop/download.htm

Boggs, C.T., M.L. Keefer, K.R. Tolotti, C.A. Peery and T.C. Bjornn. 2004b. Migration behavior of adult chinook salmon and steelhead released in the forebay of Bonneville Dam, 2000-2001. Technical Report 2004-7. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon. www.cnr.uidaho.edu/coop/download.htm

Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz and I.V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-27.

Dauble, D.D., R.L. Johnson, and A.P. Garcia. 1999. Fall Chinook salmon spawning in the tailraces of lower Snake River hydroelectric projects. Transactions of the American Fisheries Society 128:672-679.

Dauble, D.D., and R.P. Mueller. 2000. Difficulties in estimating survival for adult Chinook salmon in the Columbia and Snake rivers. Fisheries 25(8):24-34.

Eiler, J.H. 1990. Radio transmitters used to study salmon in glacial rivers. American Fisheries Society Symposium 7:364-369.

Geist, D.R., C.S. Abernethy, S.L. Blanton, and V.I. Cullinan. 2000. The use of electromyogram telemetry to estimate energy expenditure of adult fall Chinook salmon. Transactions of the American Fisheries Society 129:126-135.

Goniea, T.M. 2002. Temperature influenced migratory behavior and use of thermal refuges by upriver bright fall Chinook salmon. Masters thesis, University of Idaho, Moscow.

Groot, C., and L. Margolis, editors. 1991. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia, Canada.

High, B. 2002. Effect of water temperature on adult steelhead migration behavior and survival in the Columbia River basin. Master's thesis. University of Idaho, Moscow, ID.

Hinch, S.G., R.E. Diewart, T.J. Lissimore, A.M.J. Prince, M.C. Healey, and M.A. Henderson. 1996. Use of electromyogram telemetry to assess difficult passage areas for river-migrating adult sockeye salmon. Transactions of the American Fisheries Society 125:253-260.

Keefer, M.L, T.C. Bjornn, C.A. Peery, K.R. Tolotti, R.R. Ringe, P.J. Keniry, and L.C. Stuehrenberg. 2002. Migration of adult steelhead past Columbia and Snake River dams, through reservoirs and distribution into tributaries, 1996. Technical Report 2002-2. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho for the U.S. Army Corps of Engineers, Portland, Oregon. www.cnr.uidaho.edu/coop/download.htm

Keefer, M.L., C.A. Peery, T.C. Bjornn and M.A. Jepson. 2004a. Hydrosystem, dam, and reservoir passage rates of adult chinook salmon and steelhead in the Columbia and Snake rivers. Transactions on the American Fisheries Society 133: 1413-1439.

Keefer, M.L., C.A. Peery, R.R. Ringe, and T.C. Bjornn. 2004b. Regurgitation rates of intragastric radio transmitters by adult Chinook salmon and steelhead during upstream migration in the Columbia and Snake rivers. North American Journal of Fisheries Management 24; 47-54.

Keefer, M.L., C.A. Peery, W.R. Daigle, M.A. Jepson, S.R. Lee, C.T. Boggs, K.R. Tolotti, and T.C. Bjornn. 2004c. Escapement, harvest and unaccounted-for loss of radio-tagged adult chinook salmon and steelhead in the Columbia-Snake River hydrosystem, 1996-2002. U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit. University of Idaho, Moscow, Idaho 83844-1141 for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Keefer, M.L., C.A. Peery, M.A. Jepson, K.R. Tolotti, and L.C. Stuehrenberg. 2004d. Stock-specific migration timing of adult spring–summer Chinook salmon in the Columbia River basin. North American Journal of Fisheries Management 24:1145-1162.

McCutcheon, C.S., E.F. Prentice, and D.L. Park. 1994. Passive monitoring of migrating adult steelhead with PIT tags. N. Am. J. Fish. Manage. 14: 220-223.

Mellas, E.J., and J.M. Haynes. 1985. Swimming performance and behavior of rainbow trout (*Salmo gairdneri*) and white perch (*Morone americana*): effects of attaching telemetry transmitters. Canadian Journal of Fisheries and Aquatic Sciences 42:488-493.

Mendel, G. and D. Milks. 1995. Upstream passage and spawning of fall Chinook salmon in the Snake River. Washington Department of Fish and Wildlife, Hatcheries Program, Olympia, Washington.

Monan, G.E., and K.L. Liscom. 1975. Radio tracking studies to determine the effects of spillway deflectors and fallback on adult Chinook salmon and steelhead trout at Bonneville Dam, 1974. National Marine Fisheries Service, Northwest Fisheries Center, Seattle.

Monan, G.E., and K.L. Liscom. 1979. Radio tracking studies relating to fallback at hydroelectric dams on the Columbia and Snake rivers. Pages 39-53 *in* Fifth Progress Report on Fisheries Engineering Research Program 1973-1978. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Quinn, T.P., and K. Fresh. 1984. Homing and straying in Chinook salmon (*Oncorhynchus tshawytscha*) from Cowlitz River Hatchery, Washington. Canadian Journal of Fisheries and Aquatic Sciences 41:1078-1082.

Quinn, T.P., R.S. Nemeth, and D.O. McIsaac. 1991. Homing and straying patterns of fall Chinook salmon in the lower Columbia River. Transactions of the American Fisheries Society 120:150-156.

Reischel, T.S. and T.C. Bjornn. 2003. Influence of fishway placement on fallback of adult salmon at Bonneville Dam on the Columbia River. North American Journal of Fisheries Mangement 23:1214-1223.

Ricker, W.E. 1972. Hereditary and environmental factors affecting certain salmonid populations. *In* R.C. Simon and P.A. Larkin (eds.), The stock concept in Pacific salmon. p. 27-160. H.R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B.C.

Robards, M.D., and T.P. Quinn. 2002. The migratory timing of adult summer-run steelhead in the Columbia River over six decades of environmental change. Transactions of the American Fisheries Society 131:523-536.

Stuehrenberg. L.C., G.A. Swan, L.K. Timme, P.A. Ocker, M.B. Eppard, R.N. Iwamoto, B.L. Iverson, and B.P. Sandford. 1995. Migrational characteristics of adult spring, summer, and fall Chinook salmon passing through reservoirs and dams of the mid-Columbia River. Coastal Zone and Estuarine Studies Division, Northwest Fisheries Science Center, National Marine Fisheries Sevice. Seattle WA. Final Report. 117 p.

U.S. Army Corps of Engeinners (USACE). 2001. Annual fish passage report. U.S. Army Engineer Districts, Portland, Oregon and Walla Walla, Washington.

Wagner P. and T. Hilsen. 1992. 1991 evaluation of adult falllback throught the McNary Dam juvenile bypass system. Washington Department of Fisheries, Habitat Management Division, Olympia, WA.

Zar, J. 1999. Biostatistical Analysis. Fourth addition. Prentice Hall Press, New Jersey.