Technical Report 2017-2

MIGRATION OF ADULT SALMONIDS IN THE FEDERAL COLUMBIA RIVER HYDROSYSTEM: A SUMMARY OF RADIOTELEMETRY STUDIES, 1996-2014

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Prepared for:
U.S. Army Corps of Engineers
Portland District

FINAL

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SPRING–SUMMER CHINOOK SALMON
TAG FILE: CK_TAG_DATA
FATE FILE: CK_FATE_DATA
GENERAL MIGRATION FILE: CK_MIGRATION

FALL CHINOOK SALMON
TAG FILE: FC_TAG_DATA
FATE FILE: FC_FATE_DATA7
GENERAL MIGRATION FILE: FC_MIGRATION

SOCKEYE SALMON
TAG FILE: SK_TAG_DATA
FATE FILE: SK_FATE_DATA
GENERAL MIGRATION FILE: SK_MIGRATION

STEELHEAD
TAG FILE: SH_TAG_DATA
FATE FILE: SH_FATE_DATA
GENERAL MIGRATION FILE: SH_MIGRATION

RECEIVER DEPLOYMENTS
RECIEVER_DEPLOYMENTS

Executive Summary

Radiotelemetry has been used by University of Idaho and research partners to study migration and dam passage behavior of adult salmon and steelhead in the Federal Columbia River Power System (FCRPS) since the 1990s. During fifteen return years in the period 1996-2014, more than 26,800 adult salmonids were tagged at Bonneville Dam and monitored as they migrated through the FCRPS and into tributaries. Monitoring varied through time in response to evolving study objectives and there is an extensive series of technical reports and peer-reviewed papers that have summarized annual and multi-year study results. However, there has not been a single-source compilation of the data, methods, and results across the nearly two-decade time series. This document and supporting appendices and databases address four primary objectives:

Metadata: Document radiotelemetry metadata, including antenna deployment sites, fish handling and tagging protocols, and telemetry data processing and quality control procedures;

Database Delivery: Compile and standardize all data associated with the radio-tagged fish, including filtered (i.e., 'coded') radiotelemetry and PIT-tag detection histories into a master database for each species and run;

Bibliography: Provide a bibliography and key-word index of technical reports and peer-reviewed papers associated with the radiotelemetry studies to expedite researcher and manager access to existing results;

FCRPS Adult Passage Metrics: Generate selected adult salmon and steelhead passage behavior and passage performance metrics for all study years and species at eight FCRPS projects: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, and Lower Granite dams.

To meet these objectives we present a multi-component synthesis that includes:

Section 1: A brief overview of the telemetry project objectives;

Section 2: Descriptions of collection and tagging protocols and sample summaries;

Section 3: Metadata on radiotelemetry monitoring sites and database assembly;

Section 4: Summaries of major structural and operational changes and environmental conditions at FCRPS dams during the study period;

Section 5: A bibliography and key word index for all technical reports and publications from the projects;

Section 6: Data summaries across all projects and years for key adult passage metrics.

The six narrative sections are accompanied by detailed appendices of radio antenna locations and databases housing complete migration histories indexed to individual fish trait and fate data.

1.0 INTRODUCTION

In the Federal Columbia River Power System (FCRPS), a series of Biological Opinions (BiOps) required that the U.S. Army Corps of Engineers (Corps) address the potential impacts of FCRPS dams on adult salmon and steelhead (*Oncorhynchus* spp) behavior and survival. The BiOp directives necessitated evaluations of the potential impacts of various structural and operational modifications at FCRPS dams on upstream migrants. The resulting series of radiotelemetry studies amassed a very large dataset of individual fish behaviors at FCRPS dams and in FCRPS reservoirs, in addition to providing their complete migration histories through the FCRPS to spawning tributaries. These studies collected data from ~18,300 upriver-migrating spring-, summer- and fall-run Chinook salmon (*O. tshawytscha*), ~1,400 sockeye salmon (*O. nerka*), and ~ 7,800 steelhead (*O. mykiss*) over 15 study years from 1996-2014.

The radiotelemetry studies addressed a diverse mix of study goals that ranged from site-specific assessments at individual FCRPS dams, to broad, system-wide evaluations of survival. Objectives changed frequently among years and FCRPS projects in response to structural and operation changes at the dams and to the data needs of the FCRPS action agencies and other stakeholders.

The value of long-term research and monitoring programs like this one is greatly enhanced through: (1) full documentation of study procedures, protocols, and objectives; (2) proper database archiving for future use; and (3) retrospective analyses. This report and the accompanying databases and appendices (Figure 1) were compiled to provide decision makers a single information source for the adult salmon and steelhead radiotelemetry studies. The project is intended to be a data archive and general reference to help address FCRPS programmatic research and management questions as they arise.

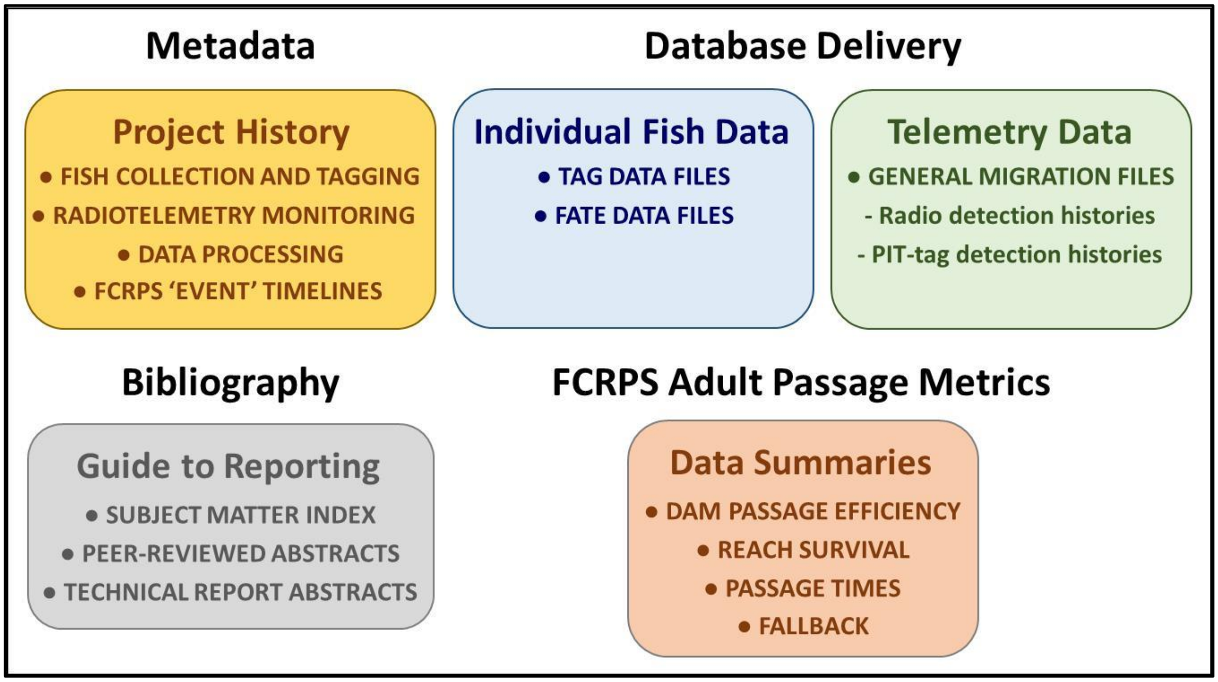

Figure 1. Schematic of the four components of this adult salmon and steelhead synthesis project.

1.1 SUMMARY OF OBJECTIVES

1.1.1 RADIOTELEMETRY STUDY METADATA

The metadata objective was addressed by compiling summary information on the many technical elements of the adult salmon and steelhead radiotelemetry project. We report the details of fish collection, anesthesia, handling, and tagging at the Bonneville adult fish facility (AFF). The fish metadata sections also include details of transmitter types used, secondary tags used, tissue sampling (for genetic analyses), fish condition scoring (e.g., injuries, marine mammal injuries, etc.), and summaries of basic trait information (hatchery, wild; size) and known-origin (previously PIT-tagged) samples.

Over the study period, there were hundreds of antenna deployments at FCRPS dams, in reservoirs, and in Columbia and Snake River tributaries. We compiled summary information on each receiver and antenna deployment location along with generalized maps showing monitoring effort and photo documentation for many locations. Protocols for radiotelemetry data management, including downloading, pre-processing, automated filtering and manual coding / quality control assessments of data are described; descriptions of the data fields in each dataset are also provided.

In a third metadata element, we assembled brief chronological summaries of Corps actions at FCRPS dams that may have affected adult salmon and steelhead passage. These actions were often the trigger for the adult radiotelemetry studies.

1.1.2 COMPILE AND ARCHIVE RADIOTELEMETRY DATA

From 1996-2014, we assembled 35 individual databases with radiotelemetry data for salmon and steelhead collected and tagged at Bonneville Dam, including: 15 datasets for adult spring–summer Chinook salmon, 8 for adult fall Chinook salmon, 9 for adult summer steelhead, 3 for adult sockeye salmon, and 2 for jack spring–summer Chinook salmon. In total, the migration histories in these databases have several million filtered (‘coded’) radio detection records at FCRPS dams and at other radio monitoring sites along with thousands of adult PIT-tag detections inside adult fishways and at tributary monitoring sites.

To address the database delivery objective, we standardized and aggregated the coded radiotelemetry data, PIT-tag detections, and tag and recapture records that make up migration histories into one master ‘General Migration’ dataset for each species and life history type (4 in total: 1 each for spring–summer Chinook salmon, fall Chinook salmon, sockeye salmon, and steelhead). Similarly, we created a pair of databases for each species/life history type that contain summary information for each fish: (1) data collected at the time of radio-tagging at Bonneville Dam; and (2) fish fate as estimated from the combination of radio and PIT telemetry histories plus reported harvest and other transmitter recovery information. The compiled databases will be archived at the University of Idaho Library and by the U.S. Army Corps of Engineers.

1.1.3 BIBLIOGRAPHY OF RESEARCH REPORTS AND PAPERS

The adult salmon and steelhead radiotelemetry study generated thousands of pages of technical reporting. We identified 31 peer-reviewed papers, 58 technical reports, and 51 brief ‘letter reports’ summarizing research results. We used two methods to facilitate access to paper and report content. First, we collated the abstracts and/or executive summaries from all publications and organized the material chronologically with the full citations so that users can search for specific content. Second, we reviewed each publication, identified keywords from the content, and then populated a subject-matter index that is organized by FCRPS project and includes a section for system-wide information.

The full publications will be archived at the University of Idaho Library and by the U.S. Army Corps of Engineers.

1.1.4 SUMMARY OF ADULT PASSAGE METRICS

The value of long-term monitoring projects is often not fully realized due to year-to-year changes in study objectives. For example, time series of key adult salmon and steelhead passage metrics have not been reported for all FCRPS dams and years despite their potential value for researchers and managers. Therefore, we used the master databases assembled in Objective 2 to calculate a series of adult salmon and steelhead behavior and passage metrics at the eight FCRPS study dams and over longer migration reaches. The data compilation is organized by passage metric (e.g., fish passage times, fishway and dam passage efficiency, fallback percentages and rates, FCRPS reach conversion, etc.). Whenever possible, data from all species, life history types, years, and FCRPS dams or river reaches are presented together to facilitate comparisons.

2.0 ADULT FISH COLLECTION, TAGGING, AND RELEASE

2.1 ADULT FISH FACILITY AT BONNEVILLE DAM

2.1.1 FISH COLLECTION AND SELECTION

Adult salmon and steelhead, and some jack Chinook salmon, were trapped at the Bonneville Dam adult fish facility (AFF) adjacent to the Washington-shore fishway. Each day that fish were to be radio-tagged, fish were diverted from the ladder by a set of picket leads and redirected up a false ladder into a collection pool (Figure 2). The pool had two false weirs operated by AFF personnel. Fish passed through the weirs, down a flume, and either directly returned to the main adult fishway without handling or were diverted into an anesthetic tank for tagging.

Fish were diverted for tagging using two methods. In the primary method, AFF personnel could visually identify a fish suitable for radio-tagging and then activate a pneumatic gate to divert the fish from a flume into the anesthetic tank. The person selecting fish had about 1 second to identify species and then operate the pneumatic gate. In this method, fish from the targeted species were randomly selected insomuch as possible. The primary exceptions to non-selective sampling were: (1) we selected for ‘upriver bright’ fall Chinook salmon (and against ‘Tule’ fall Chinook salmon); (2) we did not tag jack salmon except in targeted studies in 2013-2014; and (3) we avoided collecting and tagging fish with large, visible injuries that penetrated the body cavity. In the second method, some adults that had been PIT-tagged as juveniles could trigger an alarm signaling that they were available for radio-tagging. This selection for ‘known-origin’ fish relied on lists of PIT-tag codes for selected sample groups that had been compiled into a database and linked to the PIT-tag detectors in the AFF (i.e., ‘sort-by-code’). When a desired PIT-tag code was detected, AFF personnel could divert the fish from a flume into the anesthetic tank.

The length of the AFF trapping period each day depended on the number of salmon and/or steelhead to be radio-tagged, the number of fish to be sampled by other biologists (e.g., tribal organizations), and the numbers of fish moving up the Washington-shore fishway. Regulations restricting handling of adult fish in the AFF during periods of high water temperatures (≥ 22.2 ºC) also limited sampling. Once tagging was finished each day, the diversion weir pickets were removed from the main fishway and fish in the collection pool and trapping system were allowed to proceed up the ladder.

Figure 2. Left: the adult fish facility (AFF) at Bonneville Dam, showing the flumes below the false weir where fish exited the holding pool (behind technician in photo on right). Adult fish were selected for radio-tagging by the by a technician who initiated a pneumatic gate that diverted fish to an anesthetic tank at the base of the chutes (not shown).

2.1.2 FISH HANDLING PROTOCOLS

Methods developed for radio-tagging adult salmonids in the Snake River and at John Day Dam (Bjornn et al. 1995; Stuehrenberg et al. 1995) in years prior to 1996 were implemented and refined in the early study years at Bonneville Dam. Fish selected for radio-tagging entered a large tank (Figure 3) with either a 100 mg/L solution of tricaine methanesulfonate (MS-222, primarily used prior to 2000) or a ~25 mg/L solution of clove oil or synthetic eugenol. Once a fish was anesthetized, it was moved to a smaller, shallow anesthetic tank (Figure 3) where we recorded its length, estimated sex based on body and head morphology, and recorded a variety of condition and injury metrics (see Section 3.1.1 for details). In some years, fish were weighed, lipid content was assessed using a noninvasive Distell Fatmeter, and/or fish were photographed. A small fin tissue sample was collected and stored in alcohol for genetic testing, but genetic data were processed only in 2013-2014. Scale samples were collected from almost all radio-tagged fish so that age classes could be identified if necessary. However, the scales have not been aged to date; they have been archived.

A radio transmitter coated with glycerin was inserted intra-gastrically into the stomach. On larger fish, a smooth wooden dowel was used to fully insert the transmitter. The transmitter antenna was then bent at the corner of the fish's mouth and allowed to trail alongside the fish. An early transmitter retention experiment indicated that attaching a piece of surgical tubing to the transmitter reduced transmitter regurgitation rate. A ~5-mm wide piece of latex surgical tubing (~2-mm thick; ~12-mm inside diameter) or similar was therefore used in all subsequent study years. Transmitters were sized so that tag mass did not exceed 2% of fish body mass. Consequently, smaller transmitters were used in sockeye salmon, jack Chinook salmon, and some steelhead while larger transmitters were used in adult Chinook salmon and larger-bodied steelhead.

After tagging and collection of trait data, fish were placed in a wetted sleeve and manually moved to a transport tank filled with Columbia River water for recovery. The transport tank was a 2,275 L (~300 gal), insulated, fiberglass tank with a large top door where fish were placed for recovery, and a large sliding door on the rear for fish release (Figure 4). Air stones on the tank bottom supplied oxygen from bottles mounted on the side of the tank. After a group of fish was radio-tagged, an overhead crane was used to move the transport tank, which was attached to a trailer, in and out of the AFF. The total time from fish collection to release was usually less than 3 hours and depended on AFF trap collection rates, desired sample size per transport event, and water temperatures (i.e., shorter holding times when river temperature was warmer).

References

Bjornn, T.C., J.P. Hunt, K.R. Tolotti, P.J. Keniry, and R.R. Ringe. 1995. Migration of Chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries, 1993. Annual report for 1993 to the U.S. Army Corps of Engineers. University of Idaho, Moscow.

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. Report of the National Marine Fisheries Service to the Chelan, Douglas, and Grant County Public Utility Districts. Wenatchee, East Wenatchee, and Ephrata, Washington.

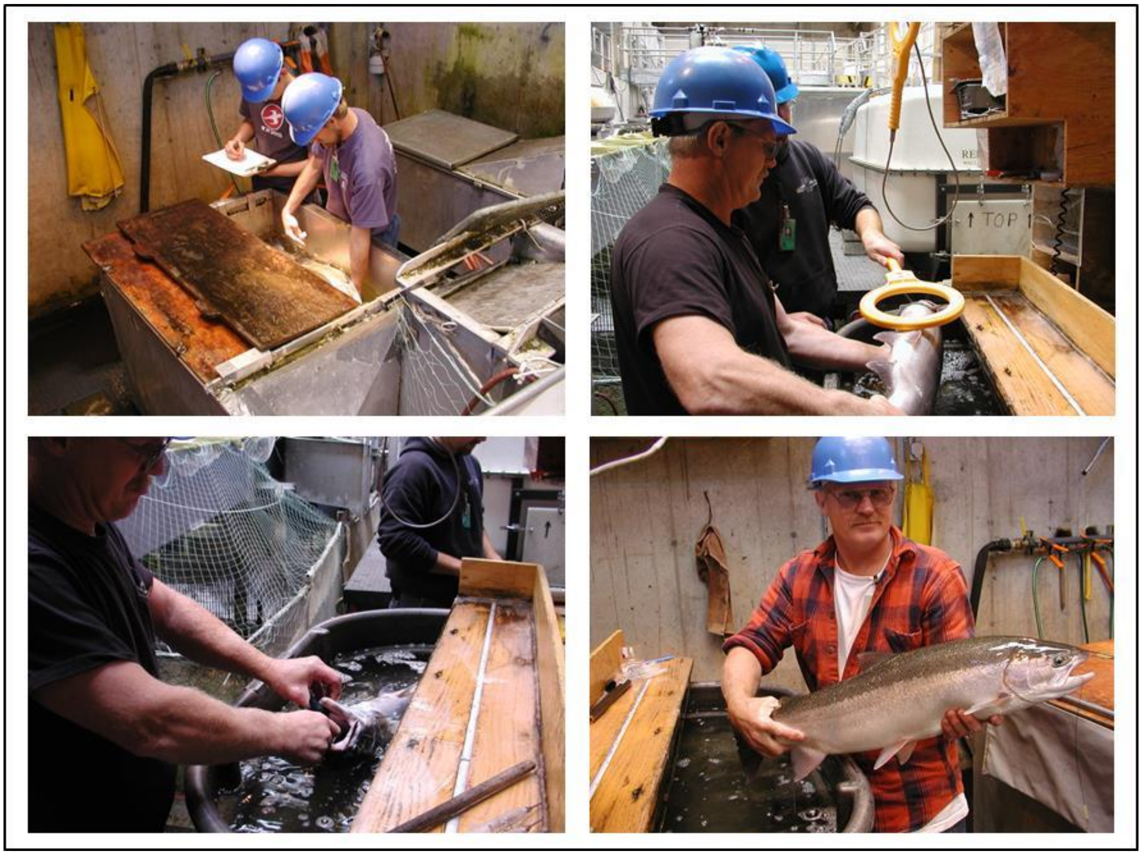

Figure 3. Top left: anesthetic tank at the base of the AFF diversion chutes. Top right: tagging station with measuring board and fish being scanned for a PIT tag. Bottom left: intragastric insertion of a radio transmitter. Bottom right: radio-tagged steelhead with antenna wire visible below lower mandible.

Figure 4. Left: 2,275-L transport tank used to haul radio-tagged salmon and steelhead to release sites. Right: tagged fish being released at Skamania Landing via a flume attached to the transport tank.

2.1.3 RADIO TRANSMITTERS, SECONDARY TAGS, AND TAG REWARD PROGRAMS

Ten radio transmitter models, all from Lotek Wireless Inc. (Newmarket, ONT), were used during the study (Table 1). Model changes reflect evolving radiotelemetry technology with a general trend towards smaller batteries and smaller overall size for a given tag life. A large majority of the transmitters had only a radio signal, but some had additional features. For example, the LTD-100 had sensors that recorded pressure (fish depth) and internal body temperature, a combination referred to as radio data storage transmitters (RDST). These transmitters were used to address specific objectives related to fish temperature exposure and exposure to, or avoidance of dissolved gas-supersaturated water. The CART 16-1 transmitters were a combination radio-acoustic tag that were used to evaluate potential adult mortality in deeper water where radio signals were attenuated. Summaries of the transmitters used in each study year and for each species are shown in Tables 2-5.

From 1996-2009, we used the Lotek 2000 coded set, which allowed for 212 unique codes per frequency (channel) on the 149MHz frequency range (149.320-149.800). Starting in 2010, the code set was changed to the Lotek 2003 code set, which allowed for 520 unique codes per channel and frequency was changed to 167 MHz frequency range (167.320-167.800) per FCC regulations.

Several types of secondary markers were used in the radio-tagged fish. From 1996-2000, a uniquely-coded, alphanumeric visual implant (VI) tag was inserted into the clear tissue posterior to the eye (left usually). In these years, a 1 mm-long piece of magnetic wire (coded wire tag) was also inserted into the muscle near the dorsal fin to trigger the coded-wire tag detector at Lower Granite Dam so that fish could be diverted and inspected if desired. Starting in 2000 – and exclusively thereafter – PIT tags were used as the secondary markers. All fish that did not have a PIT tag before being radio-tagged received a new, sterilized PIT tag injected into the abdominal cavity as part of the tagging procedure.

A tag reward program was used to increase return rate of tags from fisheries. In most years, tag labels included notification of a US $25 reward for return of the tag to the University of Idaho for most tag types. LDT-100 tags provided $100 rewards. University of Idaho personnel placed tag reward posters at popular boat ramps and periodically visited fisherman’s meetings to further improve tag returns.

Table 1. Lotek Wireless Inc. radio transmitter models used in adult and jack salmon and steelhead, 1996-2014, with voltage, dimensions, and weight. Standard radio burst rate was 5 sec. Note: physical dimensions and weights were typically within ±3% of listed values.

Model	Voltage	Length (cm)	Diameter (cm)	Weight in air (g)
CART 16-1	3V	6.0	1.6	28.0
LTD-100	3V	9.0	2.0	34.0
MCFT2-3A	3V	4.6	1.6	16.0
MCFT2-3BM	3V	4.3	1.1	7.7
MCFT-3A	3V	4.3	1.4	11.0
MCFT-3B	3V	4.3	1.4	11.0
MCFT-7A	7V	8.3	1.6	29.0
MCFT-7F	7V	8.8	1.6	31.0
MST-930	-	2.6	1.0	4.0
NTC-6-2	-	3.0	0.9	4.3

Table 2. Annual numbers of radio-tagged adult spring–summer Chinook salmon by transmitter model, 1996-2014

Year	CART 16-1	LTD-100	MCFT2-3A	MCFT2-3BM	MCFT-3A	MCFT-3B	MCFT-7A	MCFT-7F	MST-930	NTC-6-2	Total
1996							853				853
1997							1014				1014
1998						136	821				957
2000		213				15	904				1132
2001	206						911				1212
2002	201	183					831				1215
2003	232						952				1184
2004						17	539				556
2005					5	22	116				143
2006					204		176				380
2007					165		165				500
2009							599				599
2010							600				600
2013			40	1			169	386		304	900
2014				157				599	144		900

Table 3. Annual numbers of radio-tagged adult fall Chinook salmon by transmitter model, 1996-2014

Year	CART 16-1	LTD-100	MCFT2-3BM	MCFT-3A	MCFT-3B	MCFT-7A	MCFT-7F	Total
1997						55		55
1998					76	956		1032
2000		80				1038		1118
2001	205					787		992
2002	186	36				843		1065
2003	231		1			315	119*	666
2004					344	262		606
2005				547	11	42		600

*Exact dimensions and weight of MCFT-7F model not known in 2003

Table 4. Annual numbers of radio-tagged adult sockeye salmon by transmitter model, 1996-2014

Year	MCFT2-3A	MCFT2-3BM	MCFT-3B	MST-930	NTC-6-2	Total
1997			577			577
2013	45	353			1	399
2014		393		6		399

Table 5. Annual numbers of radio-tagged adult steelhead by transmitter model, 1996-2014

Year	CART 16-1	LTD-100	MCFT2-3A	MCFT-3B	MCFT-7A	Total
1996				391	378	769
1997				427	548	975
2000		154		369	637	1160
2001	231			283	637	1151
2002	224	229		271	549	1273
2003	223			287	105	615
2004				222	78	300
2013			789			789
2014			800			800

2.1.4 FISH RELEASE LOCATIONS

Release sites varied among years, but the Dodson (OR-shore) and Skamania (WA-shore) sites, ~8 km downstream from Bonneville Dam, were used for a majority of the radio-tagged fish (Figure 5). In 2005, a group of salmon was released at the Hamilton Island boat ramp (WA-shore) approximately 1 km downstream from Powerhouse 2 in an effort to maximize the number of tagged salmon first approaching Powerhouse 2 sites where barred gates (sea lion exclusion devices - SLEDs) were deployed. More generally, all downstream release sites were used so that fish behaviors in the tailrace and fishways at Bonneville Dam could be evaluated (e.g., fishway use, passage times, etc.).

Fish were released at several sites in the Bonneville forebay near the Oregon shore in 1998-2002 (Figure 6) as part of a series of studies to evaluate a potential reconstructed fishway that would have a ladder exit on the Oregon shoreline rather than on Bradford Island. The Bradford Island exit was (and continues to be) associated with relatively high adult fallback rates via the spillway.

Releases into the Washington-shore ladder at the AFF occasionally occurred for the sake of expediency when there was an inability to safely release fish in the forebay or downstream from the dam (i.e., mechanical problem with truck or hauling trailer). The release of 600 fall Chinook salmon into the ladder from the AFF in 2005 was the only exception.

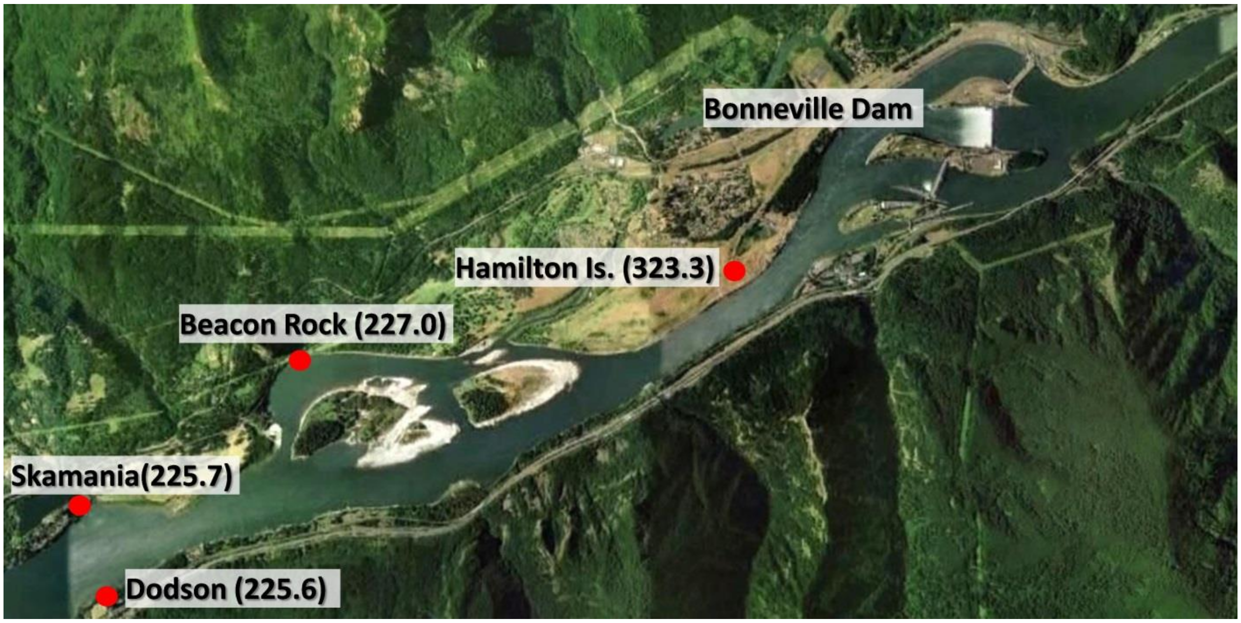

Figure 5. Map showing the Bonneville Dam and tailrace and the downstream sites where radio-tagged adult salmon and steelhead were released: Hamilton Island boat ramp (rkm 323.3), Beacon Rock (rkm 227.0), Skamania boat ramp (225.7), and Dodson boat ramp (225.6).

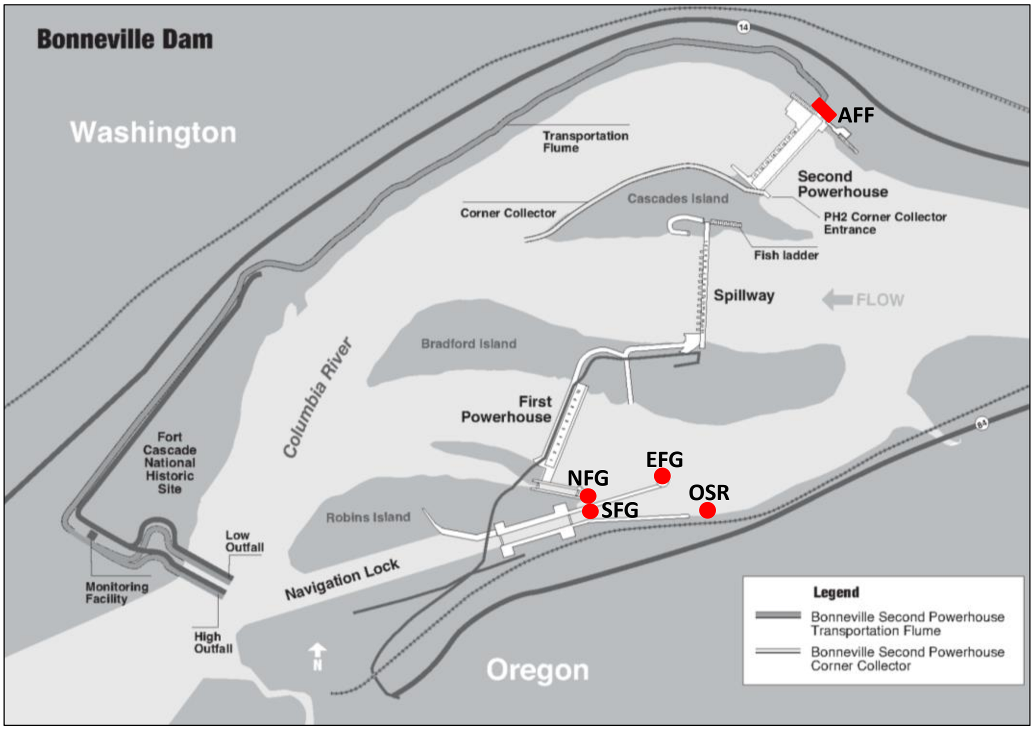

Figure 6. Map of Bonneville Dam showing the location of the Adult Fish Facility (AFF) and sites in the forebay where radio-tagged adult salmon and steelhead were released: north guide wall (NFG), south guide wall (SFG), east guide wall (EFG), and Oregon shore (OSR).

2.2 RADIO-TAGGED SAMPLE SUMMARY

2.2.1 NUMBERS OF FISH TAGGED AND RELEASED

Sample sizes were highest in early study years (1996-2003, Table 6) because the objectives included an evaluation of the basin-wide distribution and FCRPS survival of adult migrants. These studies also required larger sample sizes to address dam-specific passage metrics at upstream dams after harvest and tributary turnoff in lower river reaches. Studies in years 2004-2010 were typically related to evaluating effects of specific structural or operational modifications at individual FCRPS dams (e.g., fishway reconstruction projects at Bonneville and John Day dams, spill wall construction at The Dalles Dam, spill tests, modifications for Pacific lamprey, etc.) on adult salmonid behavior. Studies in 2013 and 2014 were primarily for evaluating reach-specific upstream conversion rates with some dam-specific objectives. Overall, there were 15 study years and total numbers of fish tagged and released were: 11,545 spring-summer Chinook salmon, 6,134 fall Chinook salmon (8 study years), 7,832 steelhead (7 study years), and 1,375 sockeye salmon (3 study years) (Table 6).

Table 6. Annual numbers of adult and Jack salmon and steelhead that were radio-tagged at Bonneville Dam, 1996-2014, with their release locations.

		Spring-Summer Chinook		Fall		
Year	Release site	Adult	Jack	Chinook	Sockeye	Steelhead
1996	Downstream	853	-	-	-	769
1997	Downstream	1,014	-	55	577	975
1998	Downstream	956	-	1,032	-	-
	BON AFF	1	-	-	-	-
2000	Downstream	973	-	745	-	843
	Forebay	159	-	373	-	317
2001	Downstream	882	-	561	-	802
	BON AFF	4	-	-	-	2
	Forebay	238	-	431	-	347
2002	Downstream	898	-	755	-	945
	Forebay	317	-	310	-	328
2003	Downstream	1,183	-	665	-	615
	BON AFF	1	-	1	-	-
2004	Downstream	548	-	571	-	296
	BON AFF	8	-	35	-	4
2005	Downstream	96	-	-	-	-
	BON AFF	47	-	600	-	-
2006	Downstream	358	-	-	-	-
	BON AFF	22	-	-	-	-
2007	Downstream	307	-	-	-	-
	BON AFF	193	-	-	-	-
2009	Downstream	599	-	-	-	-
2010	Downstream	600	-	-	-	-
2013	Downstream	600	300	-	399	789
2014	Downstream	600	300	-	399	800
Total	**All**	**11,545**	**600**	**6,134**	**1,375**	**7,832**

2.2.2 KNOWN-ORIGIN FISH

Starting in 2000, each annual sample included some salmon and steelhead that had received passive integrated transponder (PIT) tags as juveniles. PIT tags identified natal streams or rivers, and these ‘known-origin’ sub-samples were useful for validating stock assignments and fish behaviors, including permanent and temporary inter-basin straying, natal-river overshoot, and survival. Across years, 1,886 spring–summer Chinook salmon, 302 fall Chinook salmon, and 1,514 steelhead had PIT tags that had been implanted as juveniles (Table 7).

Known-origin sub-samples were not random with respect to stock, reflecting juvenile monitoring priorities that favored upper basin fish, especially from the Snake River (Tables 8 and 9). Selection for PIT-tagged fish peaked in 2000-2004, to match study objectives in those years. Including these fish in the annual samples added some bias with respect to random sampling. However, the value of known origin outweighed strictly representative sampling in those years. Starting in 2005, there were regional restrictions on adult radio-tagging of previously PIT-tagged fish in an effort to minimize adult handling that might adversely affect objectives from the original PIT-tagging studies. The tagging restrictions on many known-origin groups introduced a bias by exclusion for the adult samples and reduced our ability to address some homing and survival objectives.

Table 7. Numbers of radio-tagged adult and jack salmon and steelhead that had been tagged with PIT tags as juveniles (i.e., ‘known-origin’ fish), 1996-2014.

		Spring-Summer Chinook		Fall		
Year	Release site	Adult	Jack	Chinook	Sockeye	Steelhead
1996	All	-	-	-	-	-
1997	All	4	-	-	-	1
1998	All	10	-	-	-	-
2000	All	68	-	9	-	12
2001	All	778	-	130	-	703
2002	All	449	-	66	-	588
2003	All	306	-	67	-	133
2004	All	135	-	27	-	75
2005	All	35	-	3	-	-
2006	All	19	-	-	-	-
2007	All	12	-	-	-	-
2009	All	10	-	-	-	-
2010	All	54	-	-	-	-
2013	All	5	-	-	-	2
2014	All	1	-	-	-	-
Total	**All**	**1,886**	**-**	**302**	**-**	**1,514**
None	***All***	***9,660***	***600***	***5,833***	***1,375***	***6,319***

Table 8. Numbers of adult Chinook salmon radio-tagged at Bonneville Dam that were pit-tagged as juveniles, by juvenile origin site, 1996-2014.

Site /Dam or Tributary	1997	1998	2000	2001	2002	2003	2004	2005	2006	2007	2009	2010	2013	2014	**Total**
Columbia River below Snake															
< Bonneville Dam													1		**1**
Bonneville Dam											1				**1**
Wind River			1	29	49	15	7		1	1					**103**
Klickitat River												1			**1**
The Dalles Dam			1	11											**12**
Deschutes River		1		1			3				1				**6**
John Day River					15	9	3			2					**29**
Umatilla River					3										**3**
Snake River															
Lower Monumental Dam	1			30	15	3	4								**53**
Tucannon River				1											**1**
Lower Granite Dam	2	4	23	271	91	74	17			1	1	35			**519**
Snake River > LGR Dam	1			28	8	1	2								**40**
Clearwater River		1	1	13	11	2			1	1	3	3	1		**37**
Grand Ronde River		1	1	19	24	3	1			1	1	2			**53**
Salmon River		3	1	84	30	3	41	35	14	1	2	9	1		**224**
Imnaha River			2	29	7	5	2		1	1		1			**48**
Columbia River above Snake															
Yakima River				120	97	10	16					2			**245**
Priest Rapids Dam						51				2					**53**
Rock Island Dam			15	57	50	65									**187**
Wenatchee River				7	7	1	30		2		1		2		**51**
Rocky Reach Dam			12	34	34	61	1			1					**143**
Entiat River							3			1					**4**
Wells Dam			6	19											**25**
Wells Hatchery			5	21	1		1								**28**
Methow River				4	4		4							1	**13**
Okanogan River					3	3									**6**
Total	**4**	**10**	**68**	**778**	**449**	**306**	**135**	**35**	**19**	**12**	**10**	**54**	**5**	**1**	**1886**

Table 9. Numbers of adult steelhead and fall Chinook salmon radio-tagged at Bonneville Dam that were pit-tagged as juveniles, by juvenile origin site, 1996-2014.

	Steelhead								Fall Chinook salmon						
Site /Dam or Tributary	1997	2000	2001	2002	2003	2004	2013	**Total**	2000	2001	2002	2003	2004	2005	**Total**
Columbia River below Snake															
Bonneville Dam				1				**1**			1				**1**
Wind River				1	3	1		**5**							
John Day River					10			**10**		56	1	1			**58**
Umatilla River			10	9	3			**22**			4	1			**5**
McNary Dam		1			4			**5**	1	2	5	43	10	3	**64**
Walla Walla River			2	2		1		**5**							
Snake River															
Lower Monumental Dam				2				**2**	4	19	12	11	5		**51**
Lyons Ferry Hatchery										2		1			**3**
Tucannon River		1	2	2	4	4		**13**				1			**1**
Little Goose Dam					2			**2**							
Lower Granite Dam		2	301	355	78	23	1	**760**	1	1	3				**5**
Snake River > LGR Dam			4	4	2	2		**12**		2	3		8		**13**
Clearwater River	1	2	19	33	3			**58**	2	38	21		3		**64**
Grand Ronde River			5	18	3	1		**27**							
Salmon River		2	16	12	5	5		**40**							
Imnaha River		1	15	9	6	4		**35**							
Hells Canyon Dam		1	1					**2**							
Columbia River above Snake															
Yakima River			1		9	5		**15**		5	5	2			**12**
Ringold Hatchery						10		**10**			1	1			**2**
Priest Rapids Dam										1	4	2	1		**8**
Rock Island Dam			70	7				**77**		1	4	1			**6**
Wenatchee River						4		**4**							
Rocky Reach Dam		1	61	2	1			**65**		1	2	3			**6**
Wells Dam		1	91	70				**162**							
Wells Hatchery			85	61		5		**151**	1	2					**3**
Methow River						8	1	**9**							
Okanogan River			20			2		**22**							
Total	**1**	**12**	**703**	**588**	**133**	**75**	**2**	**1514**	**9**	**130**	**66**	**67**	**27**	**3**	**302**

2.2.3 FIN-CLIP STATUS AND SEX ASSIGNMENTS

Adult salmon and steelhead with fin clips were considered hatchery origin. However, unclipped hatchery fish were common in the radio-tagged samples, especially in the early study years when protocols at many hatcheries did not require fin clipping. Adipose fin clips were most common, but ventral and anal fin clips were present on some fish. Across years, there were approximately an equal number of spring-summer Chinook salmon that were clipped and had no clips, more fall Chinook and sockeye salmon with no clips, and more steelhead with clips (Table 10). Sex assignment for the radio-tagged fish was based on in-hand assessment of body, head, and jaw morphology (Table 11). This assignment method is known to be inaccurate, particularly early in migration before secondary sexual characteristics are fully developed. In 2013-2014, a genetic assay was used to assess sex.

Table 10. Fin-clip status for all radio-tagged adult and jack salmon and steelhead, 1996-2014.

		Spring–summer Chinook									
		Adult		Jack		Fall Chinook		Sockeye		Steelhead	
	Rel site	Clip	None	Clip	None	Clip	None	Clip	None	Clip	None
1996	All	217	636	-	-	-	-	-	-	645	124
1997	All	505	509	-	-	5	50	5	572	834	141
1998	All	334	623	-	-	89	943	-	-	-	-
2000	All	528	604	-	-	153	965	-	-	848	312
2001	All	723	489	-	-	111	881	-	-	824	327
2002	All	611	604	-	-	92	973	-	-	671	602
2003	All	587	597	-	-	50	616	-	-	366	249
2004	All	331	225	-	-	37	569	-	-	158	142
2005	All	80	63	-	-	30	570	-	-	-	-
2006	All	272	108	-	-	-	-	-	-	-	-
2007	All	318	182	-	-	-	-	-	-	-	-
2009	All	400	199	-	-	-	-	-	-	-	-
2010	All	413	187	-	-	-	-	-	-	-	-
2013	All	290	310	156	144	-	-	8	391	474	315
2014	All	287	313	199	101	-	-	3	396	473	327
Total	**All**	**5,896**	**5,649**	**355**	**245**	**567**	**5,567**	**16**	**1,359**	**5,293**	**2,539**

Table 11. Estimated sex for all radio-tagged adult and jack salmon and steelhead based on visual inspection of body and head morphology, 1996-2014.

		Spring-summer Chinook									
		Adult		Jack		Fall Chinook		Sockeye		Steelhead	
	Rel site	F	M	F	M	F	M	F	M	F	M
1996	All	428	425	-	-	-	-	-	-	279	490
1997	All	431	583	-	-	24	31	160	417	471	504
1998	All	411	546	-	-	467	565			-	-
2000	All	489	643	-	-	545	573	-	-	608	552
2001	All	549	663	-	-	531	461	-	-	511	640
2002	All	574	641	-	-	489	576	-	-	585	688
2003	All	553	631	-	-	276	390	-	-	299	316
2004	All	258	293	-	-	303	303	-	-	216	83
2005	All	75	68	-	-	271	329	-	-	-	-
2006	All	145	235	-	-	-	-	-	-	-	-
2007	All	240	260	-	-	-	-	-	-	-	-
2009	All	322	276	-	-	-	-	-	-	-	-
2010	All	331	267	-	-	-	-	-	-	-	-
2013	All	300	299	7	292	-	-	173	216	431	356
2014	All	306	292	-	300	-	-	169	222	389	398
Total	**All**	**5,412**	**6,122**	**7**	**592**	**2,906**	**3,228**	**502**	**855**	**3,789**	**4,027**

2.2.4 FORK LENGTH DISTRIBUTIONS

We selected for adult spring-summer Chinook salmon in all years except 2013 and 2014, when jack Chinook salmon were included into the sampling design. Median fork lengths of adult spring-summer Chinook salmon ranged from 73-84 cm annually and the median fork length of the jack sample was 53 cm in each year (Figure 7). Annual median fork lengths ranged from 80-86 cm for adult fall Chinook salmon, 49-51 cm for adult sockeye salmon, and 66-74.5 cm for adult steelhead.

Within sex and fin-clip categories, the distributions of putative males and females and fin-clipped and unclipped spring–summer Chinook salmon across fork length bins were similar (Figure 8). There was a modestly higher abundance of fin-clipped salmon among adults in the 71-83 cm fork length range and nearly all of the shorter jack Chinook salmon were considered males. For fall Chinook salmon, unclipped females were proportionally more abundant among the longer fish (Figure 9). The distributions of males and females were similar among fork length bins for adult sockeye salmon, although fin-clipped fish tended to be slightly (~4 cm) longer than unclipped fish (Figure 10). We selected against the smallest adult steelhead to accommodate transmitter size; the distributions of putative steelhead sex and fin-clip status were generally similar across fork length bins (Figure 11).

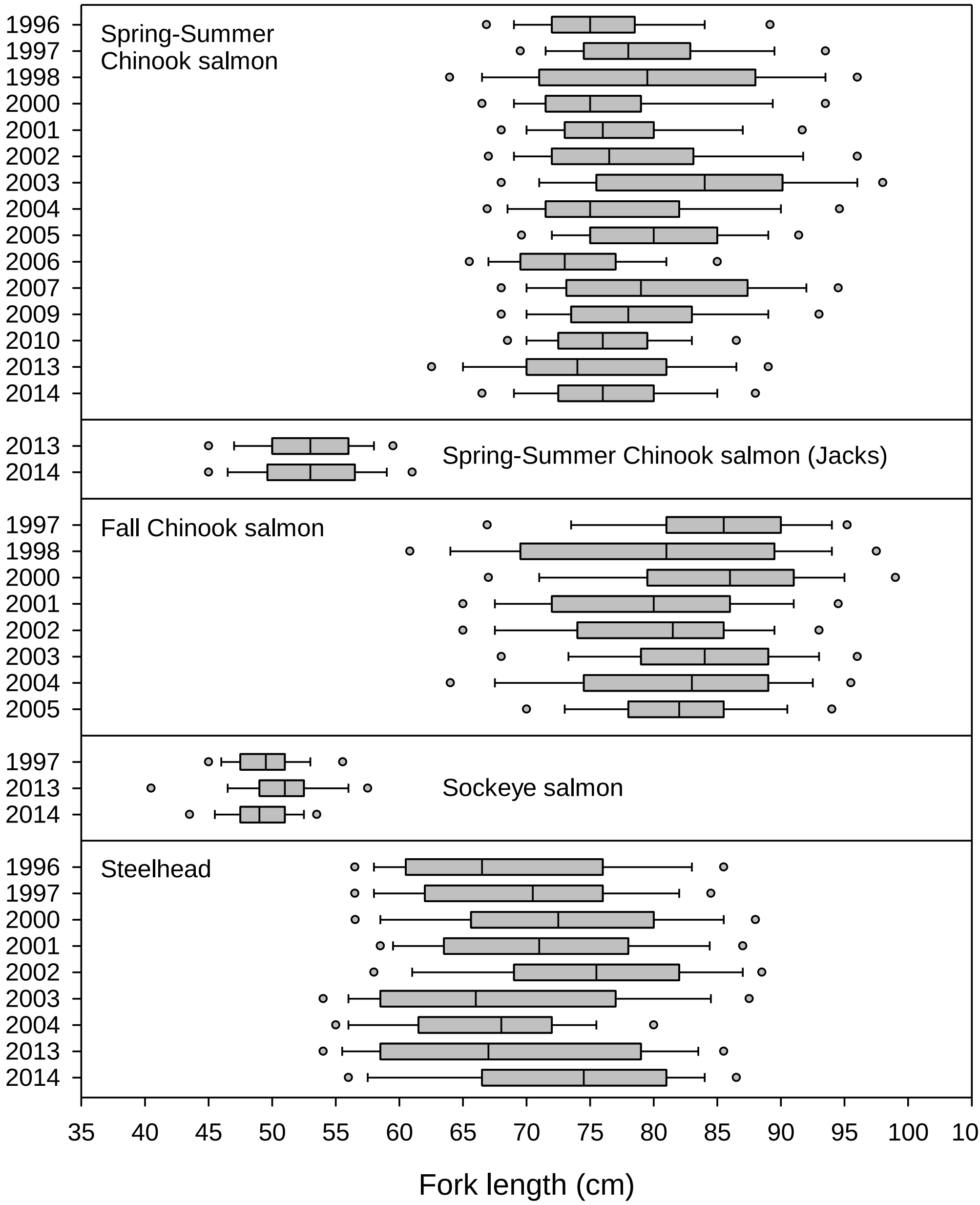

Figure 7. Box plots showing annual distributions (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of fork length for radio-tagged adult spring–summer Chinook salmon, jack spring–summer Chinook salmon, adult fall Chinook salmon, sockeye salmon, and steelhead, 1996-2014.

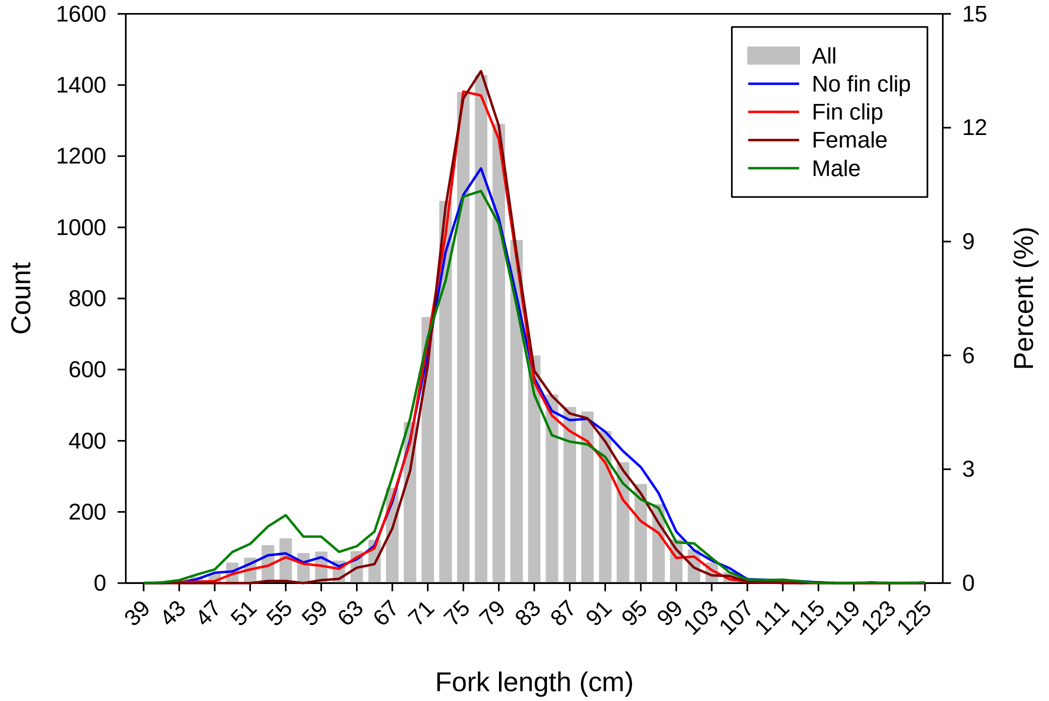

Figure 8. Histogram showing fork lengths (cm) for all radio-tagged adult and jack spring–summer Chinook salmon, 1996-2014. Lines show distributions by sex and presence or absence of fin clips.

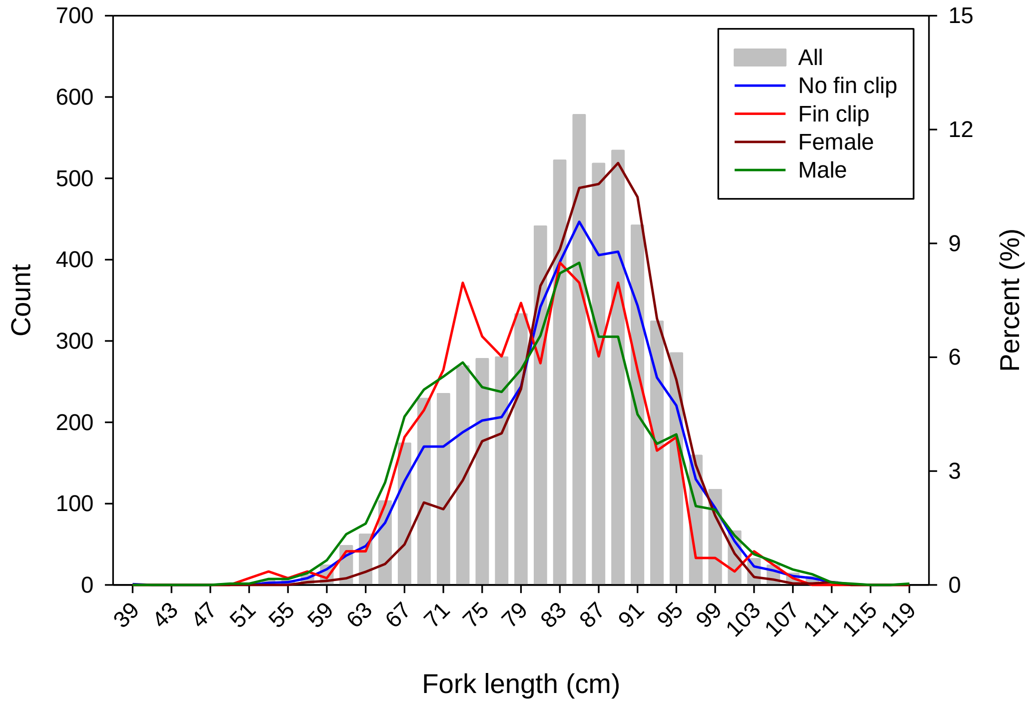

Figure 9. Histogram showing fork lengths (cm) for all radio-tagged adult fall Chinook salmon, 1996-2014. Lines show distributions by sex and presence or absence of fin clips.

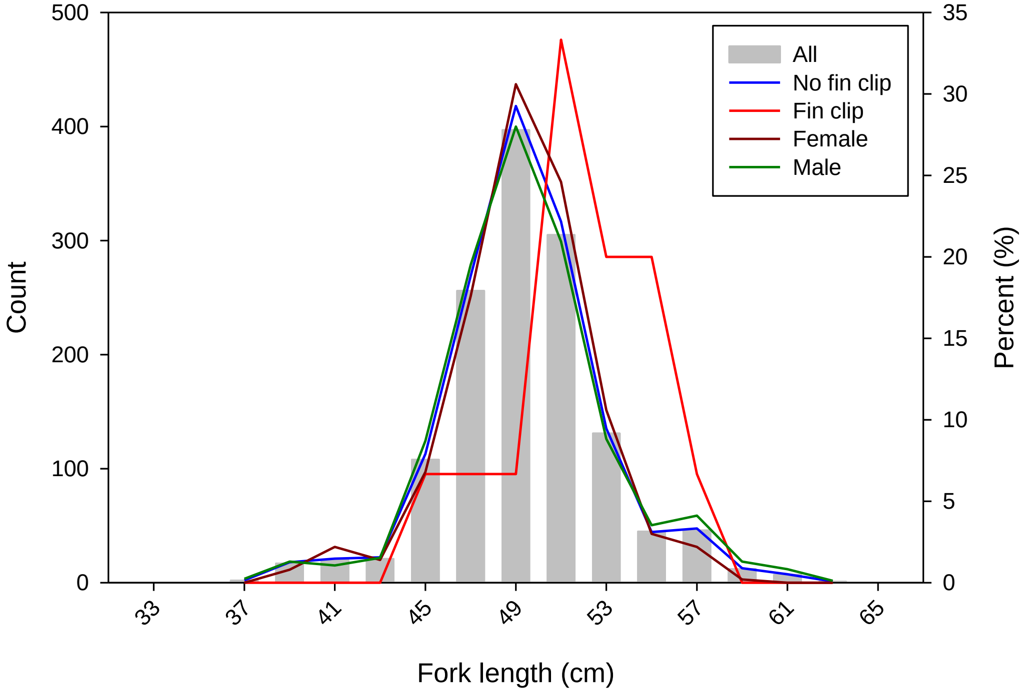

Figure 10. Histogram showing fork lengths (cm) for all radio-tagged sockeye salmon, 1996-2014. Lines show distributions by sex and presence or absence of fin clips.

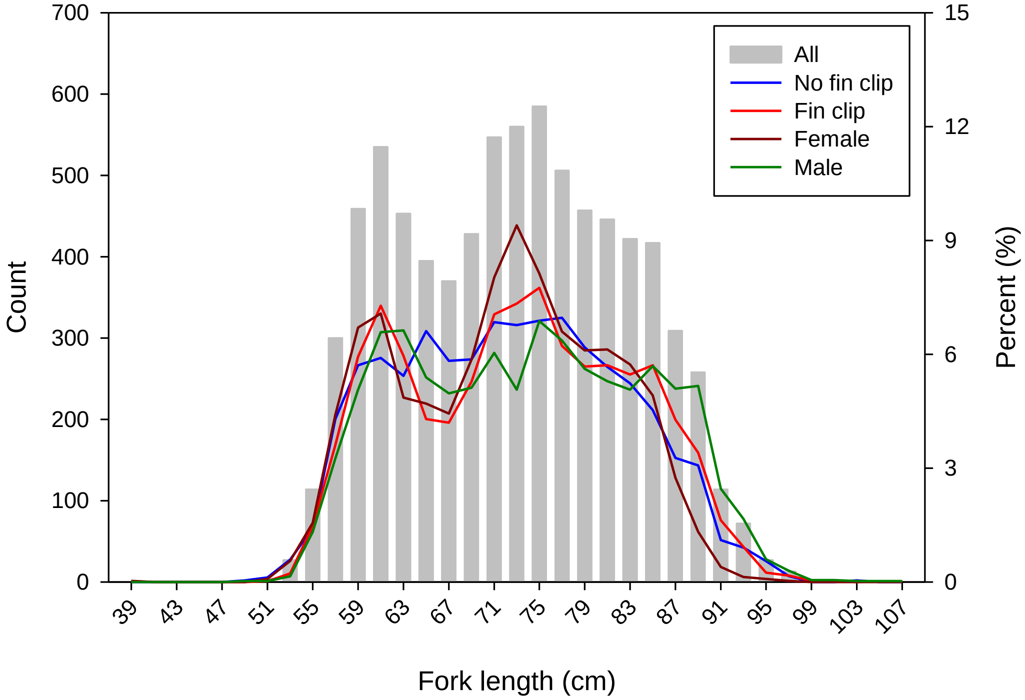

Figure 11. Histogram showing fork lengths (cm) for all radio-tagged adult steelhead, 1996-2014. Lines show distributions by sex and presence or absence of fin clips.

2.2.5 SAMPLE COLLECTION TIMING

Adult spring–summer Chinook salmon were tagged throughout each run in approximate proportion to long-term average counts at Bonneville Dam from 1996-2004 and in 2009-2010 (Figures 12-14). Variability in daily counts and annual run timing precluded precise proportional sampling. For example, summer Chinook salmon were disproportionately oversampled compared to the run in 1997 and spring Chinook salmon were disproportionately under-sampled in 2001 when migration timing diverged from expected. In 2005-2007 and 2013-2014, spring–summer Chinook salmon were not tagged in proportion to the runs. In some of these years, tagging was in blocks to address specific study objectives (e.g., an evaluation of sea lion exclusion devices in 2005-2006) or institutional issues (e.g., a contractual delay that delayed transmitter delivery in 2013) restricted proportional tagging.

During the eight fall Chinook salmon study years, radio transmitters were placed in a total of 6,134 adults, with the fall run identified using the long-established separation date of 1 August at Bonneville Dam. Fish were tagged throughout the runs in approximate proportion to long-term average counts in 2000-2005, with either daily or blocks of tagging effort (Figures 15 and 16). Exceptions to proportional tagging occurred in 1997, a pilot study year ($n = 55$) and in 1998 when no fall Chinook salmon were tagged in August. Regulations restricting handling of adult fish in the AFF during periods of high water temperatures (≥ 22.2 ºC) also limited fall Chinook salmon tagging in parts of August in 2004 and 2005.

Sockeye salmon were radio-tagged approximately in proportion to daily run counts in 1997 and 2013, but were relatively under-sampled in July of 2014 (Figure 17). Among the three study years, 2014 had the highest count of sockeye salmon passing Bonneville Dam, and the run timing distribution was unusually bimodal, with peak passage in July.

Steelhead have a protracted migration season relative to the Chinook and sockeye salmon runs (Figures 18 and 19). Steelhead tagging was restricted during warm months in some years. In general, however, we attempted to tag steelhead in approximate proportion to the overall runs, with gradually increasing daily sample sizes until the peak in passage in August and early September and declining numbers thereafter. Schedules were notably different in 2004, when temperature restrictions were extensive, and in 2013-2014 when samples were split each year into early (June-August) and late (September-October) components, with an overweighting of late-run fish that were targeted for FCRPS overwintering evaluations.

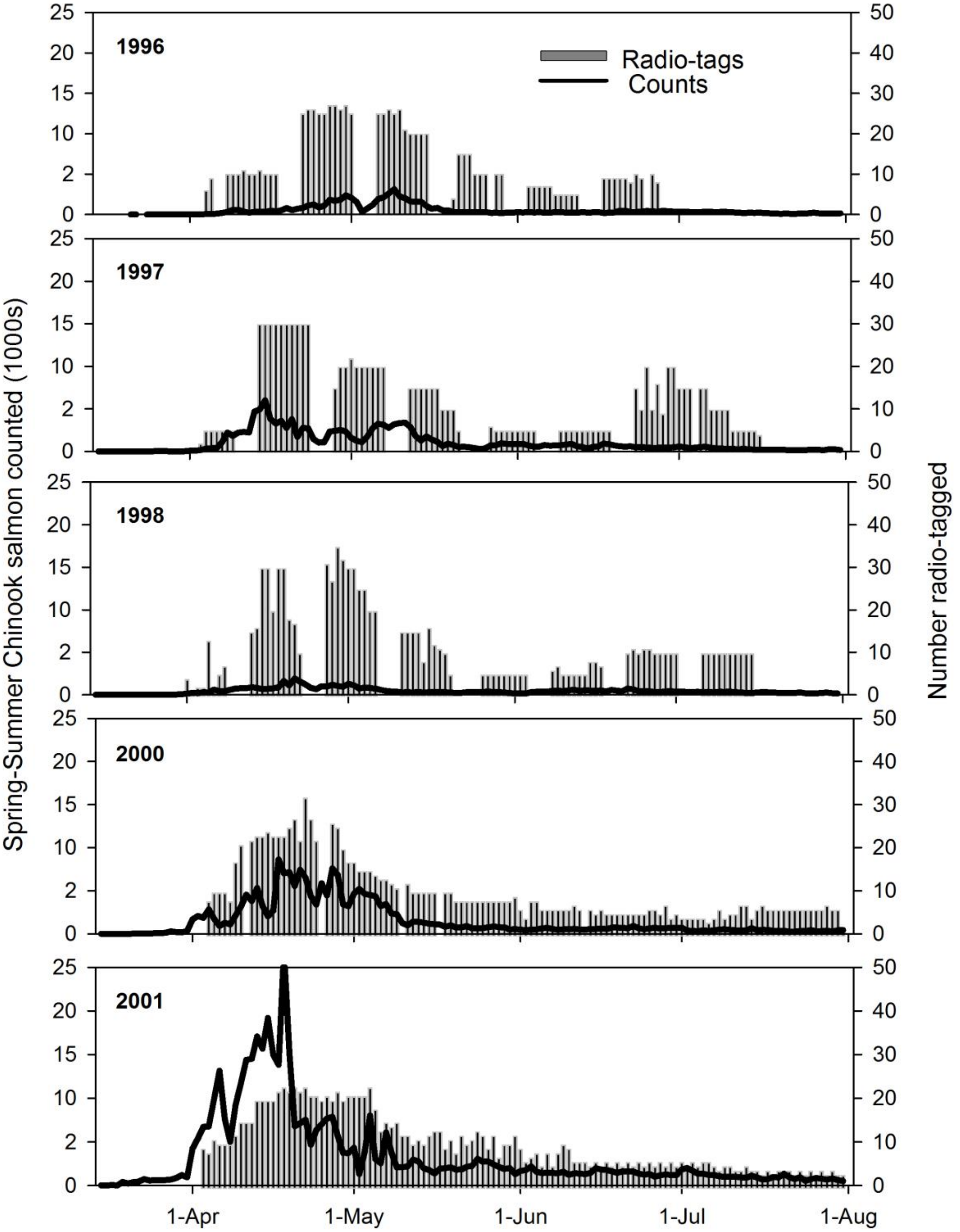

Figure 12. Annual distributions of collection and release dates for radio-adult tagged spring–summer Chinook salmon (bars) in relation to counts of adult spring–summer Chinook salmon at Bonneville Dam (lines), 1996-2001.

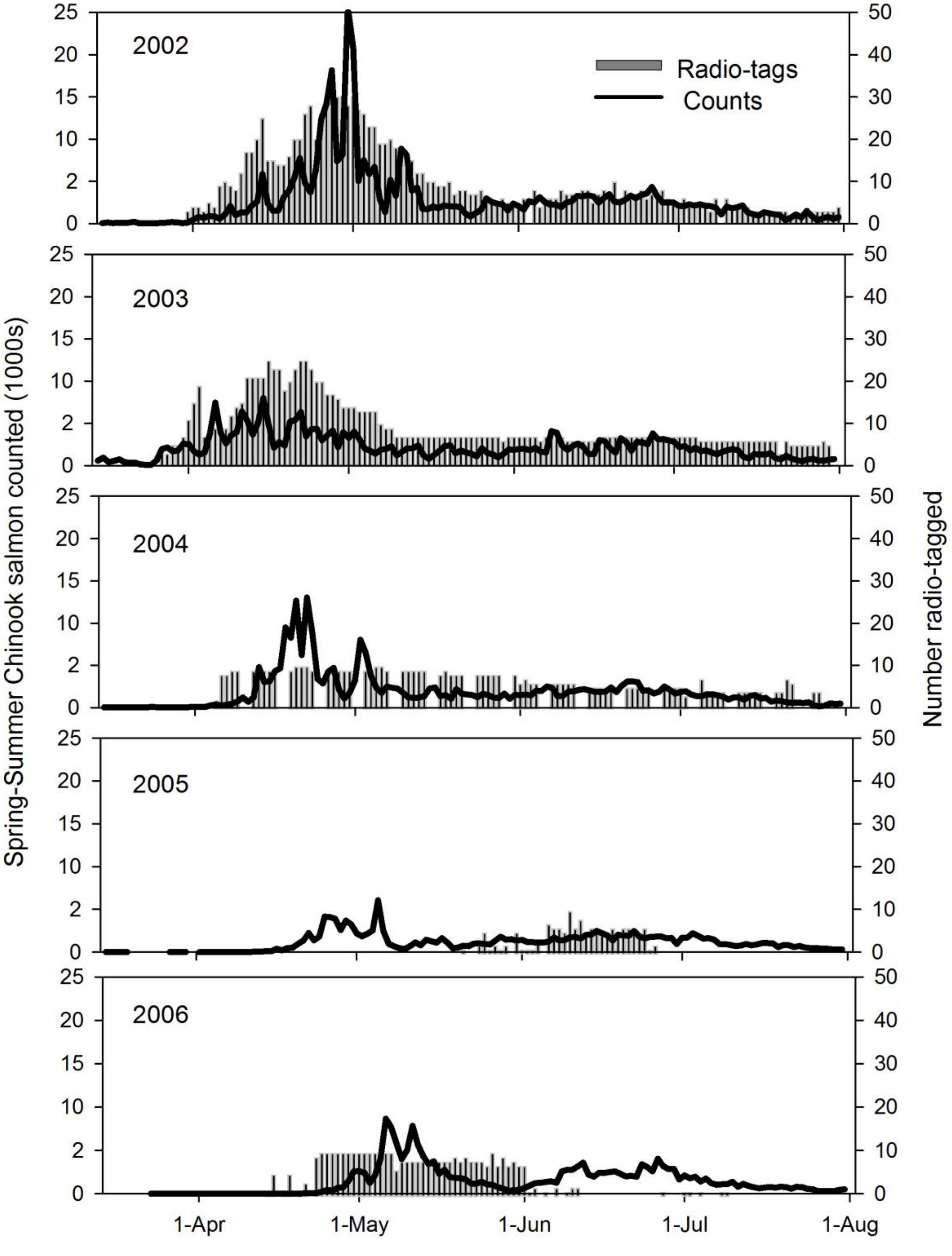

Figure 13. Annual distributions of collection and release dates for radio-tagged adult spring–summer Chinook salmon (bars) in relation to counts of adult spring–summer Chinook salmon at Bonneville Dam (lines), 2002-2006.

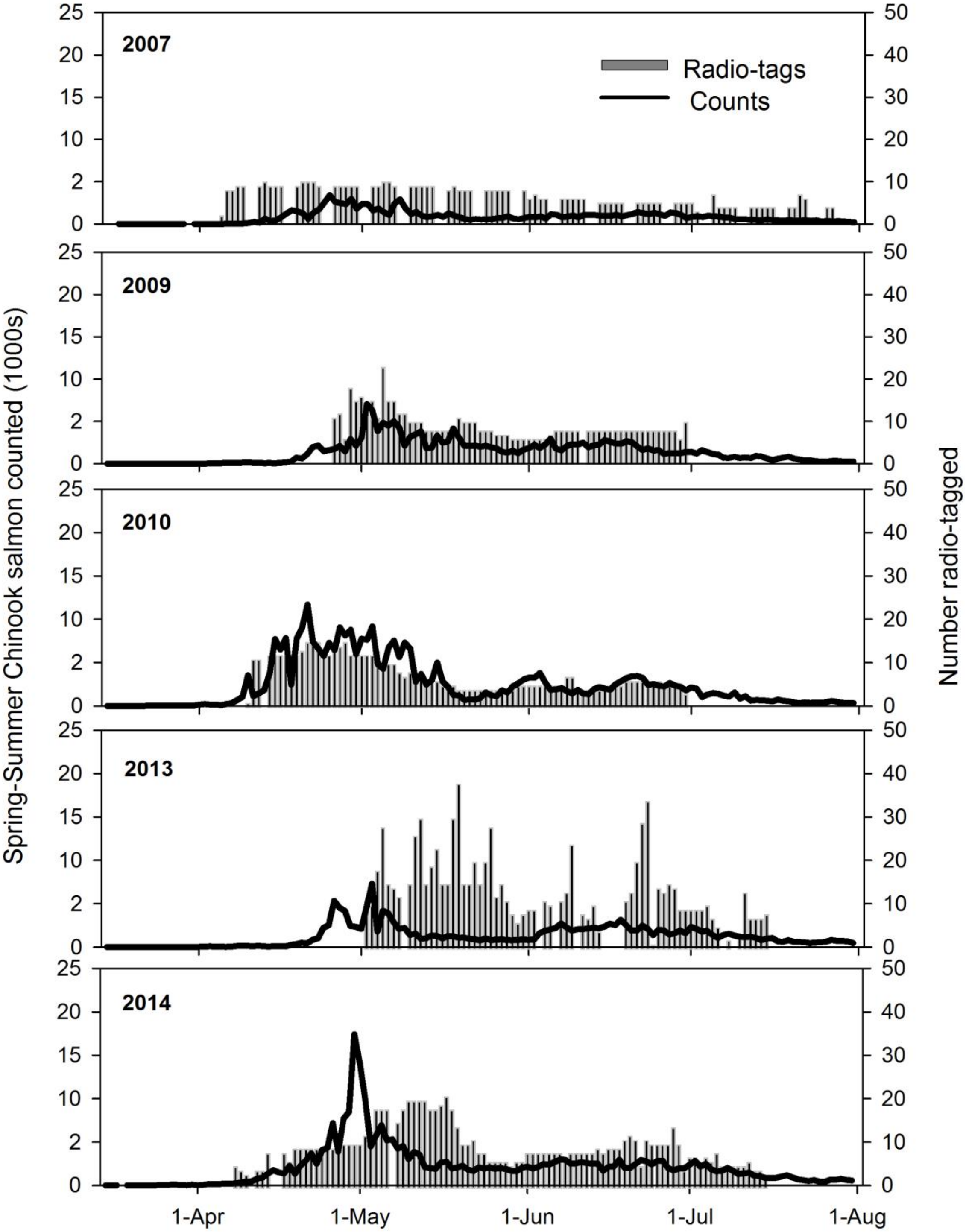

Figure 14. Annual distributions of collection and release dates for radio-tagged adult spring–summer Chinook salmon (bars) in relation to counts of adult spring–summer Chinook salmon at Bonneville Dam (lines), 2007-2014.

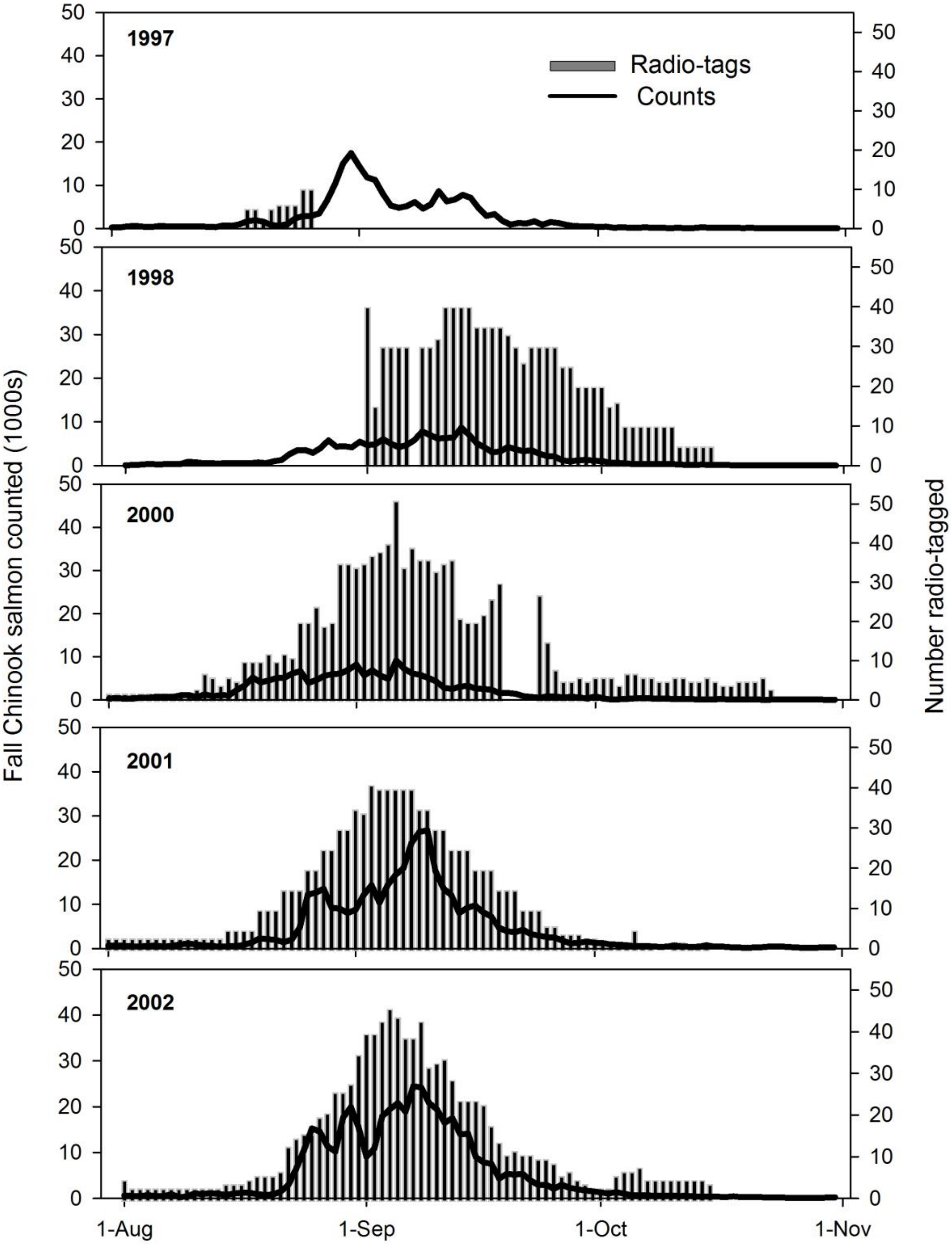

Figure 15. Annual distributions of collection and release dates for radio-tagged adult fall Chinook salmon (bars) in relation to counts of adult fall Chinook salmon at Bonneville Dam (lines), 1997-2002.

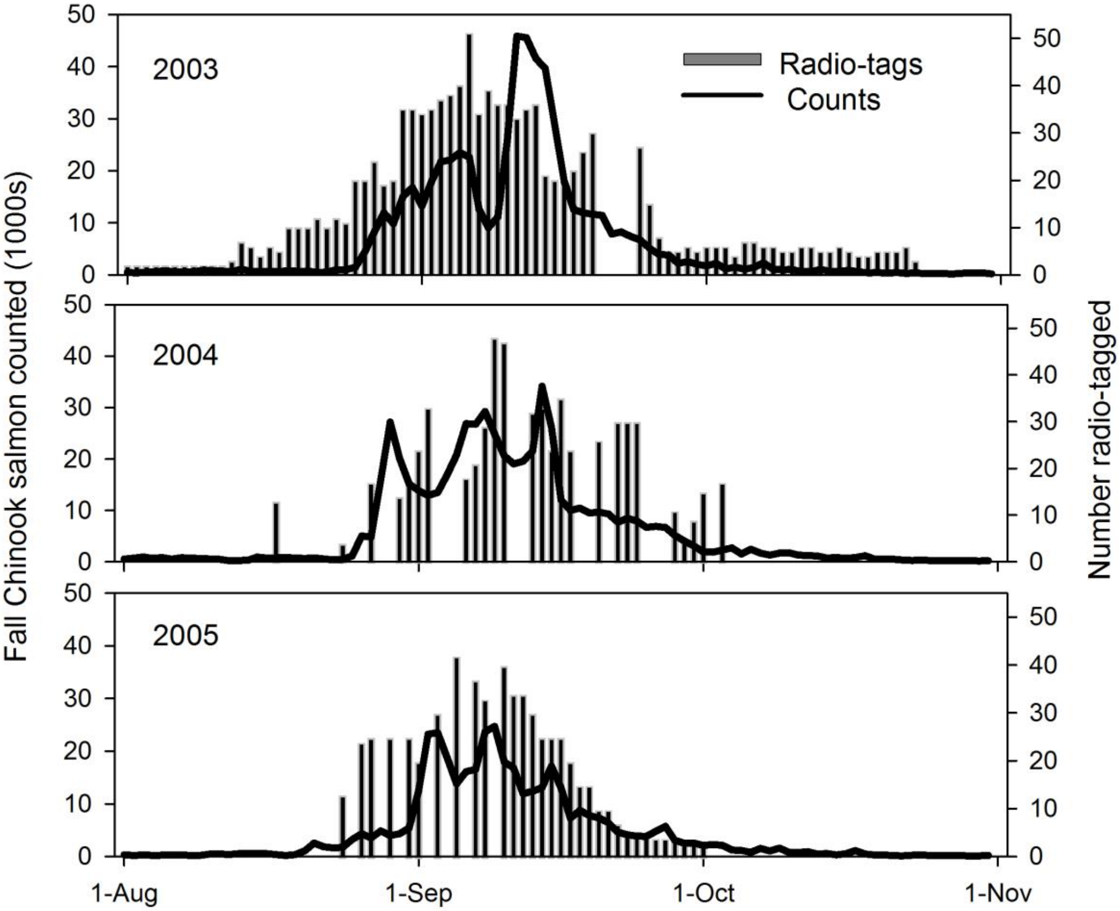

Figure 16. Annual distributions of collection and release dates for radio-tagged adult fall Chinook salmon (bars) in relation to counts of adult fall Chinook salmon at Bonneville Dam (lines), 2003-2005.

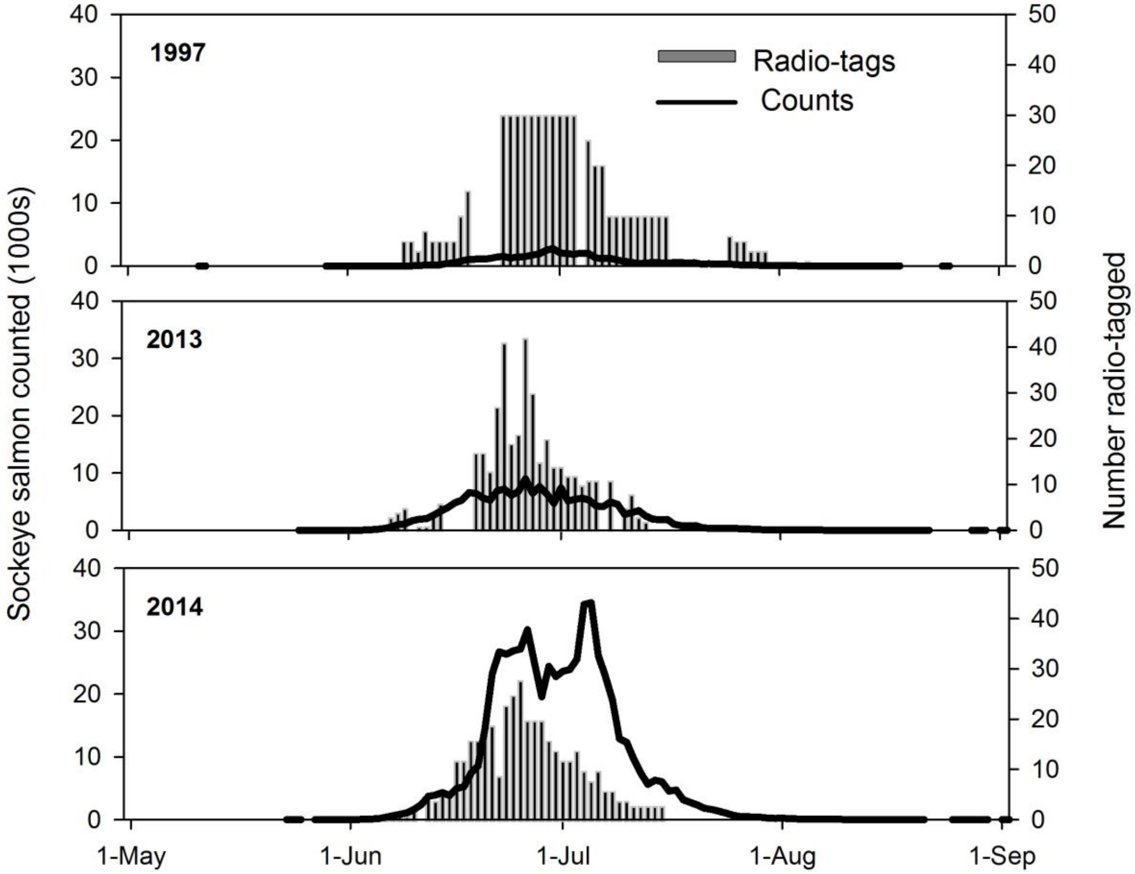

Figure 17. Annual distributions of collection and release dates for radio-tagged adult sockeye salmon (bars) in relation to counts of adult sockeye salmon at Bonneville Dam (lines), 1997-2014.

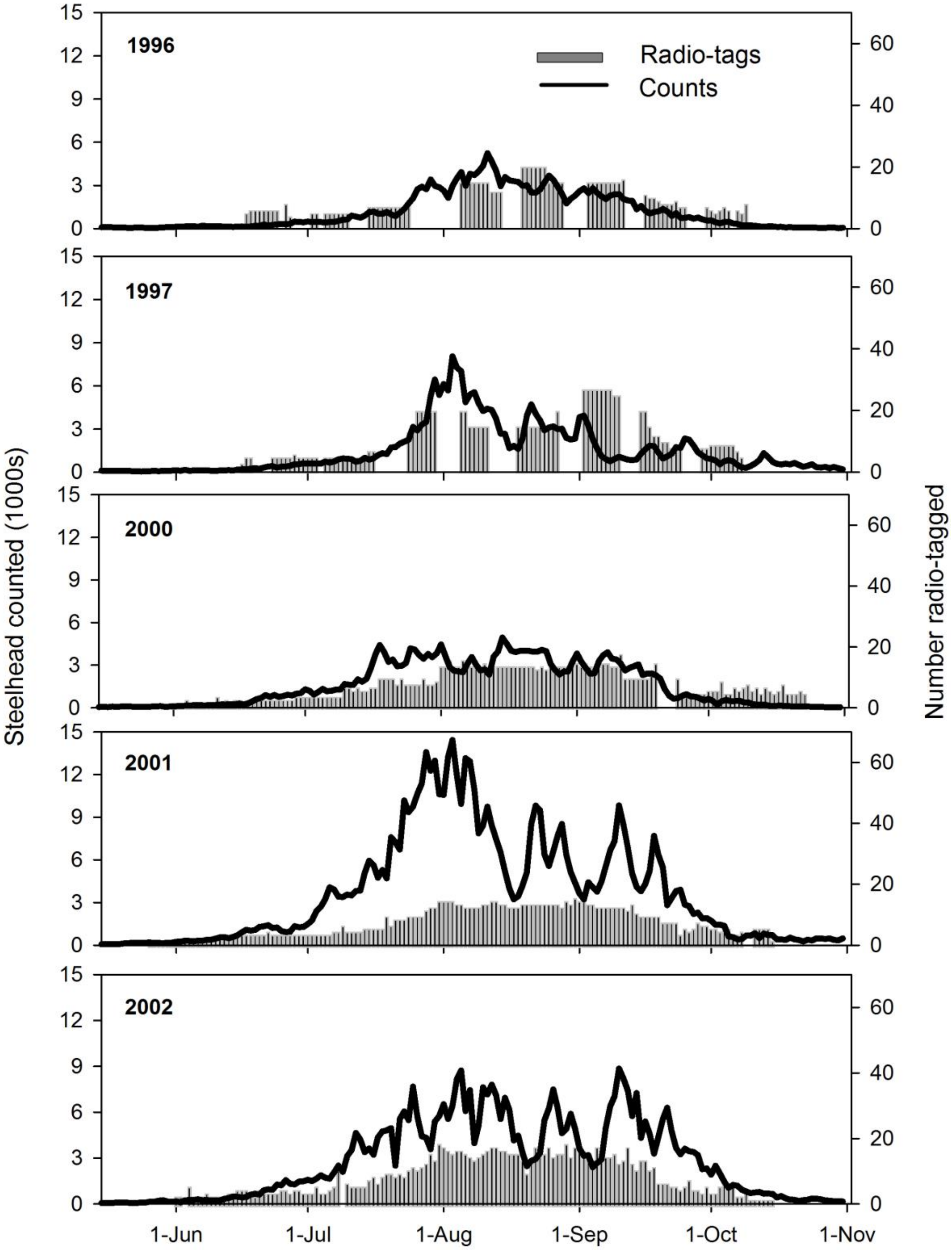

Figure 18. Annual distributions of collection and release dates for radio-tagged adult steelhead (bars) in relation to counts of adult steelhead at Bonneville Dam (lines), 1996-2002.

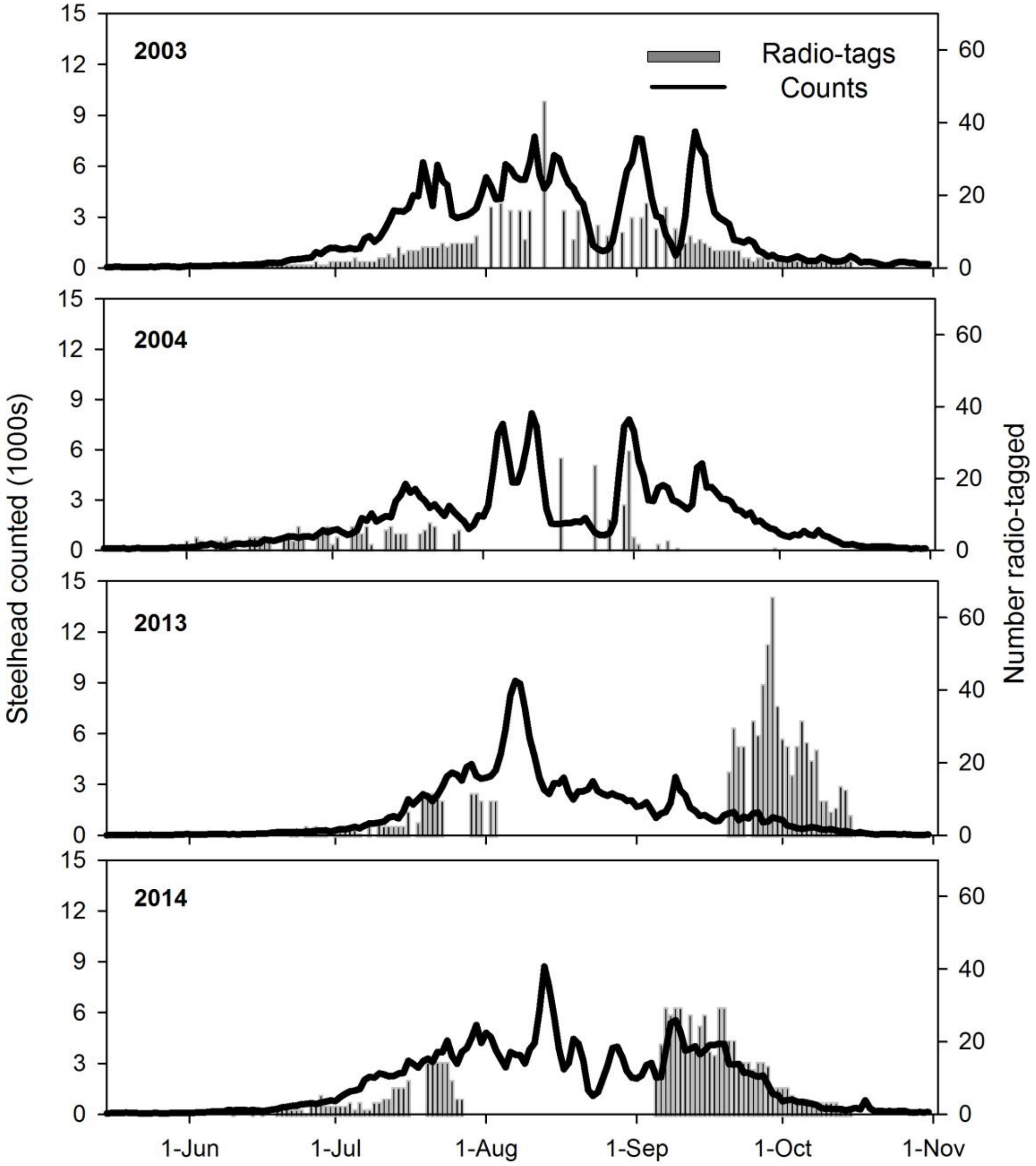

Figure 19. Annual distributions of collection and release dates for radio-tagged adult steelhead (bars) in relation to counts of adult steelhead at Bonneville Dam (lines), 2003-2014.

3.0 COMPILE AND ARCHIVE RADIOTELEMETRY DATA

This section provides information on the construction and organization of the databases that house the individual fish, radiotelemetry histories, PIT-tag detection histories, and monitoring infrastructure used in the adult salmon and steelhead studies (Figure 20). The datasets were provided to the Corps in dBase (.dbf) and Microsoft Access (.accdb) formats and will be archived at the University of Idaho Library and by the U.S. Army Corps of Engineers.

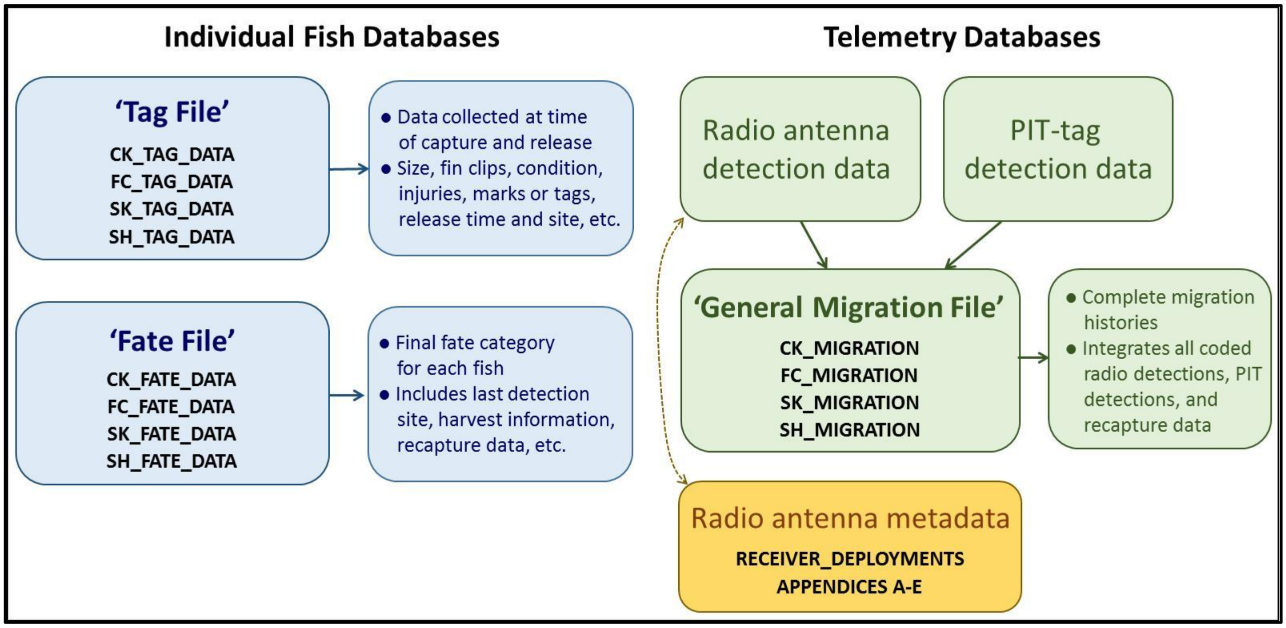

Figure 20. Summary of the individual fish and telemetry databases

3.1 TELEMETRY DATA

3.1.1 INDIVIDUAL FISH DATABASES: 'TAG FILES'

The 'Tag Files' contain the suite of information that was collected when adult and jack salmon and steelhead were collected and tagged at Bonneville Dam (see Section 2.1.2 on handling protocols for details). While fish were anesthetized, they were scanned for a previously-inserted PIT tag, and a variety of trait metrics were recorded and electronically entered into the tagging database (Table 12). The files contain a single record for each fish that includes the channel and code of each transmitter, any previously- or newly-injected PIT tag code, other existing or secondary marks or tags, an estimate of fish sex based on morphological traits, fin clip information, fork length, and a variety of descaling and injury metrics (Table 12). The most detailed metric was for injuries associated with seals and sea lions (see Table 13). UI personnel used a logbook to record the times that groups of fish were released downstream from Bonneville Dam and these data were subsequently entered electronically into the tag files along with a unique fish id and origin information for fish with previously-inserted PIT tags.

Table 12. ‘Tag File’ database definitions

Database column	Definition
TAGYEAR	Year fish was radio-tagged
SPECIES	CK= spring– summer Chinook salmon, FC=fall Chinook salmon, SK=sockeye salmon, SH=steelhead
LIFE_STAGE	Adult or jack
TAG_ID	A unique identifier of individual fish
CHAN	Radio tag channel (frequency)
CODE	Unique radio tag identification within a channel (frequency)
RELDATE	Release date
RELTIME	Release time
SITE	Release site
RKM	River kilometer (from the mouth of the Columbia River)
PIT_TAG	Passive Integrated Transponder (PIT) tag
PIT_MARK_SITE	Location where fish was PIT tagged as juvenile
PIT_REL_SITE	Location where PIT tagged juvenile was released
PIT_REL_DESCR	Description of site where PIT tagged juvenile was released
PIT_REL_YEAR	Year PIT tagged juvenile was released
VITAG	Visual implant tag
FKLENGTH	Fork length (cm)
WEIGHT	Weight (kg)
SEX	M=male, F=female, U=unknown (Estimated based on external characteristics)
CLIPS	AD=adipose, LP=left pectoral, LV=left ventral, RM=right maxillary, RP=right pectoral, RV=right ventral
DESCALE	Percent of scale loss (0=none, 1<10%, 2=10-25%, 3>25%)
NET_MARKS	Marks by nets (N=No, and Y=Yes)
MM_MARKS	Injuries by pinnipeds (see Table 13 for definitions)
GRT_TAG	A replacement radio tag that a fish received at Lower Granite Dam Trap

Table 13. Scoring rubric for marine mammal (i.e., pinniped) marks or injuries observed on radio-tagged adult salmon and steelhead (Database Column MM_MARKS in Table 12).

MM_MARKS	Definition
0	No marks or injuries
1	Evidence of injuries, descaling, or cuts but not likely caused by pinnipeds
2	Skin scrapes (minor descaling <15%) as indicated by arches or parallel body scrapes
3	Skin scrapes (major descaling >15%) s indicated by arches or parallel body scrapes
4	Light cuts (small ≤4 cm shallow cut) evident by broken skin
5	Light cuts (large >4cm shallow cut) evident by broken skin
6	Deep cuts (small deep cut) broken skin and open muscle tissue or body cavity
7	Deep cuts (moderate deep cut) broken skin and open muscle tissue; portion of muscle tissue may be missing
8	Deep cuts (large deep cut) broken skin and muscle tissue; muscle tissue easily visible and portion of muscle tissue may be missing
11	Fresh scrape
12	Fresh bite
21	Old/healed scrape
22	Old/healed bite
D	Dorsal (back of fish along spine or dorsal surface)
H	Head or opercle area
K	Caudal peduncle
L	Left side of body
N	No marks or injuries
O	Old injury
R	Right side of body
T	Tail
V	Ventral (belly of fish up to where the pectoral and pelvic fin bases are located)

3.1.2 INDIVIDUAL FISH DATABASES: ‘FATE FILES’

The ‘Fate Files’ contain our best estimate of the final disposition of each radio-tagged salmon or steelhead. Fate files contain a single record for each fish and share common fields with the Tag Files (e.g., fish id, transmitter frequency, PIT tag, etc.) along with four fields that describe the estimated or known fate (Table 14). The FATESITE1 and FATESITE2 fields include details of the final estimated fish location at both general (e.g., Clearwater River) and more specific (e.g., South Fork Clearwater River or Carson National Fish Hatchery) spatial scales.

The FATETYPE1 field is categorical and primarily includes fish assignment to main stem fishery, tributary, or ‘unaccounted for’ fate types. The fate type was generated from records of transmitters that were recovered (i.e., ‘recaptured’, RECAP field) at hatcheries, adult traps, weirs, or in spawning ground surveys that were provided to us by cooperating federal, state, and tribal agencies. Transmitters were also returned from commercial, sport, and tribal fisheries through a transmitter return reward program offered in all study years. Standard reward values printed on transmitters were US$25 but ranged up to US$100. The information provided about the circumstances and location of some angler harvest events could not be verified and this uncertainty was encoded in the General Migration File (see below). Lastly, likely post-spawn telemetry detections were excluded from fate assignments. For example, a steelhead that returned to the John Day River, spawned, and then outmigrated as a kelt the following spring was given a fate site of ‘John Day River’ and a fate type of ‘Tributary’.

Table 14. ‘Fate File’ database definitions

Database column	Definition
TAGYEAR	Year when fish was tagged
SPECIES	CK= spring– summer Chinook salmon, FC=fall Chinook salmon, SK=sockeye salmon, SH=steelhead
TAG_ID	A unique identifier of individual fish
CHAN	Radio tag channel (frequency)
CODE	Unique radio tag identification within a channel (frequency)
GRT_TAG	A replacement radio tag a fish received at Lower Granite Dam Trap
RELDATE	Release date
RELSITE	Release site
PIT_TAG	Passive Integrated Transponder (PIT) tag
FATESITE1	General location of last detection or transmitter recovery
FATESITE2	More specific details of final location (e.g., specific rkm, secondary tributary, etc.)
FATETYPE1	Presumed final fate (e.g., fishery, hatchery, tributary, unaccounted for, etc.)
RECAP	Fish recapture type (e.g., fishery, hatchery, spawning ground survey, etc.)

3.1.3 MONITORING: FIXED-SITE ANTENNA LOCATIONS

We used Lotek VHF radio receivers with W16 firmware in all years. Model SRX400 was used from 1996-2009 and model SRX400A was used after the transmitter code set was changed in 2010 (see Section 2.1.3). The SRX400A was also used to monitor the combined radio-acoustic transmitters in some years, with W31 or W32 firmware.

Radio-tagged fish were monitored with an extensive array of aerial and underwater antennas at Columbia and Snake River dams and tributaries (Tables 15-16). We used fixed-site radio receivers at each dam, at the mouths of major tributaries, and at the lower end of unimpounded sections of their main stems. We used SRX receivers with Yagi antennas to determine when fish first entered the tailrace area of a dam (Figure 21). Digital spectrum processors (DSP) added to SRX receivers could simultaneously monitor several frequencies and antennas; DSPs were particularly helpful in monitoring movements of adults into and through fishways at the dams. SRX/DSP receivers were connected to underwater antennas made of coaxial cable and were positioned near all fishway entrances, exits, and inside fishways at dams where fish were monitored intensively (Figure 21). Trucks were outfitted with 4-element Yagi antennas and SRX receivers to track fish in areas not covered by fixed-site receivers. Boats were similarly outfitted to facilitate mobile tracking in reservoirs. Outages at dams occurred primarily because of power loss, receiver malfunction, vandalism, or full memory banks.

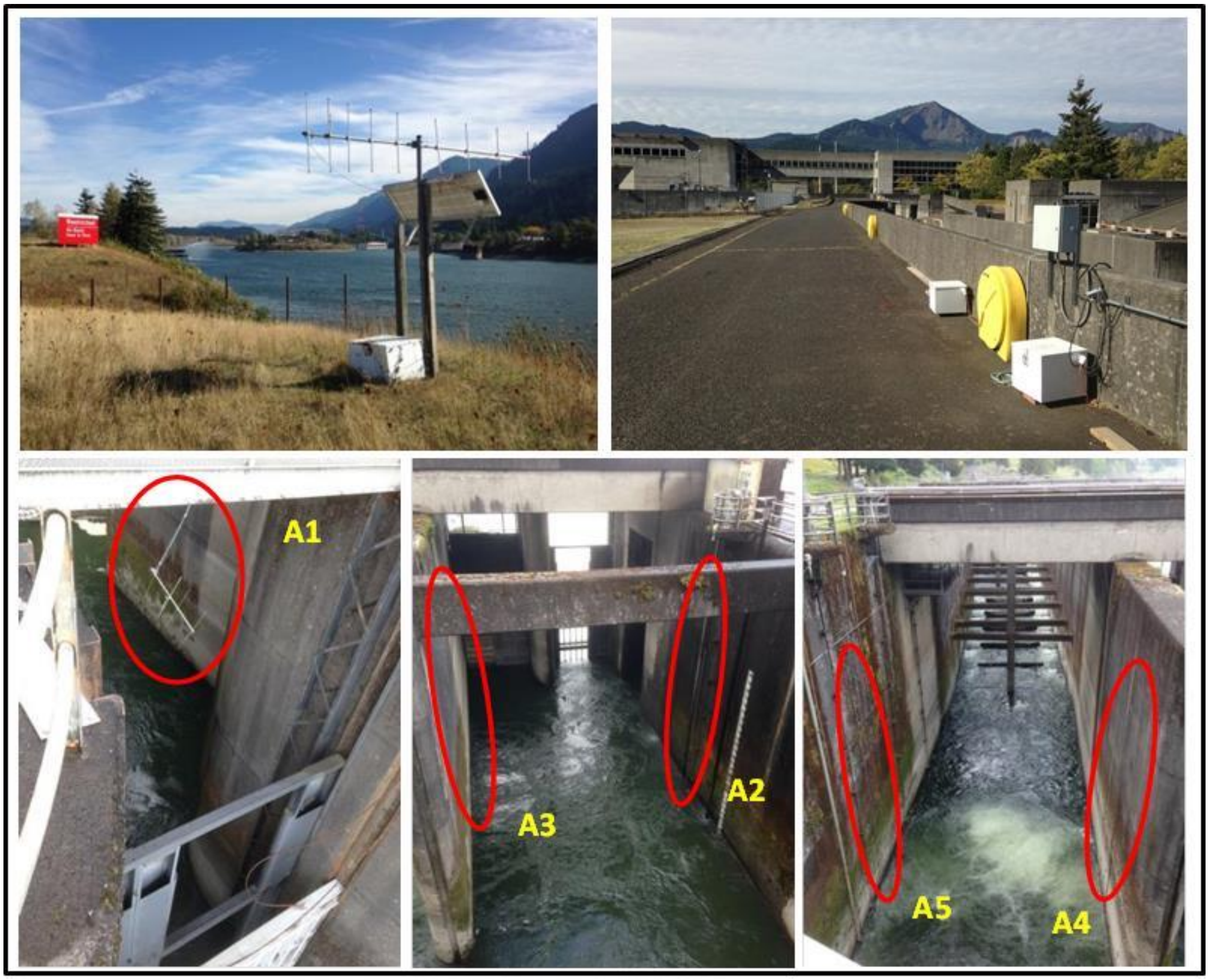

Figure 21. Top left: example of an aerial Yagi antenna and receiver box used to monitor tailrace, reservoir, or tributary sites. Top right: receiver box on decking adjacent to adult fishway. Bottom left: example of an aerial Yagi antenna used inside an adult fishway opening. Bottom middle and right: examples of underwater coaxial cable antennas used to monitor adult fishways.

Table 15. Summary of receivers deployed at Columbia and Snake River dams, with reference to the location maps and additional site details provided in Appendices A-E.

Dam	Receiver code	Appendix figure
Bonneville Dam	1BO 2BO 3BO 4BO 5BO 6BO 7BO 8BO 9BO ABO BBO CBO DBO EBO FBO GBO HBO IBO JBO KBO LBO MBO NBO OBO PBO QBO RBO SBO TBO UBO VBO WBO XBO YBO ZBO 1BS 2BS 3BS 4BS 5BS 6BS 7BS 8BS 9BS 10BS 11BS 12BS 1BT 2BT 3BT 4BT 1HR 1BU 2BU BCD BCU BF1 BF2 BF3 BF4 BF5 BF6 BF7 BHI BJP MTK	Figures A1-A6
The Dalles Dam	1TD 2TD 2TL 3TD 4TD 5TD 6TD 7TD 8TD 9TD ATD BTD CTD DTD ETD FTD GTD HTD JTD KTD LTD MTD NTD PTD QTD RTD STD TTD UTD VTD WTD XTD YTD ZTD 1ST 2ST 3ST 4ST LPI	Figure A7
John Day Dam	1JD 2JD 3JD 4JD 5JD 6JD 7JD 8JD 9JD AJD BJD CJD DJD EJD FJD GJD HJD KJD LLJD MJD NJD OJD PJD QJD RJD SJD TJD UJD VJD WJD XJD YJD ZJD	Figure A8
McNary Dam	1MN 2MN 3MN 4MN 5MN 6MN 7MN 8MN 9MN AMN BMN CMN DMN EMN FMN GMN HMN JMN KMN LMN MMN NMN OMN PMN QMN RMN SMN WMN	Figure A9
Ice Harbor Dam	1IH 2IH 3 IH 4IH 5IH 6IH 7IH 8IH 9IH AIH BIH CIH DIH EIH JIH MIH NIH PIH SIH TIH	Figure A10
L. Monumental Dam	1LM 2LM 3LM 7LM 8LM 9 LM ALM BLM CLM KLM TLM ZLM	Figure A11
Little Goose Dam	1GO 2GO 5GO 6GO 7GO AGO BGO CGO FGO MGO TGO	Figure A112
Lower Granite Dam	1GR 2GR 3GR 4GR 5GR 6GR 7GR 8GR 9GR AGR BGR CGR DGR FGR GGR MGR RGR SGR TGR ZGR GRT	Figure A13
Priest Rapids Dam	1PR 2PR 3PR 4PR 5PR 6PR 7PR 8PR 9PR APR BPR CPR DPR	Figure A14
Wanapum Dam	1WP 2WP 3WP 4WP 5WP 6WP 7WP 8WP 9WP BWP CWP	Figure A15
Rock Island Dam	7RI 8RI 9RI	n/a
Rocky Reach Dam	9RR	n/a

Table 16. Summary of receivers deployed at Columbia and Snake River main stem locations other than dams (black text) and in tributaries (blue text), with reference to the location maps and additional site details provided in Appendices A-E.

Receiver location	Receiver code	Appendix figure
Below Bonneville	BVR BVT CLZ LWR SAN TAN WAS WIL WLL	Figure B1
Bonneville reach	BMA BOG CLR CUR FTR HBL LWD LWU MRA MSP RCC SBL UPA VSP WHD WHU WNM 2HR 3HR 4HR 5HR 6HR 7HR EAG FMC HCK HDR HOO KLT KTR LWS WHR WHS WIN WNU WSU	Figure B2
The Dalles reach	ABL BBL CEL DSM WSM DES DSR OAK SHF	Figure B3
John Day reach	ALD IGN JDL PCK PSN PTL RVT SDL JDR RCK UMR	Figure B4
McNary reach	HFL HFR SN1 SN2 1RZ CLH EAS NAC PSR RZA SNY TEA TNM TWD WWR YAK	Figure B4
Ice Harbor reach	1CH 2CH BFL FHK WKR	Figure B5
L. Monumental reach	AYL DTC LFH PAL PLS TUC	Figure B5
Little Goose reach	SWL	Figure B5
Above Lower Granite	1WI 2WI DBR HBR HCD PLD SNR AMR AST CCR CWR EON GRR IMR JCR LCR LCW LOC LSR MCR MFS NCR ORO PCR PRS SEL SFC SFS SNR TCR TOS USR	Figure B5, Figure B7
Rock Island reach	WEN	Figure B6
Rocky Reach reach	ENT	Figure B6
Wells reach	MET OKA	Figure B6

3.1.4 MONITORING: MOBILE TRACKING

Data from fixed aerial and underwater antennas were supplemented with data collected while UI personnel surveyed segments of the basin from boats or trucks mounted with receivers and aerial antennas. The frequency of these collections varied but typically, there was an emphasis on surveying drainages shortly after known spawning times of the different species/runs. In some years, other agencies including the Washington and Oregon Departments of Fish and Wildlife supplied us with mobile tracking data for fish we tagged when they were conducting concurrent radio-telemetry studies within the Tucannon and main stem Columbia rivers, respectively. The validity of each mobile tracking record was evaluated in the context of data from fixed-site receivers during the processing of the general migration files.

3.1.5 MONITORING: PIT-TAG INTERROGATION HISTORIES

PIT records from the tag file were used to query the Pacific States Marine Fisheries Commission PIT Tag Information System database PTAGIS and any detections were subsequently integrated into the radio-telemetry general migration files for review. PIT detections in fishways, juvenile bypass systems, tributaries, and at hatcheries or collection facilities augmented our ability to discern fish movements, particularly if a radio-tag was regurgitated or removed. PIT detections within fishways were typically construed to constitute passage events at dams in the absence of any radio-data.

3.1.6 TELEMETRY DATABASES: ‘GENERAL MIGRATION FILES’

Construction of the radiotelemetry databases was a multi-step process and was conducted by field staff, data managers at the Northwest Fisheries Science Center (NMFS) in Seattle, and biologists and technicians at the University of Idaho (UI). The first step was the daily transfer of the ‘tag records’ for each fish radio-tagged at Bonneville Dam to Seattle for inclusion in the respective dataset for each species. The second step was for UI personnel to periodically download data from radio receivers into laptop computers, with the download frequency depending on the number of fish passing a site. Some sites were downloaded daily during the peaks of some runs, and some as infrequently as bi-monthly. Downloaded data were transmitted to Seattle and added to Oracle databases. Records from receivers consisted of transmitter frequency (channel), code, date, time, power of signal received, and antenna site. We created databases for all the records of individual fish at each dam. An ongoing data quality control process occurred in Seattle whereby all records were evaluated and ‘good’ records were added to the databases and ‘bad’ records were placed in a bad-record table. Bad records included those, for example, with channels and codes for fish that had not been released.

The third data processing step typically occurred as each migration season progressed, with files of data for each dam sent to the UI for coding. Coding of the records consisted of reviewing all the records for a fish at an individual dam and assigning codes to mark specific fish activities (Table 17). For example, each fish approach and entry into a fishway was coded as were exits back into the tailrace, entry and exit from tailraces and transition pools, and exits from the top of ladders into forebays. Coded records were generally the first record, and occasionally the last record, in each block of detections as fish moved from antenna to antenna. In the early study years, a semi-automated ArcView 2.0 program was developed to assist in the coding of records at dams. The program incorporated an interactive map of the dam and a decision tree that prompted trained personnel to code records manually while sequentially moving through the raw data. In later years, a fully-automated coding program was developed in Visual Basic and the coded output from the automated program was reviewed and corrected, where necessary, by trained personnel.

The fourth data processing step occurred at the end of the migration season after all fish had been coded at each dam. Specifically, records were returned to Seattle and integrated into a ‘coded’ database. At this stage, UI personnel integrated the coded data from the dams with ancillary data, including tag and release records, detection data from aerial antennas in reservoirs and in tributaries, records of fish detected by truck- and boat-based mobile tracking, records of fish that were recaptured at weirs and hatcheries, and records of harvest that were reported from fisheries in a transmitter-return reward program.

In the final quality control data step, the coded records from all dams and all ancillary records were assembled chronologically and then reviewed and further reduced (i.e., by coding detection data from tributaries and reservoirs) to create a 'general migration' file for each species-year. As part of the data compilation effort for this report, PIT-tag interrogation data from all double-tagged (radio + PIT-tag) salmon and steelhead were integrated with the radiotelemetry data in the general migration databases (Table 18). The addition of PIT-tag detections provided valuable information on fish distribution (i.e., when fish entered tributaries with PIT-antennas but not radio antennas) plus migration data for fish that either lost transmitters or for which transmitter battery life ended while fish were still alive (i.e., for steelhead kelts moving downstream after spawning).

We developed a set of suffixes for the 'RCP' entry in the CORR field of the general migration files to indicate when there was uncertainty about dates or locations of some recapture events (Table 19).

Table 17. CORR (behavior code) column definitions from general migration databases.

CORR	Definition
A	Approach (outside fishway antenna)
A1	First approach (outside fishway antenna)
E	Entrance (assigned to outside antennas but based on detections within a fishway)
E1	First fishway entrance
EFB	A record indicating a fish re-ascended a dam where it had fallen back
F	First detections in the tailrace after a fishway approach or first record in a series of records at a main stem or tributary site
F1	First detection in the tailrace of a dam
FB	Fall back (fish passed dam and was subsequently recorded downstream from it)
FP	First pool (first detection in the transition pool at a dam)
FT	First top (first detection at the ladder top)
GRT	A type of recapture record for Lower Granite Trap. Fish were released back into the ladder or transported to a hatchery
I	Detection on an antenna inside the fishway
K	A record indicating that fish has become a kelt (steelhead)
L	Last record on a tailrace site after an approach at the dam or last record in a series of records at a main stem or tributary site
LP	Last pool (Last fish detection in the transition pool before passing a dam)
LT	Last top (Last detection at the ladder top)
MBT	Mobile track (via boat, vehicle, fixed-wing aircraft, or on foot)
RCP	Recapture (fishery, trap, weir, spawning ground, unknown, etc.)
TAG	Record indicating where and when a fish was radio-tagged
U	Radio detection with an unknown location or time
UA	Approach with unknown location or time
UA1	First approach with unknown location or time
UE	Entrance with unknown location or time
UE1	First entrance with unknown location or time
UFT	First record indicating a fish passed a ladder top where it had no radio detections
ULT	Last record indicating a fish passed a ladder top where it had no radio detections (typically based on upstream detections or the absence of detections indicating a fish swam down the ladder)
UX	Exit from a fishway and the location or time is unknown
X	Exit (outside fishway antenna)

Table 18. General migration database column definitions.

Database column	Definition
TAGYEAR	Year when fish was radio-tagged
SPECIES	CK=Chinook (spring or summer), FACK=fall Chinook, SOCK=sockeye, STHD=steelhead
LIFE_STAGE	Adult or jack
TAG_ID	A unique identifier of individual fish
CHAN	Radio tag channel (frequency)
CODE	Unique radio tag identification within a channel (frequency)
DATE	Date radio tag event occurred
TIME	Time radio tag event occurred
ANTEN	Antenna on which fish was detected (0-7=radio detection; 8 =radio tag, recap, or mobile track record and 9=PIT detection)
SITE	Radio receiver on which fish was detected
CORR	Behavior code (see Table 17 for definitions)
POWER	Radio tag signal strength
RKM	River kilometer (from the mouth of the Columbia River)
JTAG	Comments
SITE_INFO	Site information of PIT detection

Table 19. List of common suffixes appended to recapture entries in the CORR field and their definitions

RCP-Suffix	Definition
RCP-A	Tag may have been in the air; it was found but it was not in a fish
RCP-D	The date associated with the recapture event is questionable or unknown
RCP-H	Recaptured at a hatchery, trap, or weir
RCP-M or -L	The location or river kilometer associated with the recapture event is questionable or unknown
RCP-R	The fish was released after the recapture event
RCP-RP	The fish was released after the recapture event and the transmitter was pulled
RCP-RPN	Fish was trapped, the transmitter was pulled, and the fish was released with a new transmitter
RCP-U	There is no reliable information about the circumstances associated with the recapture event
RCP-X	Recapture event in absence of a transmitter (i.e., based on VI or PIT tag)

4.0 FCRPS ACTIONS POTENTIALLY AFFECTING ADULT PASSAGE

The tables in this section include brief chronological summaries of Corps actions at FCRPS dams that may have affected adult salmon and steelhead passage. These actions were often the trigger for the adult radiotelemetry studies. We identified both structural and operational changes from the rationale sections of the radiotelemetry project technical reports, from Corps reports, and from a document provided by NOAA-Fisheries (Gary Fredericks, personal communication).

THE TIMELINE TABLES ARE CONSIDERED A WORK IN PROGRESS: NO COMMENTS WERE PROVIDED FOR THIS SECTION.

4.1 TIMELINES OF STRUCTURAL AND OPERATIONAL CHANGES

Table 20. Bonneville Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural			●		●	●●●	●●●		●	●●	●●			●●	●	●	●●●● ●●	●●●	●●
Operational					●	●	●	●			●	●	●	●		●●			

Structural

1998: Adult Fish Facility outfitted with PIT tag detectors

2000: PIT-tag detectors installed in Adult Fish Collection and Monitoring Facility return ladder and at Cascade Island

2001: PH1 orifice gates to collection channel closed.
Lamprey plates installed on diffuser grates on northernmost WA-shore orifices
PIT-tag detectors installed in AFF return ladder and WA-shore

2002: Lamprey passage structure (LPS) in Bradford Island AWS channel
End bay deflectors installed
PIT tag detectors installed in Bradford and Cascades Island ladders

2004: Powerhouse 2 Corner Collector installed

2005: Prototype sea lion exclusion device (SLED) installed at fishway entrances
Vertical slot PIT detector installed in Washington shore ladder

2006: Sea lion exclusion device (SLED) installed at fishway entrances (*seasonally installed thereafter*)
Vertical-slot PIT detector installed at Bradford Island ladder

Table 20. Bonneville Dam (continued)

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural			●		●	●●●	●●●		●	●●	●●			●●	●	●	●●●● ●●	●●●	●●
Operational					●	●	●	●			●	●	●	●		●●			

2009: Variable-width weir, lamprey passage structure (LPS), and bollards installed in Cascade Island entrance area
Perpendicular picket leads installed in AFF (*removed in 2010*)
2010: Picket lead spacers installed at WA shore AWS channel to allow lamprey passage
2011: Picket lead sill ramp installed at WA shore AWS channel to allow lamprey passage
2012: Pit antenna replaced at Bradford Island serpentine section
Exit channel dredged at Bradford Island ladder
B-branch spillway hole and ogee repair
Fishway picket lead modifications, including spacers for lamprey passage at Bradford Island and WA-shore
Lamprey passage structure (LFS-LPS) installed at WA-shore north downstream entrance area
Cascades Island LPS extended to forebay
2013: Adult Fish Facility (AFF) modifications installed to improve water velocity
Lamprey rest boxes installed in WA-shore ladder near UMT junction
Fishway picket lead modifications
2014: Adult Fish Facility (AFF) modifications completed
Picket lead spacing reduced to block lamprey passage into Cascade Island AWS

Operational

2000: Spill experiment
2001: Powerhouse priority switched from PH1 to PH2
2002: Spill experiment
2003: Spill experiment
2006: 100k day/night spring spill operation
2007: Fishway velocity reduced at night to test lamprey passage
2008: Fishway velocity reduced at night to test lamprey passage
2009: Fishway velocity reduced at night to test lamprey passage
2011: Diffuser failure in Washington shore ladder caused early shutdown and cleanout erosion hole under B-branch ladder caused early shutdown and repair

Table 21. The Dalles Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural									●						●			●	
Operational					●						●					●			●

Structural

2004: Bay 6-7 spillwall installed
2010: Bay 8-9 spillwall installed
2013: PIT detectors installed in north and east fishways

Operational

2000: First use of juvenile spill pattern and 40% spill
2006: First use of extended Intake Traveling Screens operation in November for steelhead fallback
2011: First season with extended ice and trash sluiceway (ITS) operation in March for steelhead fallback
2014: September split flow test with 15 kcfs spill

Table 22. John Day Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural		●	●	●				●					●		●●		●		
Operational										●									

Structural

1997: Stacked bulkheads were used in bay 20 to simulate a surface spillbay
1998: New smolt monitoring facility went on line in April
1999: Spillway deflectors installed
2003: South ladder flow control section completed
2008: Transportable spillway weirs (TSW) installed in spillbays 15 and 16 – started operation 21 April
2010: Spill deflector installed in spillbay 20 and TSWs moved to bays 18 and 19
North fishway upper ladder flow control section rebuild
2012: North ladder entrance (install variable-width entrance weir and remove lower fishway weirs) and transition pool modifications (LPS and bollards) installed. Other modifications included: removal of concrete weirs from upper North ladder; replacement of a bulkhead, crowder, light box, and picket leads near the count window, and the installation of a window washer on the count window; closure of 1 N fishway entrance slot.

Operational

2005: First season of 24 hour summer spill

Table 23. McNary Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural		●●					●●			●	●	●	●		●				●
Operational												●	●	●	●				

Structural

1997: Northern Wasco PUD turbine installed in WA shore ladder AWS system
Installation of extended-length submersible bar screen system completed
2002: PIT detectors installed in both adult fishways and in juvenile bypass system
Installed end-bay deflectors (bays 1, 2, 21, & 22)
2005: Half-duplex PIT detectors installed in ladder entrances, junction pools and ladder exits
2006: Washington shore fish counting station reconstructed
2007: First year of transportable spillway weir (TSW) use in spillbays 20 and 22.
2008: Washington shore ladder entrance and north powerhouse entrances rebuilt
2010: Holes (7.5 cm × 45.0 cm) cut into adjustable overflow weirs (upper ladder) in OR shore fishway to facilitate lamprey passage
2014: Prototype adult lamprey passage structure installed at south shore fishway entrance

Operational

2007: TSWs moved to bays 20 and 22
2008: TSWs moved to bays 19 and 20
2009: TSWs in bays 4 and 19 in spring and 19 and 20 in summer
2010: Discontinued use of TSWs in summer

Table 24. Ice Harbor Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural	●	●	●	●				●		●					●		●		
Operational																		●	

Structural

1996: New juvenile bypass system goes into operation, replacing ice and trash sluiceway bypass operation
1997-1999: Eight spillbay deflectors installed as part of gas abatement program
2003: PIT tag detectors installed in both adult fishways
2005: Removable spillway weir installed in spillbay 2
2010: Steel plates installed over south shore diffuser gratings
2012: Structural modifications to aid lamprey passage made in both adult fish ladders

Operational

2013: Newly-designed adult fish trap intermittently deployed at top of south fishway

Table 25. Lower Monumental Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural										●		●					●		●
Operational						●													

Structural

2005: North-shore adult count station reconstruction
2007: Removable Spillway Weir (RSW) installed in spillbay 8
2012: Holes (3.8 cm (h) × 30.5 cm (w)) cut into bases of weirs (near fishway floor) to facilitate lamprey passage
2014: PIT antennas installed near south ladder count station

Operational

2001: orifice gates closed to fishway collection channel

Table 26. Little Goose Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural		●●												●		●●●			●●
Operational										●			●						

Structural

1997: Fence designed to keep adults inside the collection channel installed at north powerhouse fishway opening
Extended-length submersible screens installed
2009: RSW installed at spillbay 1
2011: North powerhouse entrance (3) and North Shore entrance (3) sealed off with concrete
Fence in north powerhouse collection channel repaired and re-installed
New ramps installed in spillway section of adult fish channel
2014: New fence installed in collection channel near north powerhouse fishway opening
Lamprey passage holes cut into bases of vertical-slot weirs

Operational

2005: Spill exceeding 30% of flow blocked adult fish passage
2008: Spill patterns varied to simulate RSW installation

Table 27. Lower Granite Dam

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Structural	●●	●			●	●	●	●				●							
Operational																			

Structural

1996: Prototype surface collector installed and tested
Extended-length submersible screens installed
1997: Fence designed to keep adults inside the collection channel installed at north powerhouse fishway opening
2000: Lower five weirs in transition pool modified to decrease water flowing over weirs and increase flows through lower orifices
2001: RSW installed in spillbay 1
2002: Removable panels were affixed to the lower ladder weirs by which flows through the weirs were manipulated
2003: PIT tag detectors installed in adult fishway
2007: Forebay Behavioral Guidance Systems removed

4.2 ENVIRONMENTAL PROFILES AT FCRPS DAMS

Figures 22-29 provide annual mean monthly values for total discharge, spill, and water temperature at the eight FCRPS study dams. These data are presented because river environment directly affects operations at FCRPS dams, especially with regards to spill, and because warm water temperature thresholds at Bonneville Dam were used to limit or temporarily prohibit collection and handling of adult migrants at the AFF (see Section 2.1.1). More generally, year-to-year and month-to-month differences are important for interpreting the variability in adult salmon and steelhead behavior and performance metrics described in the reporting bibliography (Section 5.0) and presented in Section 6.0.

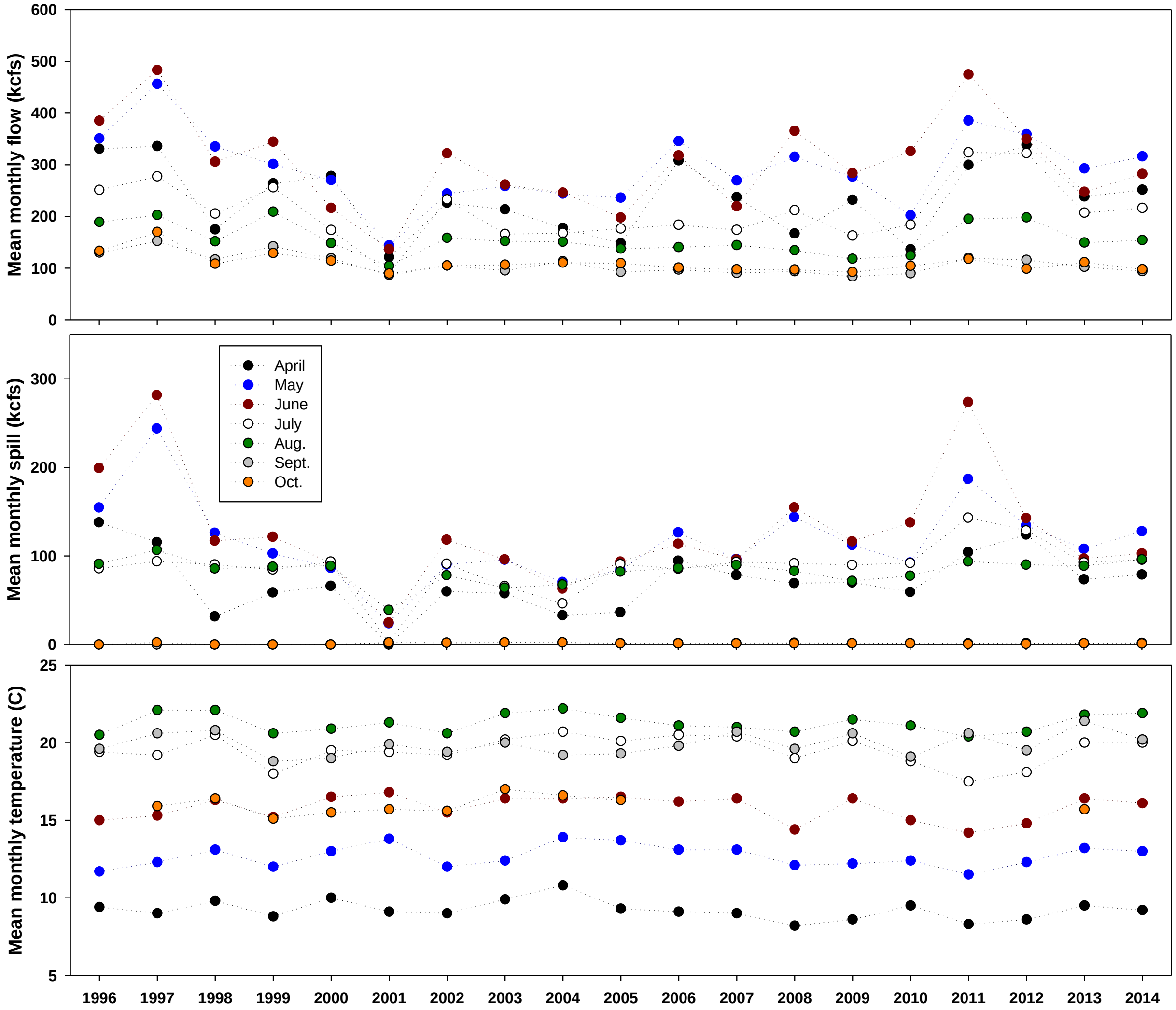

Figure 22. Mean monthly flow, spill, and forebay water temperature at Bonneville Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

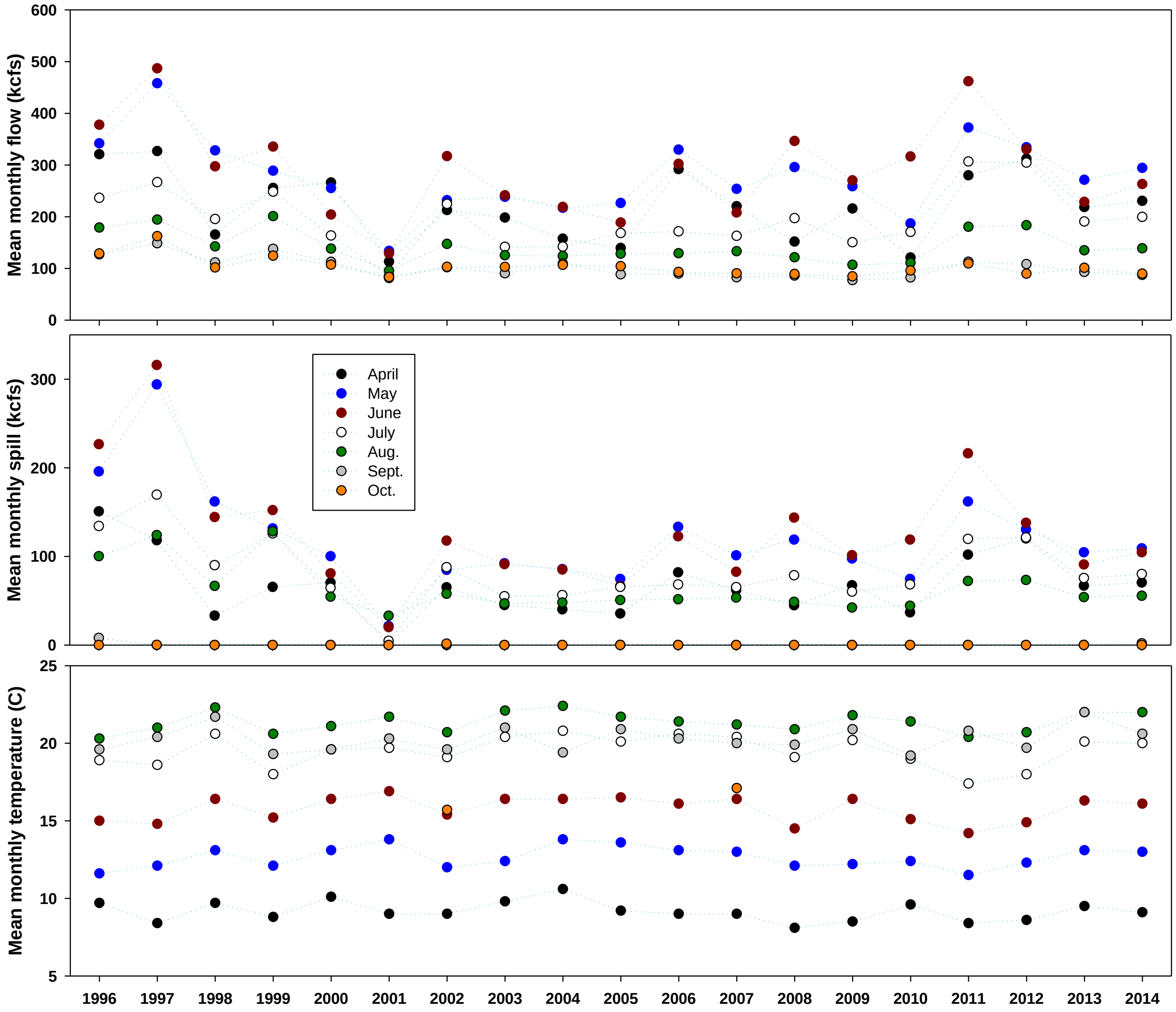

Figure 23. Mean monthly flow, spill, and forebay water temperature at The Dalles Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

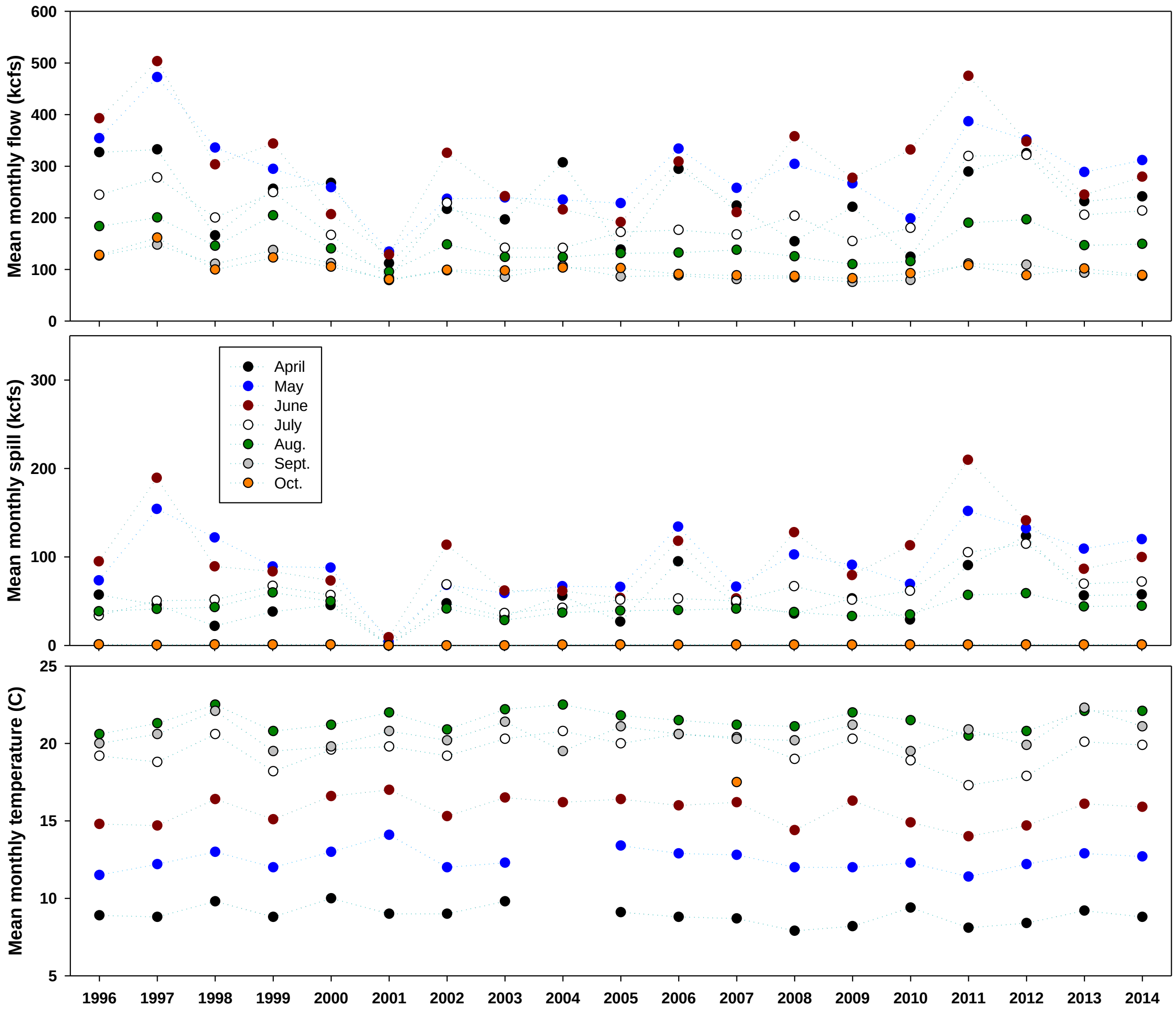

Figure 24. Mean monthly flow, spill, and forebay water temperature at John Day Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

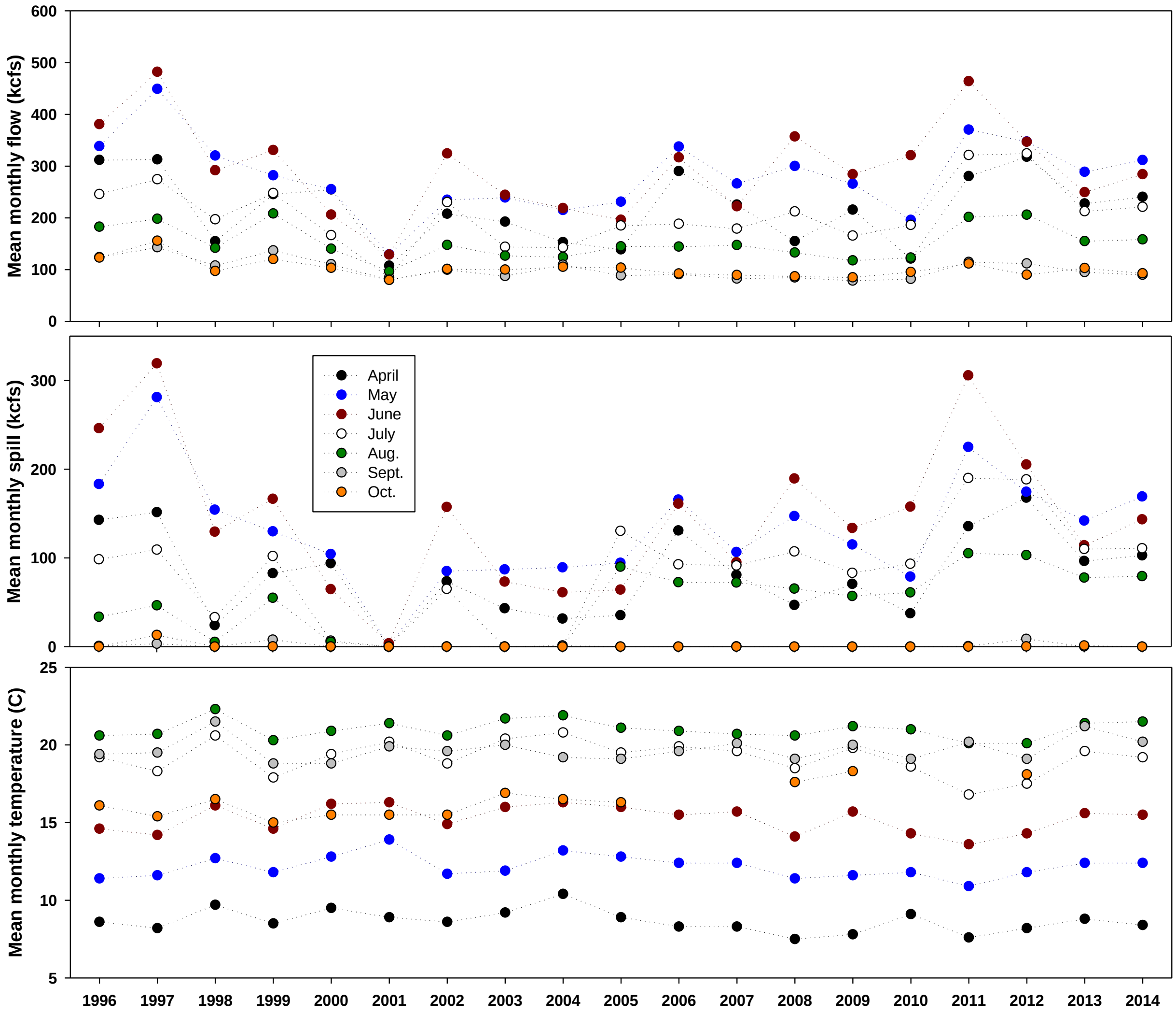

Figure 25. Mean monthly flow, spill, and forebay water temperature at McNary Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

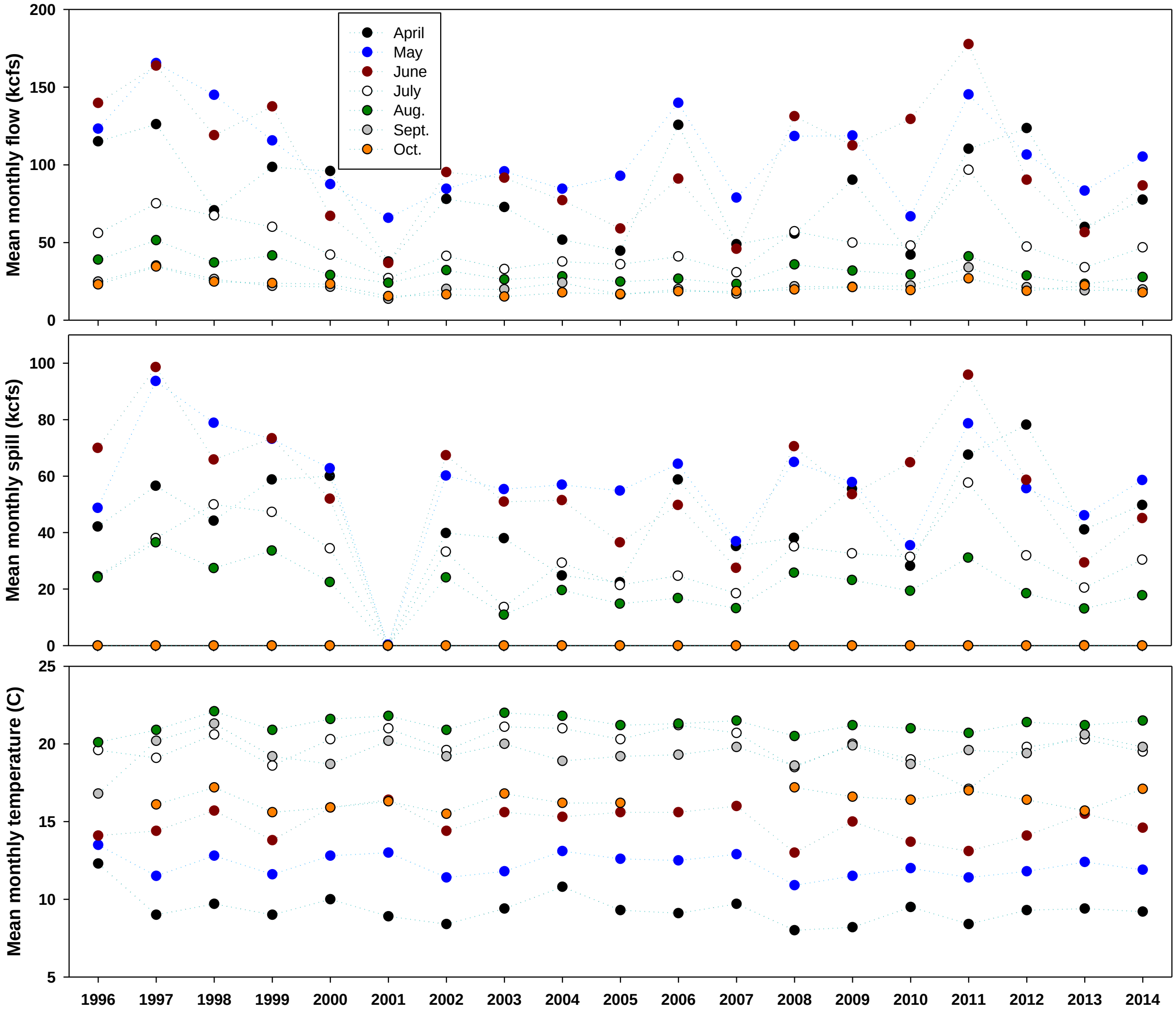

Figure 26. Mean monthly flow, spill, and forebay water temperature at Ice Harbor Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

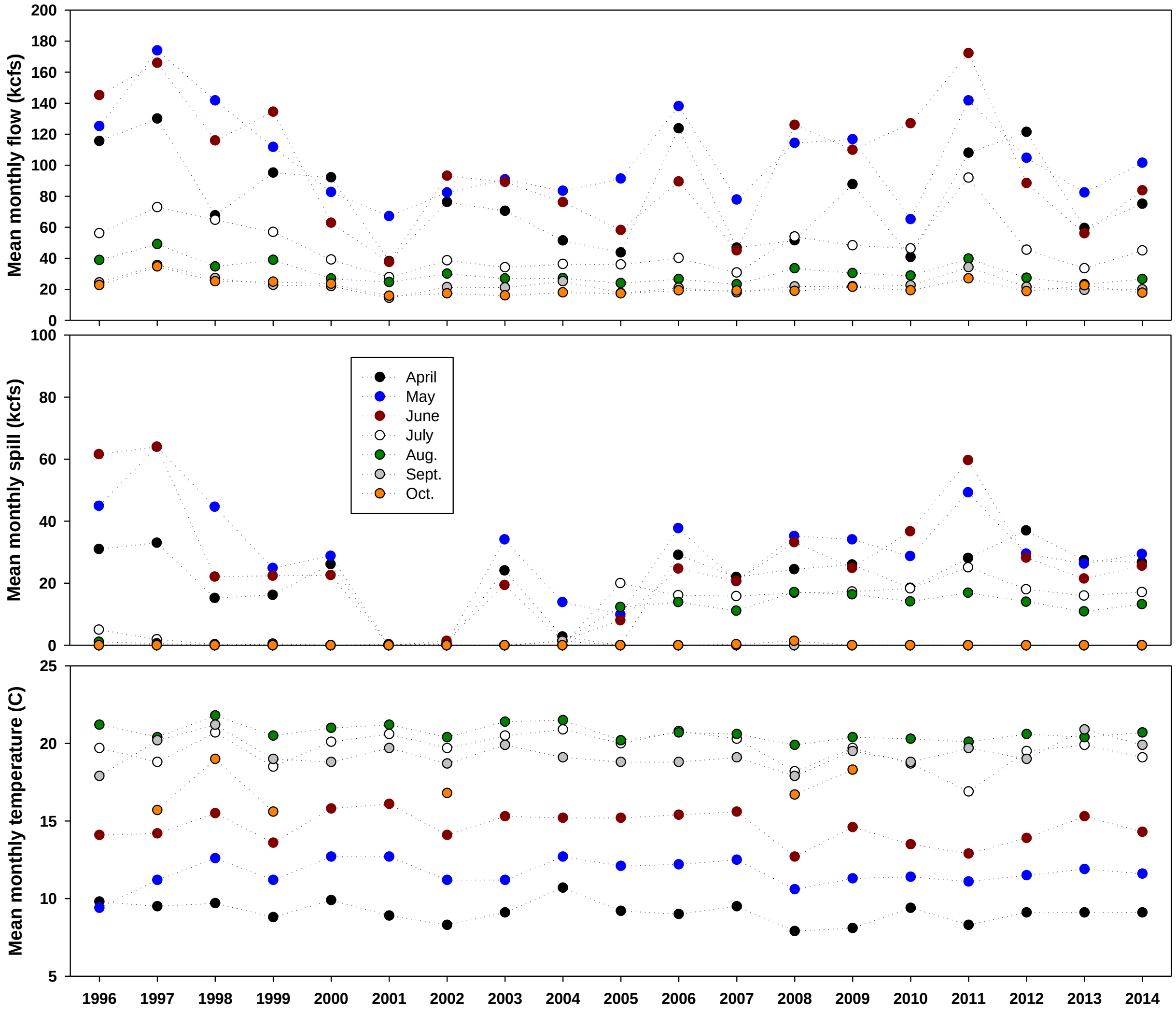

Figure 27. Mean monthly flow, spill, and forebay water temperature at Lower Monumental Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

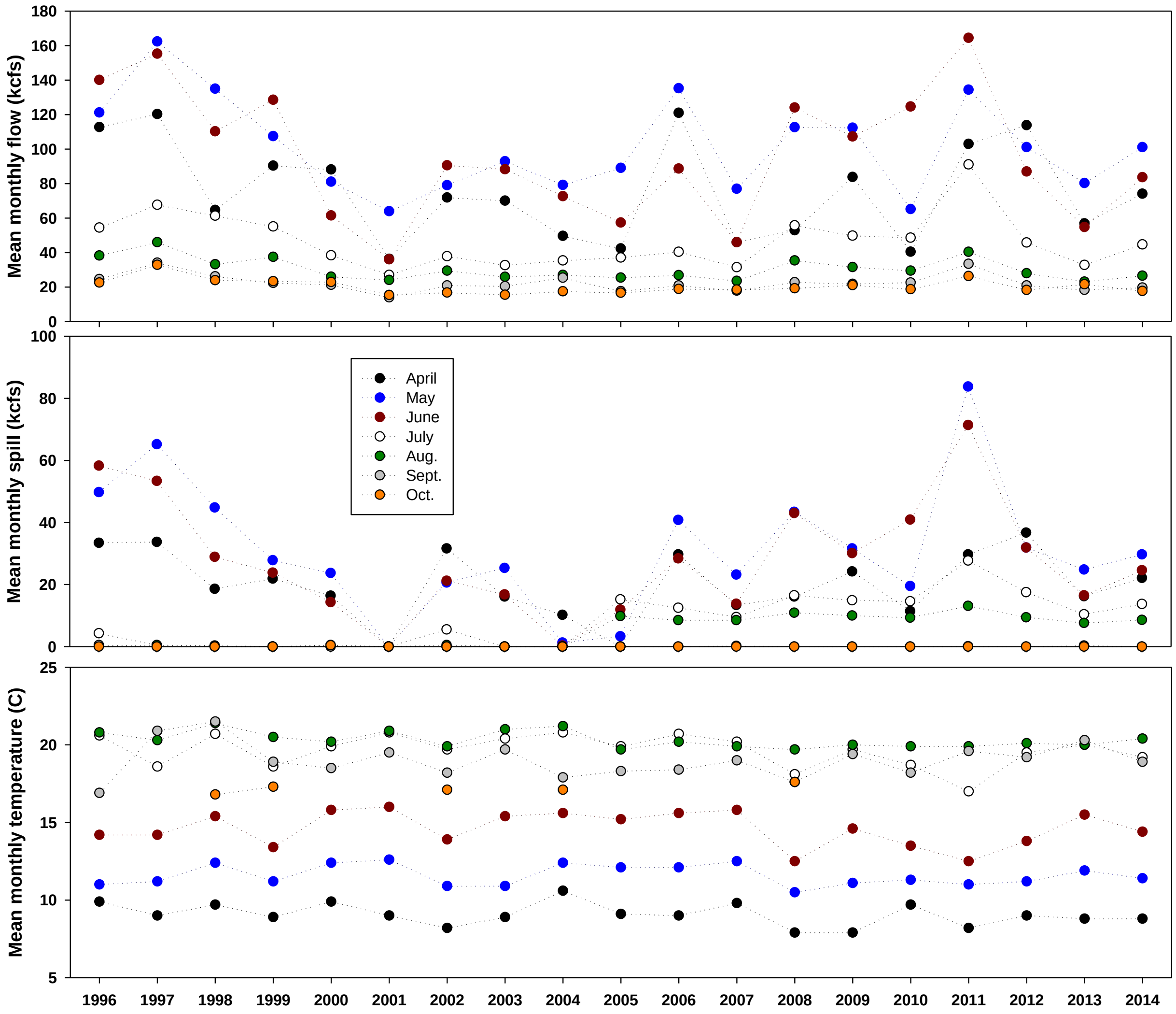

Figure 28. Mean monthly flow, spill, and forebay water temperature at Little Goose Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

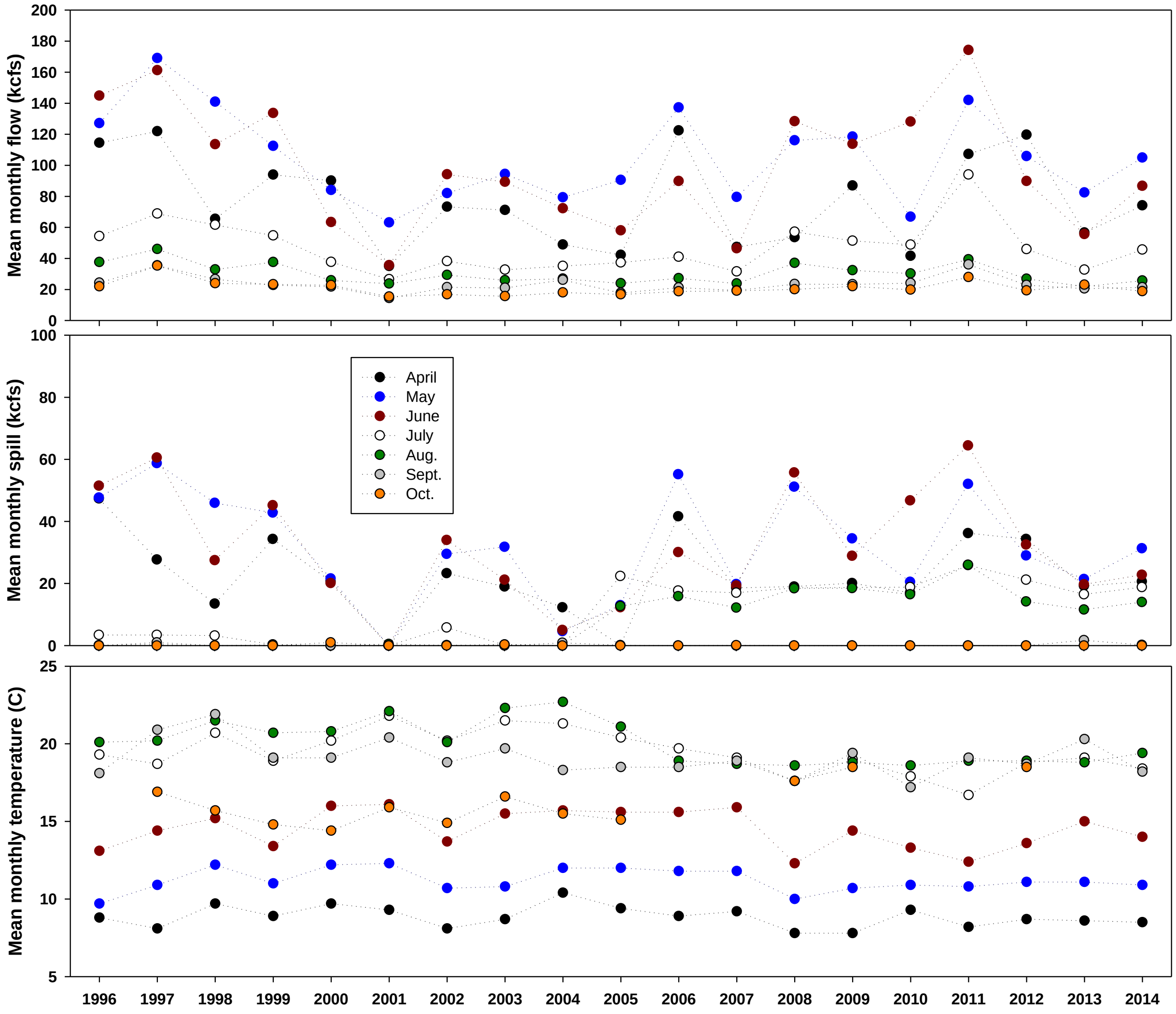

Figure 29. Mean monthly flow, spill, and forebay water temperature at Lower Granite Dam, 1996-2014. Data retrieved from http://www.cbr.washington.edu/dart/query/river_daily

5.0 BIBLIOGRAPHY OF RESEARCH RESULTS

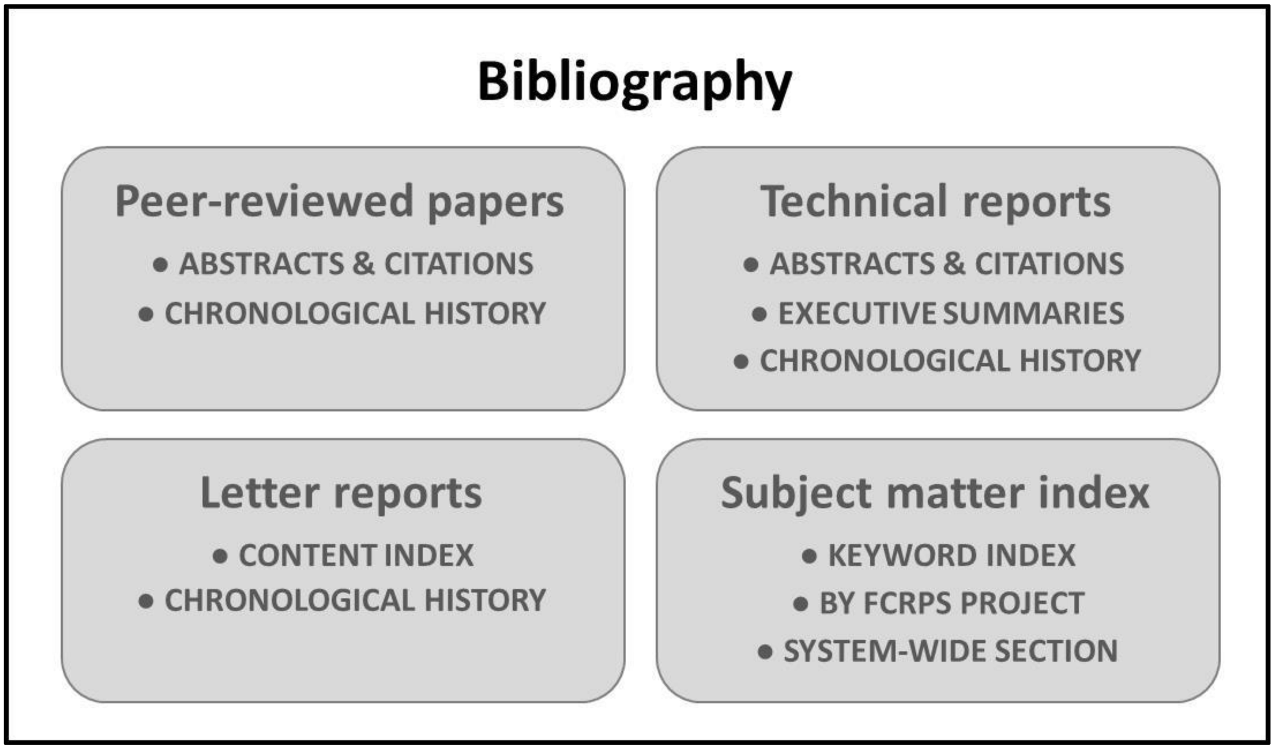

Figure 30. Schematic of the adult salmon and steelhead reporting summarized in this section

5.1 PEER-REVIEWED PAPER ABSTRACTS

Influence of fishway placement on fallback of adult salmon at the Bonneville Dam on the Columbia River

Reischel, Bjornn **N Am J Fish Manag 23:1215-1224 (2003)**

Abstract: Using radiotelemetry, we observed and quantified the behavior of upstream migrating adult Chinook salmon *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka* exiting the Bradford Island fishway at the Bonneville Dam on the Columbia River in 1997 and 1998. Nearly all of the fish that exited the fishway migrated upstream along the Bradford Island shoreline. Those fish that took the route nearest to the spillway were most likely to fall back over the spillway. From 14.5% to 21.3% of the fish tracked along the Bradford Island shore fell back over the spillway of the dam. The combined effects of spill, water temperature, and Secchi disk visibility were associated with route patterns and fallback behavior during each year. High spill was significantly and positively correlated with fallback behavior for Chinook salmon in 1998. Most of the fish we tracked that fell back reascended the fishway and migrated upstream (≥95% in 1997; ≥70% in 1998). We suggest that modifying the configuration of this fishway's exit would decrease the proportion of fish that fall back, perhaps reduce the risk of injury and fatigue, and improve the precision of counts of fish migrating upstream.

Fallback, reascension, and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake River dams

Boggs, Keefer, Peery, Bjornn, Stuehrenberg Trans Am Fish Soc 133:932-949 (2004)

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

Hydrosystem, dam, and reservoir passage rates of adult Chinook salmon and steelhead in the Columbia and Snake rivers

Keefer, Peery, Bjornn, Jepson, Stuehrenberg Trans Am Fish Soc 133:1413-1439 (2004)

Abstract: We assessed upstream migration rates of more than 12,000 radio-tagged adult Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* past a series of dams and reservoirs on the Columbia and Snake rivers. Most fish passed each dam in less than 2 d. Migration behavior in reservoirs and through multiple dam–reservoir reaches varied within and between years and between species. Within years, spring–summer Chinook salmon migrated more rapidly as water temperature and date of migration increased; between years, spring–summer Chinook salmon migrated fastest in low-discharge years. Steelhead migrations slowed dramatically when summer water temperatures peaked within each year, then increased as rivers cooled in fall. Mean summer temperatures explained more between-year variation in steelhead passage rates than did differences in discharge. Fall Chinook salmon migration rates also slowed during periods of warm water. Protracted passage times within the hydrosystem were most likely for fish from all runs that fell back over and reascended dams and for steelhead that sought thermal refugia by straying temporarily into coldwater tributaries.

Regurgitation rates of intragastric radio transmitters by adult Chinook salmon and steelhead during upstream migration in the Columbia and Snake rivers

Keefer, Peery, Ringe, Bjornn N Am J Fish Manag 24:47-54 (2004)

Abstract: Regurgitation rates for radio tags gastrically implanted into adult salmon *Oncorhynchus* spp. and steelhead *O. mykiss* are difficult to estimate in the wild because most fish are never recaptured to allow inspection of secondary tags. During 1996–2000, 9,006 Chinook salmon *O. tshawytscha* and steelhead with both radio tags and secondary tags were released near Bonneville Dam on the Columbia River (Washington–Oregon), and 1,764 fish were recaptured in midmigration 460 km upstream on the lower Snake River. Minimum annual regurgitation rates ranged from 0.4% to 10.9% for spring–summer Chinook salmon (pooled rate 5 3.0%; *n* = 838), from 3.5% to 4.3% for steelhead (pooled rate 5 4.0%; *n* = 881), and from 0% to 5.6% for fall Chinook salmon (pooled rate 5 2.2%; *n* = 45). Fish that lost transmitters retained them a median of 7 d (average = 14.1 d) before regurgitation, and a majority of losses occurred in the lower Columbia River. Transmitter retention was improved by placing rubber bands or a ring of surgical tubing around part of each tag.

Stock-specific migration timing of adult spring-summer Chinook salmon in the Columbia River basin

Keefer, Peery, Jepson, Tolotti, Bjornn, Stuehrenberg N Am J Fish Manag 24:1145-1162 (2004)

Abstract: An understanding of the migration timing patterns of Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* is important for managing complex mixed-stock fisheries and preserving genetic and life history diversity. We examined adult return timing for 3,317 radio-tagged fish from 38 stocks of Columbia River basin spring–summer Chinook salmon *O. tshawytscha* over 5 years. Stock composition varied widely within and between years depending on the strength of influential populations. Most individual stocks migrated at similar times each year relative to overall runs, supporting the hypotheses that run timing is predictable, is at least partially due to genetic adaptation, and can be used to differentiate between some conspecific populations. Arrival timing of both aggregated radio-tagged stocks and annual runs was strongly correlated with river discharge; stocks arrived earlier at Bonneville Dam and at upstream dams in years with low discharge. Migration timing analyses identified many between-stock and between-year differences in anadromous salmonid return behavior and should aid managers interested in protection and recovery of evolutionarily significant populations.

Upstream migration rates of radio-tagged adult Chinook salmon in riverine habitats of the Columbia River basin

Keefer, Peery, Jepson, Stuehrenberg J Fish Biol 65:1126-1141 (2004)

Abstract: Upstream migration rates were assessed for 1801 radio-tagged adult spring–summer Chinook salmon *Oncorhynchus tshawytscha* through 12 unimpounded river reaches in the Columbia River basin from1997 to 2002. Reaches were 36 to 241 km long (mean=130 km) and included sections of the large Columbia and Snake Rivers and smaller free-flowing tributaries. Median Chinook salmon migration rates ranged from <10 km day^{-1} in the Deschutes and Clearwater Rivers to >35 km day^{-1} in the Columbia and Snake Rivers. Using multivariate analyses, migration date explained the most variance in Chinook salmon migration rates while river discharge, migration year and migration reach were secondary. Both within and between years, Chinook salmon migrated more rapidly as migration date increased and more slowly when discharge was high. Arrival at high elevation spawning grounds at appropriate times and increased metabolic activity and reproductive maturation may explain the greater power of migration date, relative to river discharge, in predicting migration rates of Columbia basin spring–summer Chinook salmon.

Escapement, harvest, and unknown loss of radio-tagged adult salmonids in the Columbia River-Snake River hydrosystem
Keefer, Peery, Daigle, Jepson, Lee, Boggs, Tolotti, Burke
Can J Fish Aquat Sci 62:930-949 (2005)

Abstract: Accurate estimates of escapement by adult anadromous salmonids are difficult, especially in large, multistock river systems. We used radiotelemetry and a fishery reward program to calculate escapement, harvest, and unaccounted for loss rates for 10 498 adult chinook salmon (*Oncorhynchus tshawytscha*) and 5324 steelhead (*Oncorhynchus mykiss*) during six return years in the Columbia River basin. Mean annual escapements to spawning sites, hatcheries, or the upper bounds of the monitored hydrosystem were 73.4% (spring–summer Chinook salmon), 61.3% (fall Chinook salmon), and 62.6% (steelhead). Mean reported harvest rates were 8.7% (spring–summer chinook), 22.0% (fall chinook), and 15.1% (steelhead) within the mainstem hydrosystem and 5.9%, 3.4%, and 5.7%, respectively, in lower hydrosystem tributaries. On average, 12%–17% of each run had unknown fates in the mainstem hydrosystem. Escapement, harvest, and loss varied significantly between runs and years, within runs between known-origin subbasin stocks, and between interdam river reaches. Multiyear quantitative assessments like this can reduce uncertainty, clarify inter- and intra-annual variability, and help managers better evaluate fisheries, identify conservation priorities, and help protect evolutionarily significant populations.

Late-season mortality during migration of radio-tagged adult sockeye salmon (Oncorhynchus nerka) in the Columbia River
Naughton, Caudill, Keefer, Bjornn, Stuehrenberg, Peery Can J Fish Aquat Sci 62:30-47 (2005)

Abstract: We radio-tagged 577 adult sockeye salmon (*Oncorhynchus nerka*) returning to the Columbia River in 1997 to determine how migration behaviors were related to migration success in an altered river system. The probability of successful migration declined dramatically for late-entry individuals, concomitant with declines in discharge and the onset of stressful temperatures. Long dam passage times were not related to unsuccessful migration at most dams. However, when migration histories were analyzed across multiple dams or reservoirs, relatively slow migration was significantly associated with unsuccessful migration, suggesting potential cumulative effects. Median passage times at dams were rapid (7.9–33.4 h), although 0.2%–8% of salmon took more than 5 days to pass. Reservoir passage was also rapid, averaging 36.8–61.3 km$\cdot$day^{-1}, and appeared to compensate for slowed migration at dams. Rates observed in the unimpounded Hanford Reach suggest that total predam migration rates may have been similar to current rates. Overall, our results suggest that cumulative effects may be more important than negative effects of passage at single dams and that hydrosystem alteration of temperature regimes in the migration corridor may have an important indirect negative impact on adults.

Migration depths of adult spring and summer Chinook salmon in the lower Columbia and Snake rivers in relation to dissolved gas supersaturation
Johnson, Clabough, Bennett, Bjornn, Peery, Caudill, Stuehrenberg
Trans Am Fish Soc 134:1231-1227 (2005)

Abstract: High spill volume at dams can create supersaturated dissolved gas conditions that may have negative effects on fish. Water spilling over Columbia and Snake River dams during the spring and summer creates plumes with high dissolved gas that extend downstream of dam spillways and throughout reservoirs and creates gas-supersaturated conditions throughout the water column. During the spring and summer of 2000, 228 adult Chinook salmon *Oncorhynchus tshawytscha* were tagged at Bonneville Dam

with archival radio data storage transmitters (RDSTs) that recorded depth and water temperature as the fish migrated through dams and reservoirs of the lower Columbia and Snake rivers. Swimming depths from 131 of the 228 adult spring and summer Chinook salmon tagged with RDSTs were used to estimate the potential for gas bubble formation given in-river dissolved gas concentrations and hydrostatic compensation. We found that adult spring and summer Chinook salmon spent a majority of the time at depths that would have provided adequate hydrostatic compensation for in-river dissolved gas conditions during this study, which were at or slightly below long-term averages. Adult spring and summer Chinook salmon spent a majority of their time at depths deeper than 2 m, interspersed with periods lasting minutes at depths shallower than 2 m. Statistical associations were weak between the percent and duration of time fish occupied depths near the surface and dissolved gas concentrations, suggesting a lack of behavioral avoidance. Collectively, these data suggest little potential for negative effects of gas supersaturation on adult spring and summer Chinook salmon under average river conditions, despite the fact that fish tissues were probably supersaturated with dissolved gases. However, additional research over a broader range of dissolved gas conditions is needed to confirm that short, but frequent, exposure to conditions conducive to gas bubble formation does not affect survival and reproductive potential.

Performance of passive integrated transponder tags and radio tags in determining dam passage behavior of adult Chinook salmon and steelhead

Burke, Jepson **N Am J Fish Manag 26:742-752 (2006)**

Abstract: Passage of adult Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* at dams in the Columbia River basin has historically been determined by visual fish counts and radiotelemetry. Increasingly, however, passive integrated transponder (PIT) tags are being used for adult salmonid research and monitoring. Although both radiotelemetry and PIT tag technology provide accurate and cost-effective data under certain circumstances, neither alone meets all needs, and managers need to understand the strengths, weaknesses, and biases of each method. To evaluate the two tagging methods, we tagged over 3,200 adult Chinook salmon *O. tshawytscha* and steelhead during 2002 and 2003 with both a radio transmitter and a PIT tag as the fish migrated upstream past Bonneville Dam. We compared their performance in measuring upstream passage and fallback (i.e., downstream passage) behavior at each of four main-stem hydropower dams. Counts of fish passage at dams based on data from double-tagged fish were similar between methods (largest difference was 5.1%), but the two methods produced less consistent results for fallback behavior. Visual count escapement estimates based on PIT tags were 1% higher on average than those based on radio tags, suggesting there would be little impact on the management of salmonid populations with a switch from radiotelemetry to PIT tag systems as the primary data source. We also analyzed a broader group of PIT-tagged (but not radiotagged) fish to simulate the analysis one could expect from PIT tag data without radiotelemetry validation. When compared with PIT tag data from double-tagged fish, data from the PIT tag-only fish showed slight differences in the timing of peak passage. These differences were due, at least in part, to the fact that the fish in each group comprised differing proportions of fish from multiple populations, highlighting the importance of having representative stocks of fish PIT-tagged as juveniles.

Route selection in a large river during the homing migration of Chinook salmon (*Oncorhynchus tshawytscha*)

Keefer, Caudill, Peery, Bjornn **Can J Fish Aquat Sci 63:1752-1762 (2006)**

Abstract: Upstream migrating adult salmon must make a series of correct navigation and route-selection decisions to successfully locate natal streams. In this field study, we examined factors influencing migration route selections early in the migration of 4361 radio-tagged adult chinook salmon

(*Oncorhynchus tshawytscha*) as they moved upstream past dams in the large (~1 km wide) Columbia River. Substantial behavioral differences were observed among eleven conspecific populations, despite largely concurrent migrations. At dams, Chinook salmon generally preferred ladder passage routes adjacent to the shoreline where their natal tributaries entered, and the degree of preference increased as salmon proximity to natal tributaries increased. Columbia River discharge also influenced route choices, explaining some route selection variability. We suggest that salmon detect lateral gradients in orientation cues across the Columbia River channel that are entrained within tributary plumes, and that these gradients in cues can persist downstream for 10-100s of km. Detection of tributary plumes in large river systems, using olfactory or other navigation cues, may facilitate efficient route selection and optimize energy conservation by long-distance migrants.

Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures
Goniea, Keefer, Bjornn, Peery, Bennett, Stuehrenberg
Trans Am Fish Soc 135:408-419 (2006)

Abstract: The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon *Oncorhynchus tshawytscha* were studied using historical counts at dams and recently collected radiotelemetry data. The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000–2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about 20°C. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2–7°C cooler than the main stem. The proportion of radio-tagged salmon using tributaries increased exponentially as Columbia River temperatures rose within the year, and use was highest in the warmest years. The historical passage data showed significant shifts in fall Chinook salmon run timing distributions concomitant with Columbia River warming and consistent with increasing use of thermal refugia. Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants.

Fallback by adult sockeye salmon at Columbia River dams
Naughton, Caudill, Keefer, Bjornn, Peery, Stuehrenberg
N Am J Fish Manag 26:380-390 (2006)

Abstract: We implanted radio transmitters into sockeye salmon *Oncorhynchus nerka* in 1997 to determine the (1) fallback percentage and rate at eight Columbia River dams, (2) effect of fallback on adult counts at each dam, (3) relations between spillway discharge and fallback, (4) relations between injuries and fallback, and (5) relations of fallback and survival to spawning tributaries. The rate of fallback, that is, the total number of fallback events at a dam divided by the number of fish known to have passed the dam, ranged from 1.9% to 13.7% at the eight dams. The rate of fallback was highest at Bonneville Dam, the dam with the most complex fishway. Fallback produced overcounts of 2% to 7% at most dams. Fallback was weakly related to spill volume at Bonneville Dam. Significantly more sockeye salmon with head injuries fell back than fish without head injuries. About 40% of the sockeye salmon had injuries from marine mammals, but these injuries were not associated with the rate of fallback. The rate of survival was similar between fish that fell back (68.0%) and fish that did not fall back (67.5%). We suggest that fisheries managers adjust counts for fallback but note that these relationships were obtained

under high-discharge conditions. We conclude that fallback biases dam counts and that the relationship between spawning success and fallback should be an area of future research.

Temporary staging of Columbia River summer steelhead in coolwater areas and its effects on migration rates

High, Peery, Bennett **Trans Am Fish Soc 135:519-528 (2006)**

Abstract: We used radiotelemetry to evaluate the temporary staging of adult migrating steelhead *Oncorhynchus mykiss* into nonnatal tributary rivers of the Columbia River and to determine the effects of staging behavior on migration rate. By monitoring the movement patterns of 2,900 individual steelhead over 3 years (1996, 1997, and 2000), we determined that an average of 61% of the steelhead destined for upstream areas temporarily staged in one or more tributaries in the lower Columbia River for durations from less than 1 h to 237 d. Median residence time varied significantly by tributary used and year and, based on canonical correlation analysis, was correlated with main-stem Columbia River water temperature. Steelhead that temporarily staged in tributary rivers migrated through the lower Columbia River significantly more slowly than steelhead that did not use tributaries. Use of coolwater tributaries as thermal refugia during warm summertime conditions significantly influences the migratory behavior of Columbia River adult steelhead. Our results highlight the need to preserve the water quality parameters of existing cooler-water Columbia River tributaries and to rehabilitate watersheds that historically maintained cooler-water tributaries as sources of thermal refugia for adult summer steelhead returning to the basin.

Long-distance downstream movements by homing adult Chinook salmon

Keefer, Peery, Caudill **J Fish Biol 68:944-950 (2006)**

Abstract: Unusually long downstream movements totaling several hundred kilometers to >1100 km were observed during upstream homing migrations of radio-tagged spring chinook salmon *Oncorhynchus tshawytscha* in the Columbia and Snake Rivers, U.S.A. Downstream migrants, identified by their repeated ascension and fallback over a series of large hydroelectric dams within the migration corridor, were primarily hatchery-origin males.

Slow dam passage in adult Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality?

Caudill, Daigle, Keefer, Boggs, Jepson, Burke, Zabel, Bjornn, Peery

Can J Fish Aquat Sci 64:979-995 (2007)

Abstract: The relationship among behavior, environment, and migration success in anadromous fishes are poorly understood. We monitoring migration behavior at eight Columbia and Snake river dams for 18 286 adult Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (sea-run *Oncorhynchus mykiss*) over 7 years using radiotelemetry. When statistically controlling for variation in flow, temperature, fisheries take, and other environmental variables, we observed that unsuccessful individuals – those not observed to reach spawning areas – had longer passage times at nearly all dams than fish that eventually reached tributaries. In many cases, times were also longer for unsuccessful adults passing through a multiple-dam reach. Four ecological mechanisms may have contributed to these patterns: (*i*) environmental factors not accounted for in the analyses; (*ii*) inefficient responses by some fish to passage conditions at dams that resulted in slowed passage, energetic depletion, and unsuccessful migration; (*iii*) ongoing selection for traits needed to pass obstructions; and (or) (*iv*) passage rate was not directly linked to migration success, but rather, both resulted from relatively poor phenotypic condition upon river entry in unsuccessful migrants. Overall, these results illustrate the need for a mechanistic understanding of the factors that influence migration success and the need for fitness-based criteria to assess the effects of dam on anadromous fishes.

Estimating adult Chinook salmon exposure to dissolved gas supersaturation downstream of hydroelectric dams using telemetry and hydrodynamic models

Johnson, Clabough, Peery, Bennett, Bjornn, Caudill, Richmond

Riv Res App 23:963-978 (2007)

Abstract: Gas bubble disease (GBD) has been recognized as a potential problem for fishes in the Columbia River basin. GBD results from exposure to gas supersaturated water created by discharge over dam spillways. Spill creates a downstream plume of water with high total dissolved gas supersaturation (TDGS) that may be positioned along either shore or mid-channel, depending on dam operations. We obtained spatial data on fish migration paths and migration depths for adult spring and summer Chinook salmon, *Oncorhynchus tshawytscha*, during 2000. Migration paths were compared to output from a two-dimensional (2-dimensional) hydrodynamic and dissolved gas model to estimate the potential for GBD expression and to test for behavioural avoidance of the high TDGS plume. We observed salmon swam sufficiently deep in the water column to receive complete hydrostatic compensation 95.9% of the time spent in the Bonneville Dam tailrace and 88.1% of the time in the Ice Harbor Dam tailrace. The majority of depth uncompensated exposure occurred at TDGS levels >115%. Adult Chinook salmon tended to migrate near the shoreline and they tended to remain in relatively deep water. Adults moved into the high dissolved-gas plume as often as they moved out of it downstream of Bonneville Dam, providing no evidence that adults moved laterally to avoid areas with elevated dissolved gas levels. When water depths decreased due to reduced river discharge, adults tended to migrate in the deeper navigation channel downstream from Ice Harbor Dam. The strong influence of dam operations on the position of the high-TDGS plume and shoreline-orientation behaviours of adults suggest that exposure of adult salmonids to high-TDGS conditions may be minimized using operational conditions that direct the spilled water mid-channel. Our approach illustrates the potential for combined field and modelling efforts to estimate the fine-scale environmental conditions encountered by fishes in natural and regulated rivers.

Experimental evaluation of fishway modifications on the passage behaviour of adult Chinook salmon and steelhead at Lower Granite Dam, Snake River, USA

Naughton, Caudill, Peery, Clabough, Jepson, Bjornn, Stuehrenberg Riv Res App 23:99-111 (2007)

Abstract: Previous studies of Pacific salmonid passage over Snake River dams indicated slowed passage at transition pools, the transition area between the fishway entrance and the fish ladder. In 2001 and 2002, we conducted an experiment to determine if modified weirs affected adult salmon and steelhead passage times and route selection through the Lower Granite Dam transition pool. Fish attraction flows through the lower ladder weirs were experimentally increased using removable panels. During the experiment we monitored radio-tagged adult Chinook salmon and steelhead to determine passage routes and times through the transition pool. The weir treatment increased the number of spring–summer Chinook salmon passing straight through the transition pool compared to those exiting the transition pool to the collection channel or tailrace. Mean passage times through the transition pool differed among routes and were significantly lower during treatment periods for the exit-to-collection channel route in spring-summer Chinook salmon, but not for other routes. Passage times among routes differed in steelhead, but there was no evidence of treatment effects on route use or passage time. Fall Chinook exhibited similar trends in route use and passage time to spring–summer Chinook, but differences were not significant, perhaps because of relatively small sample size. Total dam passage times did not differ by treatment or route for any run. Fish depth during passage of the transition pool suggested that most fish passed through submerged orifices and supported the hypothesis that increased water velocity through these orifices caused the increase in straight-through passage in spring–summer Chinook. Collectively, the results suggested the weir modifications provided improvement to passage through the transition pool for spring–summer Chinook and no evidence of negative effects on other runs. The results from this study were used to develop new design criteria and modifications of the Lower Granite Dam fishway.

Transporting juvenile salmonids around dams impairs adult migration

Keefer, Caudill, Peery, Lee **Ecol App 18:1888-1900 (2008)**

Abstract: Mitigation and ecosystem-restoration efforts may have unintended consequences on both target and nontarget populations. Important effects can be displaced in space and time, making them difficult to detect without monitoring at appropriate scales. Here, we examined the effects of a mitigation program for juvenile salmonids on subsequent adult migration behaviors and survival. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) were collected and uniquely tagged with passive integrated transponder (PIT) tags at Lower Granite Dam (Washington State, USA) on the Snake River and were then either transported downstream in barges in an effort to reduce out-migration mortality or returned to the river as a control group. Returning adults were collected and radio-tagged at Bonneville Dam (Washington–Oregon, USA) on the Columbia River 1–3 years later and then monitored during ;460 km of their homing migrations. The proportion of adults successfully homing was significantly lower, and unaccounted loss and permanent straying into non-natal rivers was higher, for barged fish of both species. On average, barged fish homed to Lower Granite Dam at rates about 10% lower than for in-river migrants. Barged fish were also 1.7– 3.4 times more likely than in-river fish to fall back downstream past dams as adults, a behavior strongly associated with lower survival. These results suggest that juvenile transport impaired adult orientation or homing abilities, perhaps by disrupting sequential imprinting processes during juvenile out-migration. While juvenile transportation has clear short-term juvenile survival benefits, the delayed effects that manifest in adult stages illustrate the need to assess mitigation success throughout the life cycle of target organisms, i.e., the use of fitness-based measures. In the case of Snake River salmonids listed under the Endangered Species Act, the increased straying and potential associated genetic and demographic effects may represent significant risks to successful recovery for both target and nontarget populations.

Migration timing of Columbia River spring Chinook salmon: effects of temperature, river discharge, and ocean environment

Keefer, Peery, Caudill **Trans Am Fish Soc 137:1120-1133 (2008)**

Abstract: In an effort to improve run timing forecasts for Columbia River spring Chinook salmon *Oncorhynchus tshawytscha*, we examined relationships among regional ocean climate indices, in-river environmental conditions, and full run and stock-specific migration timing metrics. Results consistently indicated that adult Chinook salmon arrived earliest in years with low river discharge or warm water temperatures and arrived latest in years of cold water temperatures and high flows. As single predictors, in-river conditions generally explained more interannual variability in salmon return timing than did air temperature, the Pacific Decadal Oscillation, or the North Pacific Index. However, best-fit multiple-regression models included a combination of in-river and climate predictors. While spatial and temporal scales of the analyses were relatively coarse (i.e., monthly values were used for all predictors), clear patterns emerged that can be used to improve pre- and in-season run timing forecasting models for Columbia River spring Chinook salmon. We recommend continued refinement of climate-based and environmental predictive tools to help manage anadromous fish stocks, including the threatened and endangered populations of the Columbia River basin.

Overwintering distribution, behavior, and survival of adult summer steelhead: variability among Columbia River populations

Keefer, Boggs, Peery, Caudill **N Am J Fish Manag 28:81-96 (2008)**

Abstract: Unlike most anadromous salmonids, summer steelhead *Oncorhynchus mykiss* overwinter in rivers rather than the ocean for 6–10 months prior to spring spawning. Overwintering in rivers may make summer steelhead more vulnerable to harvest and other mortality sources than are other anadromous populations, but there has been little systematic study of this life history strategy. Here, we used a large-scale radiotelemetry study to examine the overwintering behaviors and distributions of 26 summer steelhead stocks within the regulated lower Columbia–Snake River hydrosystem. Over 6 years, we monitored 5,939 fish, of which 3,399 successfully reached spawning tributaries or the upper Columbia River basin and were assigned to specific populations. An estimated 12.4% of fish that reached spawning areas overwintered at least partially within the hydrosystem (annual estimates = 6.8–19.6%), while the remainder overwintered in tributaries. Across all populations, later-arriving fish were more likely to overwinter in the hydrosystem; overwintering percentages ranged from less than 1% for fish tagged in June to over 40% for those tagged in October. Proportionately more interior-basin steelhead (Clearwater, Salmon, and Snake River metapopulations) overwintered in the hydrosystem than did fish from lower-river populations. Steelhead were distributed in mixed-stock assemblages throughout the hydrosystem during winter, usually in reservoirs closest to their home rivers but also in nonnatal tributaries. Overwintering fish moved upstream and downstream between reaches in all months; a nadir occurred in early January and peak egress into spawning tributaries was in March. The estimated survival to tributaries was higher for fish that overwintered in the hydrosystem (82%) than for fish that did not (62%); this difference was largely attributable to low winter harvest rates. Our results suggest that large main-stem habitats, including reservoirs, may be widely used by overwintering summer steelhead. The complex migration behaviors of steelhead indicate both the potential for adaptation and possible susceptibility to future river environment changes.

Non-direct homing behaviors of adult Chinook salmon in a large, multi-stock river system

Keefer, Caudill, Peery, Boggs **J Fish Biol 72:27-44 (2008)**

Abstract: Two non-direct homing behaviours, overshoot of natal tributaries and temporary non-natal tributary use, were evaluated for 5150 radio-tagged spring–summer Chinook salmon Oncorhynchus tshawytscha from 40 populations in the large Columbia River system. Over 7 years, 2–44% (mean = 15%) of individuals within each group temporarily entered presumed non-natal tributaries. In addition, many Chinook salmon from lower river tributaries initially travelled 3 to >250 km upstream in the main-stem river beyond confluences with presumed natal tributaries before returning to the natal sites (‘overshoot’). Both overshoot and temporary tributary use behaviours declined exponentially with increasing distance from the natal tributary. Nondirect homing also increased later in the season as water temperatures rose and was associated with hatchery origin in some cases. The behaviours may reflect a mix of active searching for olfactory cues from natal sites, behavioural thermoregulation and orientation challenges in a large-river migration corridor transformed by dams and reservoirs. While anadromous salmonid homing is generally accurate and precise, these results indicate that route finding can be non-direct, potentially increasing energetic costs and harvest risks during migration.

Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (*Oncorhynchus mykiss*): variability among sympatric populations

Keefer, Peery, High **Can J Fish Aquat Sci 66:1734-1747 (2009)**

Abstract: We used radiotelemetry to assess thermoregulatory behaviors for 14 populations (*n* = 3985) of adult summer steelhead (*Oncorhynchus mykiss*) as they passed through the Columbia River migration corridor. Steelhead use of small cool-water tributaries (‘‘thermal refugia’’) rapidly increased when the Columbia River reached a temperature threshold of about 19 °C. When main stem temperatures were warmest (i.e., >21 °C), more than 70% of the tagged fish used refugia sites and these fish had median refugia residence times of 3–4 weeks. Thermoregulatory responses were similar across populations, but there were large among-population differences in the incidence and duration of refugia use likely linked to population-specific migration timing patterns. In survival analyses using 1285 known-origin steelhead, fish that used thermal refugia were significantly less likely to survive to natal basins, were harvested at relatively high rates in refugia tributaries, and had greater unknown mortality in the main stem. These results highlight the trade-off between the presumed physiological benefits of thermal refugia use and a likely increase in harvest and other mortality risks that arise when preferred thermal habitats are severely constricted.

Population composition, migration timing, and harvest of Columbia River Chinook salmon in late summer and fall

Jepson, Keefer, Naughton, Peery, Burke **N Am J Fish Manag 30:72-88 (2010)**

Abstract: We used radiotelemetry to evaluate population composition, run timing, and reservoir harvest patterns for adult Columbia River fall-run Chinook salmon *Oncorhynchus tshawytscha*. Chinook salmon (n = 5,886) were collected at Bonneville Dam during August–October over 7 years. We selected for upriver bright (URB) populations en route to interior basin spawning sites because these groups are priority populations for both fisheries and conservation efforts. Run composition varied within and among years, but in all years a relatively large percentage of the earliest migrants returned to upper Columbia River sites and the majority of late-run fish returned to the Columbia River Hanford Reach. Deschutes, Yakima, and Snake River populations typically constituted small (≤17%) but relatively constant proportions of the run throughout each migration season. Population-specific migration timing distributions indicated modest but persistent timing differences among populations, particularly for Hanford Reach and upper Columbia River populations. Annual reported reservoir harvest estimates ranged from 12% to 26%. Harvest rates varied seasonally within years, from relatively low mean rates (≤11%) for fish tagged early and late in migrations to peak rates of over 25% for those tagged in late August and early September. These patterns suggest that it may be possible to increase harvest of abundant populations and reduce harvest of some vulnerable populations by adjusting the timing of fisheries. In addition, there was evidence that larger fish were harvested at higher rates and that mean fish size differed among populations. The combined results improve our understanding of the Columbia River URB fall Chinook salmon run and should help in refining harvest and escapement management plans.

Migration depths of adult steelhead *Oncorhynchus mykiss* in relation to dissolved gas supersaturation in a regulated river system

Johnson, Clabough, Caudill, Keefer, Peery **J Fish Biol 76:1520-1528 (2010)**

Abstract: We used radiotelemetry to evaluate population composition, run timing, and reservoir harvest patterns for adult Columbia River fall-run Chinook salmon *Oncorhynchus tshawytscha*. Chinook salmon (n = 5,886) were collected at Bonneville Dam during August–October over 7 years. We selected for upriver bright (URB) populations en route to interior basin spawning sites because these groups are priority populations for both fisheries and conservation efforts. Run composition varied within and among years, but in all years a relatively large percentage of the earliest migrants returned to upper Columbia River sites and the majority of late-run fish returned to the Columbia River Hanford Reach. Deschutes, Yakima, and Snake River populations typically constituted small (≤17%) but relatively constant proportions of the run throughout each migration season. Population-specific migration timing distributions indicated modest but persistent timing differences among populations, particularly for Hanford Reach and upper Columbia River populations. Annual reported reservoir harvest estimates ranged from 12% to 26%. Harvest rates varied seasonally within years, from relatively low mean rates (≤11%) for fish tagged early and late in migrations to peak rates of over 25% for those tagged in late August and early September. These patterns suggest that it may be possible to increase harvest of abundant populations and reduce harvest of some vulnerable populations by adjusting the timing of fisheries. In addition, there was evidence that larger fish were harvested at higher rates and that mean fish size differed among populations. The combined results improve our understanding of the Columbia River URB fall Chinook salmon run and should help in refining harvest and escapement management plans.

Influence of pinniped-caused injuries on the survival of adult Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) in the Columbia River basin

Naughton, Keefer, Clabough, Jepson, Lee, Peery, Caudill

Can J Fish Aquat Sci 68:1615-1624 (2011)

Abstract: Increasing pinniped abundance in the Pacific Northwest has coincided with population declines of Pacific salmon (*Oncorhynchus* spp.) and steelhead trout (*Oncorhynchus mykiss*), and concentrated predation may affect the recovery of some threatened and endangered salmonid stocks. We used radiotelemetry to evaluate pinniped-caused injury effects on migration survival of 17 007 adult Columbia River Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout. Injuries from pinnipeds were common (mean injury rate across 29 run-years = 36.5%) and were most common for spring Chinook salmon and steelhead trout. Injury was not consistently associated with adult survival to spawning tributaries, but some negative survival effects were detected. Pinniped-caused injury rates decreased as annual run sizes increased, indicating density dependent or saturation effects. Within a run, large fish generally had a higher injury incidence than small fish, suggesting pinnipeds targeted large fish or more efficiently captured small fish. Seasonal, size-dependent, and density-dependent results imply that pinniped effects likely differ widely among salmonid populations within the Columbia River basin. A better understanding of these effects is needed to guide management and conservation strategies.

Use of radiotelemetry and direct observations to evaluate sea lion predation on adult Pacific salmonids at Bonneville Dam

Keefer, Stansell, Tackley, Nagy, Gibbons, Peery, Caudill

Trans Am Fish Soc 141:1236-1251 (2012)

Abstract: Management of protected species becomes increasingly complex when one protected population negatively affects another. This occurs along coastlines and in rivers and estuaries of the U.S. Pacific Northwest, where protected marine mammals prey on threatened and endangered Pacific salmonids *Oncorhynchus* spp. Over 9 years, we observed a growing aggregation of California sea lions *Zalophus californianus* and Steller sea lions *Eumetopias jubatus* preying upon adult Chinook salmon *O. tshawytscha* and steelhead *O. mykiss* at Bonneville Dam on the Columbia River. Both before and concurrent with the observation study, we monitored radio-tagged salmon at Bonneville Dam and during their upriver spawning migrations. Springtime sea lion abundance steadily increased from 2002 to 2010 and the aggregation formed earlier each winter. The principal prey species in winter were resident white sturgeon *Acipenser transmontanus* and migratory steelhead and then shifted to predominantly Chinook salmon when the spring run arrived. Observation-based estimates of salmonid consumption from January to May varied 12-fold among years (0.4–4.9%, mean = 2.6% of adult salmonids counted at the dam), and radiotelemetry results corroborated these estimates. The highest proportional impact was in winter and early spring. As salmonid abundance increased, per capita consumption by sea lions increased (Type II functional response) but individual salmonid risk decreased (due to prey swamping). Population-specific risk analyses indicated predation was substantially higher for early-timed than for late-timed salmon populations. The most at-risk group included Snake River and upper Columbia River Chinook salmon listed as threatened under the U.S. Endangered Species Act. These predation indices should help managers simultaneously tasked with salmon recovery and marine mammal management.

Population-specific escapement of Columbia River fall Chinook salmon: tradeoffs among estimation techniques

Hyun, Keefer, Fryer, Jepson, Sharma, Caudill, Whiteaker, Naughton

Fisheries Res 129-130:82-93 (2012)

Abstract: In the multi-stock Columbia River system, managers estimate fall Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), escapements using various combinations of spawning ground surveys, harvest data and fish counts at dams and hatcheries. Our objectives were to improve upon the traditional methods, and to evaluate trade-offs among methods. Using data from radio-tagged (n = 4421) and PIT-tagged (n = 1950) adult salmon over eight years, we applied a mark-recapture method to estimate population-specific escapements, both aggregating data within year and stratifying them by week. Mark-recapture estimates differed between estimation techniques and from estimates generated using traditional methods. Stratifying data by week measured escapement estimate uncertainty more reasonably than aggregating data within year. Radiotelemetry provided better spatial resolution among populations for tributary spawners whereas PIT tags provided low-cost, easily replicated estimates using an existing detection system. Mark-recapture techniques had several advantages over current practices: quantifying uncertainty, transparent methods and reduced sensitivity to survey biases.

Context-dependent diel behavior of upstream-migrating anadromous fishes
Keefer, Caudill, Peery, Moser **Env Biol Fishes 96:691-700 (2013)**

Abstract: Variability is a hallmark of animal behavior and the degree of variability may fluctuate in response to environmental or biological gradients. For example, diel activity patterns during reproductive migrations often differ from those in non-breeding habitats, reflecting trade-offs among efficient route selection, reproductive phenology, and risk avoidance. In this study, we tested the hypothesis that diel movements of anadromous fishes differ among freshwater migration habitats. We analyzed diel movement data from ~13 000 radio-, PIT-, and acoustic-tagged adult fishes from five Columbia River species: Chinook salmon, *Oncorhynchus tshawytscha*; sockeye salmon, *O. nerka*; steelhead, *O. mykiss*; Pacific lamprey, *Entosphenus tridentatus*; and American shad, *Alosa sapidissima*. All five species were active during most of the diel cycle in low-gradient, less hydraulically complex reservoir and riverine habitats. Movement shifted to predominantly diurnal (salmonids and American shad) or nocturnal (Pacific lamprey) at hydroelectric dam fishways where hydraulic complexity and predator density were high. Results suggest that context-dependent behaviors are common during fish migrations, and that diel activity patterns vary with the degree of effort or predation risk required for movement.

Indirect effects of impoundment on migrating fish: temperature gradients in fish ladders slow adult dam passage by adult Chinook salmon and steelhead
Caudill, Keefer, Clabough, Naughton, Burke, Peery **PLoS1 8(12):e85586 (2013)**

Abstract: Thermal layering in reservoirs upstream from hydroelectric dams can create temperature gradients in fishways used by upstream migrating adults. In the Snake River, Washington, federally-protected adult salmonids (*Oncorhynchus* spp.) often encounter relatively cool water in dam tailraces and lower ladder sections and warmer water in the upstream portions of ladders. Using radiotelemetry, we examined relationships between fish passage behavior and the temperature difference between the top and bottom of ladders (ΔT) at four dams over four years. Some spring Chinook salmon (*O. tshawytscha*) experienced $\Delta T \geq 0.5$ °C. Many summer and fall Chinook salmon and summer steelhead (*O. mykiss*) experienced $\Delta T \geq 1.0$ °C, and some individuals encountered $\Delta T > 4.0$°C. As ΔT increased, migrants were consistently more likely to move down fish ladders and exit into dam tailraces, resulting in upstream passage delays that ranged from hours to days. Fish body temperatures equilibrated to ladder temperatures and often exceeded 20°C, indicating potential negative physiological and fitness effects. Collectively, the results suggest that gradients in fishway water temperatures present a migration obstacle to many anadromous migrants. Unfavorable temperature gradients may be common at reservoir-fed fish passage facilities, especially those with seasonal thermal layering or stratification. Understanding and managing thermal heterogeneity at such sites may be important for ensuring efficient upstream passage and minimizing stress for migratory, temperature-sensitive species.

Sea-to-sea survival of late-run adult steelhead (*Oncorhynchus mykiss*) from the Columbia and Snake rivers
Keefer, Jepson, Clabough, Johnson, Narum, Hess, Caudill **CJFAS: (2018)**

Abstract: We used biotelemetry and genetic stock identification to assess sea-to-sea survival and run composition of 1212 late-migrating adult steelhead (anadromous *Oncorhynchus mykiss*) through the Columbia River and Snake River migratory corridors. The late-run was predominated by steelhead from Idaho's Clearwater and Salmon rivers that must pass eight large hydroelectric dams during both pre-spawn and post-spawn migrations. In two years (2013 and 2014), pre-spawn survival to Snake River

tributaries (>500 km) was 0.48–0.67 for the most abundant populations and was higher for females and 1-sea fish. Annual survival from Snake River tributary entry to post-spawn kelt status was 0.14–0.17, with higher survival for females and those without hatchery fin clips. Kelt outmigration survival was 0.31–0.39 past four Snake River dams and 0.13–0.20 past all eight dams and was highest for smaller kelts. Full-cycle adult freshwater survival (sea-to-sea) including 16 dam passage events was 0.01–0.02. Younger steelhead and those without fin clips survived at the highest rates. This study uniquely partitioned mortality across prespawn, reproductive, and kelt life history stages and informs management strategies for this conservation-priority metapopulation.

5.2 TECHNICAL REPORT ABSTRACTS AND EXECUTIVE SUMMARIES

Evaluation of adult Chinook salmon passage at Priest Rapids Dam with orifice gates open and closed

Bjornn, Jepson, Peery, Tolotti **Technical Report 1996-1**

Abstract: Radio-tagged adult spring and summer Chinook salmon were monitored to evaluate passage condition at Priest Rapids Dam, mid-Columbia River, during 1996. Passage times were assessed during two treatment conditions: half the powerhouse orifice gates open and all orifice gates closed. Travel times from first record in the tailrace to first approach at the dam, to first entry into the fishway, first entry to the junction pool, and to pass the dam were not significantly different with respect to orifice gate closure. Of 119 radio-tagged Chinook salmon monitored at Priest Rapids Dam, 115 salmon eventually crossed the dam. Salmon entered the fishway collection channel mainly at the east-shore and west-powerhouse entrances. There were more entries than exits at the east entrance, but more exits than entries at the west-powerhouse openings. Half the radio-tagged Chinook salmon passed Priest Rapids Dam in less than 37.6 h. About one-third of time to pass the dam was associated with movements in and out of the junction pool area. After entering the junction pool for the first time, most (79%) fish returned to the collection channel and then exited and re-entered the fishway an average of 6.5 times before successfully crossing the dam. Six fish fell back over the dam during this study, for a fallback rate of 5.2%. Four fish re-ascended the dam in an average of 9.8 days.

Evaluation of adult Chinook and sockeye salmon passage at Priest Rapids and Wanapum dams – 1997

Peery, Bjornn, Tolotti **Technical Report 1998-5**

Abstract: Radio-tagged adult spring and summer Chinook salmon Oncorhynchus tshawytscha and sockeye salmon O. nerka were monitored to evaluate passage conditions at Priest Rapids and Wanapum dams, mid-Columbia River, during 1997. Passage conditions were assessed during two treatment conditions: half the powerhouse orifice gates open and all orifice gates closed. Six travel time variables were analyzed using ANOVA analysis and two non-parametric tests. We concluded that closing orifice gates at Priest Rapids and Wanapum dams did not have a significant effect on passage of Chinook and sockeye salmon in 1997. Chinook and sockeye salmon passed through the Hanford Reach section of the Columbia River in 2 to 3 d. Of 217 Chinook salmon that reached Priest Rapids Dam, 199 eventually passed the dam, in 37.6 h, and reached Wanapum Dam. One hundred and ninety Chinook salmon are known to have crossed Wanapum Dam in 20.1 h. Of 440 sockeye salmon that reached Priest Rapids Dam, 427 eventually crossed the dam, in 18.6 h, and reached Wanapum Dam. Four hundred and nine sockeye

salmon are known to have crossed Wanapum Dam in 29.7 h. A prototype fishway fence installed inside the west-powerhouse entrance (Lew2) at Priest Rapids Dam was not effective at reducing the number of salmon that exited from the fishway at that point. Salmon were not held up at the fish counting station in the east-shore ladder at Priest Rapids Dam. However, passage times were about three times longer to pass the coded-wire-tag trap near the top of the ladder when the trap was operating as compared to the same section of ladder when the trap was not operating, resulting in median delays 42 min for Chinook salmon and 2.1 h for sockeye salmon. Salmon used the new vertical-slot gate placed at the west-shore fishway entrance (Rew2) as readily as the two other main entrances (Se2 and Se3) at Wanapum Dam. Six (3.0%) Chinook salmon and 16 (3.9%) sockeye salmon fell back at Priest Rapids Dam. Five Chinook salmon and 15 sockeye salmon eventually re-crossed Priest Rapids Dam after an average delay of about 26 h. Eight (4.1%) Chinook salmon and 19 (4.5%) sockeye salmon fell back at Wanapum Dam. Seven Chinook salmon and 12 sockeye salmon eventually re-crossed Wanapum Dam after average delays of about 42 to 48 h.

Radio telemetry assessments of migration patterns and fallbacks of adult salmon and steelhead in the forebay of Bonneville Dam, 1997-1998

Bjornn, Reischel, Ringe, Tolotti, Stuehrenberg **Technical Report 1999-1**

Abstract: Migration routes of adult spring and summer Chinook *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka*, and steelhead *O. mykiss* were monitored in the forebay of Bonneville Dam in 1997 to obtain information that could be used to reduce fallback of adults at the dam. Adult spring and summer Chinook salmon were also radio-tracked in 1998 as a continuation of the 1997 study. In 1996, we determined in the adult passage studies that significant numbers of Chinook salmon fell back over Bonneville Dam, and that most of the fallbacks were fish that had passed the dam via the Bradford Island fishway. In 1997, 991 adult spring and summer Chinook salmon, 577 sockeye salmon, and 975 steelhead were trapped at Bonneville Dam, outfitted with radio transmitters, and released downstream from the dam. In 1998, adult spring/summer (957 fish) and fall Chinook salmon (1022 fish) were trapped, tagged and released downstream from Bonneville Dam, but only a sample of the spring/summer Chinook salmon were tracked in the forebay. As the fish with transmitters reascended the dam and exited the Bradford Island fishway into the forebay, they were followed by boat to determine their route through the forebay of powerhouse I and on upstream. We were particularly interested in routes that led to fallbacks at the dam. Because of high flows in 1997, there was an extended period of forced spill that lasted into July. During the April-July period, 122 spring/summer Chinook salmon, 110 sockeye salmon, and 10 steelhead in 1997, and 129 adult spring/summer Chinook in 1998 were tracked in the forebay of Bonneville Dam.

In 1997 and 1998, radio tracked adult salmon and steelhead moved along four migrations routes after leaving the Bradford Island fishway: 1) along the south shore of Bradford Island to the spillway (90 fish in 1997 with 43 fallbacks; 39 fish in 1998 with 20 fallbacks), 2) along the shore of Bradford Island then across the forebay of the spillway to the Washington shore (56 fish; 60 fish), 3) along Bradford Island to the upstream end then across to the Oregon shore (71 fish; 19 fish), and 4) across the powerhouse φ forebay to the Oregon shore and then upstream (16 fish; 8 fish). Twenty-one percent (26 of 122 fish) of the Chinook salmon and 14% (16 of 110) of the sockeye salmon tracked in 1997 fell back over Bonneville Dam. In 1998, 15% (20 of 129) of the Chinook salmon tracked fell back at the dam.

Mean migration time for all species combined (n=126) from the Bradford Island fishway exit upstream to the receiver at the Bridge of the Gods in 1997 was 0.41 d, with a range of 0.03 to 8.01 d, and a median travel time of 0.08 d. Mean times for each species to pass the Bridge of the Gods were 0.42 d for steelhead (8 fish), 0.62 d for Chinook salmon (59 fish), and 0.19 d for sockeye salmon (57 fish). Median travel times for all three species in 1997 were similar, ranging from 0.08 to 0.11 d. In 1998, mean migration time for spring and summer Chinook (n=103) from the Bradford Island fishway exit to the receiver at the Bridge of the Gods was 0.19 d with a range of 0.03 to 4.80 d, and a median of 0.07 d.

Effects of a shad fishery on passage of adult Chinook salmon through the Oregon-shore fishway ladder at The Dalles Dam – 1996

Peery, Bjornn, Tolotti, Stuehrenberg **Technical Report 1999-4**

Abstract: A fishery for American shad *Alosa sapidissima* at the exit of the Oregon-shore ladder at The Dalles Dam in the spring of 1996 had the potential to disrupt passage of adult Chinook salmon *Oncorhynchus tshawytscha* through the ladder. We evaluated the effects of the shad fishery on passage by monitoring Chinook salmon with radio transmitters as they passed through the Oregon-shore fishway. Passage times for 54 radio-tagged Chinook salmon that exited the ladder during the period the shad fishery occurred were compared to passage times for 62 radio-tagged Chinook salmon that passed the dam prior to the shad fishery. We found no differences in median times for Chinook salmon to pass through and exit the ladder before and during the shad fishery using this simple comparison.

Effects of spill in fall on passage of adult steelhead at John Day Dam, 1997

Peery, Bjornn, Tolotti, Stuehrenberg **Technical Report 1999-5**

Abstract: A study was conducted in 1997 to determine the effects of low levels of daytime spill during the early fall on use of the north-shore fishway by steelhead at John Day Dam. Passage of steelhead with transmitters were monitored at the dam during alternating periods with and without daytime spill at the north end of the spillway. We found no significant difference in the proportion of steelhead that first approached and first entered the north-shore entrance (NSE), or eventually passed the dam using the north-shore fishway on days with and without spill. Likewise, median passage times for steelhead to first approach, first enter, and pass the dam using the north-shore fishway were not significantly different with and without spill. Spill levels used during the study averaged 1.7 kcfs, or about 1% of river flow on days with spill, and were insufficient to counter the outflow from the powerhouse near the south shore.

Evaluation of running turbine 1 at maximum capacity on passage of adult salmon and steelhead at John Day Dam – 1997

Bjornn, Peery, Tolotti, Jepson, Stuehrenberg **Technical Report 1999-6**

Abstract: Passage rates and routes of adult Chinook and sockeye salmon and steelhead with radio transmitters were monitored at John Day Dam in 1997 with turbine 1 (south end of powerhouse) operated at two levels (100 and 150 MW). A split-block experimental design was used to compare where fish approached and entered fishways, and mean and median times for fish to first approach and enter fishways when turbine 1 was operated at either of the two generation levels. Proportions of salmon and steelhead that approached and entered the south-shore fishway entrance and mean and median times for all three species to first approach and first enter fishways did not vary significantly in relation to turbine 1 operation. We conclude that operating turbine 1 at maximum capacity did not significantly affect passage for salmon and steelhead at John Day Dam in 1997.

Adult Chinook and sockeye salmon, and steelhead fallback rates at Bonneville Dam - 1996-1998

Bjornn, Keefer, Peery, Tolotti, Ringe, Stuehrenberg **Technical Report 2000-1**

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

Adult Chinook and sockeye salmon, and steelhead fallback rates at The Dalles Dam – 1996, 1997, and 1998

Bjornn, Keefer, Peery, Jepson, Tolotti, Ringe, Stuehrenberg **Technical Report 2000-2**

Abstract: We outfitted 853 spring and summer Chinook salmon *Onchorhynchus tshawytscha* with radio transmitters at Bonneville Dam in 1996, 1,016 in 1997, and 957 in 1998. We outfitted 577 sockeye salmon *O. nerka* in 1997, 770 steelhead *O. mykiss* in 1996, 975 steelhead in 1997, and 1,032 fall Chinook salmon in 1998. Of these, 1,894 spring and summer Chinook salmon, 616 fall Chinook salmon, 485 sockeye salmon, and 1,219 steelhead retained transmitters and were recorded passing The Dalles Dam via fishways. An additional 1% to 3% were known to pass the dam, either via the navigation lock or during antenna outages. We monitored passage and fallbacks at The Dalles Dam using antennas/receivers in the tailrace and fishways in all years and supplemented that data with recapture records, telemetry records from receivers at upriver dams and the mouths of tributaries, and locations of fish by mobile trackers.

We calculated the percentage of steelhead, and Chinook and sockeye salmon that fell back, fallback rates that included multiple fallback events by individual fish, and escapement adjustment factors to adjust counts of fish passing through fishways. We also calculated fallback percentages and rates separately for fish that passed the Oregon- and Washington-shore fishways. We summarized fallback timing for all fish, and whether fish had been upriver prior to fallback events. We also examined the effects of environmental conditions (flow, spill, Secchi disk visibility, dissolved gas pressure, and water temperature) on fallback rates with a variety of techniques.

Overall known fallback percentages for spring and summer Chinook salmon that passed the dam ranged from 11.0% to 14.2% and were highest in 1997. Fallback percentages were 4.9% for sockeye salmon, 6% for steelhead tagged in 1996, 6.7% for steelhead tagged in 1997, and 10.4% for fall Chinook salmon in 1998. Fallback rates for spring and summer Chinook salmon ranged from 13.8% to 18.4% and were also highest in 1997. Fallback rates were 5.1% for sockeye salmon, 6.8% to 7.7% for steelhead, and 11.8% for fall Chinook salmon. Percentages and rates were less than 4.5% for steelhead when we only included data through 31 October of the year they were tagged, the date when almost all steelhead had passed the dam. Standard 95% confidence intervals on fallback rates and percentages for all species were +/- 1% to 4% for radio-tagged fish. Confidence intervals were slightly wider when weighted by total passage at the dam for some species.

Between 55% and 68% of spring and summer Chinook salmon that fell back eventually reascended the dam and were last recorded at upstream sites. About 75% of steelhead and sockeye salmon eventually reascended; 23% of fall Chinook salmon reascended after fallback.

With the exception of sockeye salmon (72%), less than one third of the fish that fell back did so within 24 h of passing the dam. About 60% of spring and summer Chinook salmon, 24% of sockeye salmon, 67% of steelhead, and 85% of fall Chinook salmon were recorded at upstream sites before falling back. We did not observe a significant pattern of higher fallbacks associated with either ladder for spring and summer Chinook salmon or fall Chinook salmon, although rates tended to be higher for the Oregon-shore ladder. Sockeye salmon that passed over the Washington-shore ladder fell back at significantly higher rates than those that passed the Oregon-shore ladder. Most steelhead that fell back within 24 h of passage had passed the dam via the Oregon-shore fishway.

Ladder count adjustment factors based on pooled data for spring and summer Chinook salmon were 0.840 in 1996, 0.839 in 1997, and 0.875 in 1998. Using pooled correction factors, positive biases due to fallbacks in counts of spring and summer Chinook salmon passing ladders at The Dalles Dam were about 5,900 fish in 1996, 14,400 fish in 1997, and 5,100 fish in 1998. The adjustment factor for sockeye salmon in 1997 using pooled data was 0.951, and the positive bias was about 1,600 fish. For steelhead tagged in 1996, the pooled correction factor was 0.937 and the positive bias was about 10,200 fish. The pooled correction factor was 0.926 for steelhead tagged in 1997, with a positive bias of about 12,200 fish. The pooled correction factor was 0.888 for fall Chinook salmon, with a positive bias of about 10,400 fish. Weighted correction factors were similar to pooled values for spring and summer Chinook salmon and sockeye salmon, and were slightly higher for steelhead and fall Chinook salmon. Escapement adjustments based on values weighted by total counts of fish passing via ladders were generally similar to adjustments based on pooled data and were not consistently higher or lower than adjustments based on pooled data.

Limited antenna coverage at The Dalles Dam in all years made it difficult to monitor specific fallback routes, but we believe that most radio-tagged spring and summer Chinook salmon and sockeye salmon fell back via the spillway. Between 94% and 100% of fallbacks by spring and summer Chinook salmon and sockeye salmon occurred on days with forced spill. About 43% of fallbacks by steelhead tagged in 1996 and 29% of fallback by steelhead tagged in 1997 fell back on days with spill. Radio-tagged fall Chinook salmon did not begin passing the dam until after the period of no-spill began on 1 September. A small number of fish may have fallen back through the navigation lock and via the ice and trash sluiceway in all years, but we did not monitor those routes. It was not clear how many fish fell back through powerhouses, as routes through turbine intakes also were not monitored, but we believe few fell back via that route.

The percentage of spring and summer Chinook salmon that fell back and fallback rates were highest in 1997, the year with highest flow and spill. Rates and percentages were nearly as high in 1996, which was also a relatively high flow year and also had a period of high turbidity. Fallback percentages and rates were intermediate for 1998 spring and summer Chinook salmon, when flow and spill were lower than the previous two years. Fallback percentages and rates were relatively low for 1997 sockeye salmon and steelhead tagged in both 1996 and 1997.

We used a variety of methods to test relationships between fallback within 24 h of dam passage and environmental conditions at the dam. Fallback ratios based on moving averages, consecutive 5-d blocks and variable-day bins tended to increase with increased flow, spill, and dissolved gas, and decrease with increased turbidity for spring and summer Chinook salmon in 1996 and 1997 and sockeye salmon in 1997. Some linear and logistic regression models were significant, but most r^2 values were < 0.25. Few steelhead or fall Chinook salmon fell back within 24 h during zero spill conditions in any year. T-tests and logistic regressions using binary datasets (fallback or no fallback within 24 h of passage) showed few significant differences in environmental conditions for fallback fish. Flow and spill at the time of passage were higher for spring and summer Chinook salmon in 1996 and 1997, sockeye salmon in 1997, and fall Chinook salmon in 1998 that fell back within 24 h, but differences were not significant at ($P < 0.05$). Spill was significantly higher for steelhead that fell back within 24 h in 1997 ($P < 0.05$) and Secchi visibility was significantly lower for spring and summer Chinook salmon that fell back in 1996 (P <

0.005). We found few indications that water temperature affected fallback by salmon or steelhead, except that fallback ratios for 1997 spring and summer Chinook salmon and sockeye salmon spiked higher at approximately 18º C.

Stepwise multiple regression models produced results similar to univariate models. The addition of multiple variables did not improve model predictions for fallback ratios for spring and summer Chinook or sockeye salmon. We did not run multivariate models for steelhead or fall Chinook salmon.

We used complete general migration information to determine the final distribution of fish that fell back at The Dalles Dam. Approximately 62% to 76% of spring and summer Chinook salmon, 57% (1996) and 47% (1997) of steelhead, 67% of sockeye salmon, and 62% of fall Chinook salmon that fell back at The Dalles Dam were subsequently recorded at tributary locations or the uppermost monitoring sites and potentially spawned, or were transported from adult traps to hatcheries. Of those that fell back, from 15% to 26% of spring and summer Chinook salmon, 11% of steelhead tagged in 1996, 0% of steelhead tagged in 1997, 13% of sockeye salmon, and 46% of fall Chinook salmon entered tributaries downriver from The Dalles Dam, indicating some fallbacks were likely caused by wandering, overshoot behavior, or other migration factors. From 24% to 35% of spring and summer Chinook salmon and 18% to 20% of steelhead that fell back were recorded in tributaries upriver from Lower Granite Dam or were transported from the adult trap at Lower Granite Dam to hatcheries. About 54% of the sockeye salmon that fell back at The Dalles Dam were last recorded in tributaries to the upper Columbia River, mostly in the Wenatchee and Okanogan rivers. Fish not recorded in tributaries or the uppermost monitoring sites (24% to 38% of spring and summer Chinook salmon, sockeye salmon, and fall Chinook salmon, 43% to 53% of steelhead) were last detected primarily at dam sites or in reservoirs throughout the lower-Columbia River/Snake River hydrosystem.

Adult Chinook and sockeye salmon, and steelhead fallback rates at John Day Dam – 1996, 1997, and 1998

Peery, Bjornn, Peery, Tolotti, Stuehrenberg **Technical Report 2000-3**

Abstract: We outfitted 853 spring and summer Chinook salmon *Onchorhynchus tshawytscha* with radio transmitters at Bonneville Dam in 1996, 1,016 in 1997, and 957 in 1998. We outfitted 577 sockeye salmon *O. nerka* in 1997, 770 steelhead *O. mykiss* in 1996, 975 steelhead in 1997, and 1,032 fall Chinook salmon in 1998. Of these, 1,564 spring and summer Chinook salmon, 410 fall Chinook salmon, 430 sockeye salmon, and 1,024 steelhead retained transmitters and were recorded passing John Day Dam via fishways. An additional 19 to 45 spring and summer Chinook salmon, 71 fall Chinook salmon, 38 sockeye salmon, and 17 to 23 steelhead were known to pass the dam, either via the navigation lock, during fishway antenna outages, or with malfunctioning or lost transmitters. We monitored passage and fallbacks at John Day Dam using antennas/receivers in the tailrace and fishways in all years and supplemented that data with recapture records, telemetry records from receivers at upriver dams and the mouths of tributaries, and locations of fish by mobile trackers.

We calculated the percentage of steelhead, and Chinook and sockeye salmon that fell back, fallback rates that included multiple fallback events by individual fish, and escapement adjustment factors to adjust counts of fish passing through fishways. We also calculated fallback percentages and rates separately for fish that passed the Oregon- and Washington-shore fishways. We summarized fallback timing for all fish, and whether fish had been upriver prior to fallback events. We also examined the effects of environmental conditions (flow, spill, Secchi disk visibility, dissolved gas pressure, and water temperature) on fallback rates with a variety of techniques.

Overall known fallback percentages for spring and summer Chinook salmon that passed the dam ranged from 9.4% to 12.3% and were highest in 1996. Fallback percentages were 3.8% for sockeye salmon, 10.0% for steelhead tagged in 1996, 7.9% for steelhead tagged in 1997, and 4.0% for fall Chinook salmon in 1998. Fallback rates for spring and summer Chinook salmon ranged from 11.4% to 14.4% and were also highest in 1996. Fallback rates were 4.1% for sockeye salmon, 9.0% to 11.1% for

steelhead, and 4.0% for fall Chinook salmon. Percentages and rates were < 6.7% for steelhead when we only included data through 31 October of the year they were tagged, the date when almost all steelhead had passed the dam. Standard 95% confidence intervals on fallback rates and percentages for all species were +/- 1% to 4% for radio-tagged fish. Confidence intervals were slightly wider when weighted by total passage at the dam for some species.

Between 60% and 82% of spring and summer Chinook salmon that fell back eventually reascended the dam and were last recorded at upstream sites. About 46% of steelhead tagged in 1996, 75% of steelhead tagged in 1997, and 89% of sockeye salmon eventually reascended; 5% of fall Chinook salmon reascended after fallback.

With the exception of sockeye salmon (95%), less than 40% of the fish that fell back did so within 24 h of passing the dam. Between 33% and 46% of spring and summer Chinook salmon, 5% of sockeye salmon, 25% of steelhead, and 42% of fall Chinook salmon were recorded at upstream sites before falling back. We did not observe a pattern of higher fallbacks associated with either ladder for spring and summer Chinook salmon, fall Chinook salmon, sockeye salmon, or steelhead.

Ladder count adjustment factors based on pooled data for spring and summer Chinook salmon were 0.871 in 1996, 0.889 in 1997, and 0.894 in 1998. Using pooled correction factors, positive biases due to fallbacks in counts of spring and summer Chinook salmon passing ladders at John Day Dam were about 3,900 fish in 1996, 9,200 fish in 1997, and 4,000 fish in 1998. The adjustment factor for sockeye salmon in 1997 using pooled data was 0.961, and the positive bias was about 1,400 fish. For steelhead tagged in 1996, the pooled correction factor was 0.895 and the positive bias was about 16,500 fish. The pooled correction factor was 0.916 for steelhead tagged in 1997, with a positive bias of about 13,400 fish. The pooled correction factor was 0.961 for fall Chinook salmon, with a positive bias of about 3,100 fish. Weighted correction factors were similar to pooled values for spring, summer, and fall Chinook salmon and sockeye salmon, and were slightly higher for steelhead. Escapement adjustments based on values weighted by total counts of fish passing via ladders were generally similar to adjustments based on pooled data, but tended to be slightly lower than adjustments based on pooled data for all species except fall Chinook salmon. Positive biases further decreased when we included estimated passage through the navigation lock, which compensated for bias in counts in ladders.

Limited antenna coverage at John Day Dam in all years made it difficult to monitor specific fallback routes, but we believe that most radio-tagged spring and summer Chinook salmon and sockeye salmon fell back via the spillway. All fallbacks by spring and summer Chinook salmon and sockeye salmon occurred on days with forced spill. About 76% of fallbacks by steelhead tagged in 1996 and 46% of fallback by steelhead tagged in 1997 fell back on days with spill. A small number of fish may have fallen back through the navigation lock, via the ice and trash sluiceway, or via the juvenile bypass in all years, but we did not monitor those routes (except juvenile bypass in 1998). Radio-tagged fall Chinook salmon did not begin passing the dam until after the period of no-spill began on 1 September in 1998, and we suspect most fall Chinook salmon fell back via the unmonitored navigation lock based on evidence from Bonneville and McNary dams. It was not clear how many fish fell back through powerhouses, as routes through turbine intakes also were not monitored, but based on high reascension rates for most species, we believe few fish fell back via turbines.

We used a variety of methods to test relationships between fallback within 24 h of dam passage and environmental conditions at the dam. Fallback ratios based on moving averages, consecutive 5-d blocks and variable-day bins tended to increase with increased flow and spill, and decrease with increased turbidity for spring and summer Chinook salmon in all years and sockeye salmon in 1997. Some linear and logistic regression models were significant, but most r^2 values were < 0.20. Fallback ratios for spring and summer Chinook salmon and sockeye salmon also tended to increase with increased dissolved gas in 1996 and 1997. Ratios tended to decrease with increased water temperature for spring and summer Chinook salmon and sockeye salmon, except that ratios spiked in some years when temperatures exceeded 18°C. Few steelhead or fall Chinook salmon fell back within 24 h in any year, particularly during zero spill conditions. T-tests and logistic regressions using binary datasets (fallback or no fallback within 24 h of passage) showed few significant differences in environmental conditions for fallback fish.

Flow and spill at the time of passage were higher for spring and summer Chinook salmon in 1996 and 1997, sockeye salmon in 1997, and steelhead in 1996 and 1997 that fell back within 24 h, but differences were not significant at ($P < 0.05$), except for steelhead tagged in 1997 ($P = 0.03$ for flow, $P < 0.001$ for spill). We found that water temperature, dissolved gas, and Secchi visibility did not significantly ($P < 0.05$) affect fallback by salmon or steelhead. However, we did observe fallback ratios for some sockeye salmon, steelhead, and fall Chinook salmon spiked higher at approximately 18º C.

Spring and summer Chinook salmon that fell back within 5 d of passage passed the dam under significantly higher flow and spill conditions in both 1997 and 1998, as did steelhead tagged in 1997 ($P < 0.005$). Dissolved gas levels were also higher for fallback spring and summer Chinook salmon in 1997 ($P <0.005$), and water temperatures were significantly lower for fallback spring and summer Chinook salmon in 1996 and 1997 ($P < 0.05$). Secchi visibility was significantly lower ($P < 0.005$) for fall Chinook salmon that fell back within 5 d of passage.

Stepwise multiple regression models produced results similar to univariate models. The addition of multiple variables did not improve model predictions for fallback ratios for spring and summer Chinook or sockeye salmon. We did not run multivariate models for steelhead or fall Chinook salmon.

We used complete general migration information to determine the final distribution of fish that fell back at John Day Dam. Approximately 72% to 83% of spring and summer Chinook salmon, 57% (1996) and 64% (1997) of steelhead, 78% of sockeye salmon, and 53% of fall Chinook salmon that fell back at John Day Dam were subsequently recorded at tributary locations or the uppermost monitoring sites and potentially spawned, or were transported from adult traps to hatcheries. Of those that fell back, from 19% to 24% of spring and summer Chinook salmon, 14% to 28% of steelhead tagged, 6% of sockeye salmon, and 47% of fall Chinook salmon entered tributaries down river from John Day Dam, indicating some fallbacks were likely caused by wandering, overshoot behavior, or other migration factors. From 31% to 38% of spring and summer Chinook salmon and 17% to 36% of steelhead that fell back were recorded in tributaries upriver from Lower Granite Dam or were transported from the adult trap at Lower Granite Dam to hatcheries. About 67% of the sockeye salmon that fell back at John Day Dam were last recorded in tributaries to the upper Columbia River, mostly in the Wenatchee and Okanogan rivers. Most fall Chinook salmon that fell back were last recorded downstream from John Day Dam. Fish not recorded in tributaries or the uppermost monitoring sites (17% to 28% of spring and summer Chinook salmon and sockeye salmon, 36% to 44% of steelhead, 47% of fall Chinook salmon) were last detected primarily at dam sites or in reservoirs throughout the lower-Columbia River/Snake River hydrosystem.

Migration of adult spring and summer Chinook salmon past Columbia and Snake River dams, through reservoirs and distribution into tributaries, 1996

Bjornn, Keefer, Peery, Tolotti, Ringe, Keniry, Stuehrenberg **Technical Report 2000-5**

Abstract: We captured 853 spring and summer Chinook salmon Oncorhynchus tshawytscha in the adult trapping facility at Bonneville Dam in 1996, released them with radio transmitters, and studied their passage past dams, through reservoirs and into tributaries. Radio receivers were set up at Columbia and Snake river dams and at the mouths of major tributaries to monitor movements of salmon. Recaptures of salmon at hatcheries, weirs and traps, and data from mobile tracking were used to complete the migration history.

Of 853 salmon released downstream with transmitters, 703 were classified as spring Chinook salmon and 150 as summer Chinook salmon. At the release site, 15 Chinook salmon regurgitated transmitters and 838 retained transmitters. Of the 838 fish, 99% were recorded back at the Bonneville Dam tailrace and 96.5% were known to have passed the dam. Fifty-nine percent of the 838 fish passed The Dalles Dam, 45% passed John Day Dam, 36% passed McNary Dam, 14% passed Ice Harbor Dam, 14% passed Lower Granite Dam and 14% passed Priest Rapids Dam.

Median times for Chinook salmon to pass individual Columbia River dams ranged from 0.93 d at The Dalles Dam to 1.51 d at Priest Rapids Dam. Median passage times at the monitored Snake River dams

were 0.75 d at Ice Harbor Dam and 1.59 d at Lower Granite Dam, where operation of the adult trap extended passage times for fish diverted into the trap. From release downstream from Bonneville Dam, median passage times past multiple dams were 11.9 d to the top of McNary Dam, 16.8 d to the top of Ice Harbor Dam, 27.2 d to the top of Lower Granite Dam and 16.7 d to the top of Priest Rapids Dam.

Adult Chinook salmon passed most tailrace receiver sites throughout the day and night, but typically moved through fishways and past top-of-ladder receivers during daylight hours. Most Chinook salmon that were in fishways at nightfall did not pass the dam until the next day.

Summer Chinook salmon migrated more rapidly than spring Chinook salmon, with median passage times about 66% of those of spring Chinook salmon. Median passage rates for spring and summer Chinook salmon through lower Columbia River reservoirs were 43 km/d through the Bonneville pool, 45 km/d through The Dalles pool, 62 km/d through the John Day pool and 56 km/d through the McNary pool. Median passage times through the Bonneville and The Dalles reservoirs were significantly ($P < 0.005$) shorter for summer Chinook salmon than for spring Chinook salmon.

Periods of relatively high flow and spill in 1996, and a block of turbid water in late April/early May appeared to delay passage of salmon with and without transmitters. Nadirs in Chinook salmon counts at dams and in passage of Chinook salmon with transmitters coincided with high flow and spill in late May and into June, particularly at Lower Granite and Ice Harbor dams. Sharp drops in Chinook salmon counts also occurred during periods of high turbidity; the largest declines were during early-May at Bonneville Dam and during mid-May at Ice Harbor and Lower Granite dams. Passage times at individual dams, however, were not strongly correlated with flow, spill, or turbidity.

Cumulative passage times were best predicted by the date that fish first passed into the Bonneville Dam tailrace, with summer Chinook salmon migrating at faster rates than spring Chinook salmon. The number of times salmon fell back over dams was also a good predictor of passage times, because fish with one or more fallbacks during their migration had significantly lower migration rates. Movement back out into the tailrace from the fishways also contributed to significantly longer times to pass upriver sites for some sites. Secchi disk depths, spill, and flow at lower Columbia River dams explained relatively low proportions of the variability in passage times past multiple dams. High spill was correlated with higher fallback rates at Bonneville, The Dalles, and John Day dams and thus had some indirect effect on passage times. Environmental conditions at Lower Granite Dam accounted for more than 35% of the variability in passage times from the Ice Harbor tailrace to the top of Lower Granite Dam.

A total of 185 Chinook salmon, 23% of the fish with transmitters that passed Bonneville Dam, fell back over or through Bonneville or other dams 326 times in 1996. Forty-one percent of all fallback events occurred at Bonneville Dam and 12 to 15% of the fish that passed Bonneville, The Dalles and John Day dams fell back. About 9% of the fish that passed McNary and Ice Harbor dams fell back, 5% fell back after passing Priest Rapids and 1% fell back after passing Lower Granite Dam. Fallback rates increased with high flow and spill, but correlations were not strong.

Fallbacks at any dam added significantly to overall passage time past multiple dams. Using median passage times, one or more fallbacks at any dam added approximately five days to overall passage time when compared to Chinook salmon that did not fall back. Differences in median passage times between fish that did and did not fall back were greater for spring Chinook salmon than for summer Chinook salmon. For all Chinook salmon, the number of cumulative fallback events by individual fish was correlated with longer passage times. One or more fallback events at any location added from 4.1 to 6.7 d to median times from release to passage at upriver dams, differences that were significantly ($P < 0.05$) longer than for fish that did not fall back.

About 66% of Chinook salmon that fell back subsequently reascended all dams at which they fell back. Of the remaining 34%, about half were recorded in tributaries downstream from the location of the fallback event and half were not accounted for in tributaries or fisheries. From 66 to 74% of Chinook salmon that fell back at lower Columbia River dams eventually returned to tributary sites up- or downstream from the dam where they fell back. By comparison, the fish that fell back at Lower Granite Dam was subsequently recorded in an upriver tributary, 100% of those that fell back at Ice Harbor Dam entered tributaries (78% upriver and 22% in the Umatilla River), and all fish that fell back at Priest

Rapids Dam reascended. Fish that fell back over dams and then reascended ladders added positive biases to fish counted at the dams. Spring and summer Chinook salmon counts reported in the 1996 USACE annual fish passage report were inflated by an estimated 2,600 to 9,250 fish at lower Columbia River dams and from about 75 to 700 fish at Ice Harbor, Lower Granite, and Priest Rapids dams. Adjustment factors for fish that fellback and reascended ranged from 0.86 at Bonneville Dam and 0.85 at The Dalles Dam to 0.99 at Lower Granite Dam.

About 71.4% of the Chinook salmon that fell back at Bonneville Dam survived to enter major tributaries or pass over the top of Priest Rapids Dam, while the survival rate for fish that did not fall back was 77.7%, a difference of about 6%. When we included fish that returned to Lower Granite trap without transmitters as survived, salmon that did not fall back at Bonneville Dam survived at significantly ($P < 0.10$) higher rates than fish that did fall back at Bonneville Dam (79.3% versus 72.3%). Survival to tributaries for Chinook salmon that fell back at any dam was 74.1%, compared to 77.7% for fish that did not fall back at any location, a difference that was not significant ($P > 0.10$).

Chinook salmon arrived at tributaries in a predictable progression from lower Columbia River to upriver locations. Migrations into individual tributaries were typically spread over 6 to 8 weeks, with fish recorded at tributary mouths throughout the day and night.

In 1996, about 70% of spring Chinook salmon with transmitters were last recorded in the lower Columbia River and its tributaries. The highest number of summer Chinook salmon were last recorded at Priest Rapids Dam or in tributaries upriver from the dam. Summer Chinook salmon also made up substantial portions of the returns to the Imnaha, Klickitat and Salmon rivers. Overall, final distribution for all Chinook salmon outfitted with transmitters appeared to reflect the general distribution of Columbia River spring and summer Chinook salmon runs in 1996.

Final distribution records were also linked to dates when specific stocks passed Bonneville Dam. Some, like Snake River and Deschutes River stocks passed Bonneville Dam throughout the migration season, while lower- and mid-Columbia stocks were more clearly associated with spring or summer portions of the 1996 run.

About 20% of the Chinook recorded at Ice Harbor Dam and about 5% of the fish that passed Priest Rapids Dam made temporary excursions into lower Columbia River tributaries. Most tributary dip-ins were for less than one day. Stocks that returned to lower- Columbia River tributaries also entered a variety of other tributaries, in some cases at higher rates than upriver stocks.

Although there were limitations in our ability to monitor survival to tributaries, we calculated survival rates of approximately 76% for all Chinook salmon that retained transmitters after release. About 90% of summer Chinook salmon survived to tributaries or to the top of Priest Rapids Dam (above which telemetry coverage was limited), a rate that was significantly ($P < 0.01$) higher than the 73% survival rate for spring Chinook salmon. A significantly ($P < 0.05$) higher percentage (78%) of Chinook salmon without fin clips survived to enter tributaries than fish with fin clips (70%). Of about 200 fish (24% of those that retained transmitters after release) that did not survive to enter tributaries, about 20% were recaptured in fisheries and reported to us, and the fate of the remaining 80% was mostly unknown.

Approximately 40% of all Chinook salmon outfitted with transmitters in 1996 were recaptured in fisheries, at hatcheries, weirs or traps (not including the Bonneville or Lower Granite traps), at spawning grounds, or their transmitters were found along river corridors. Fifteen percent of reported recaptures were in sport fisheries, 13% in tribal fisheries, 61% at hatcheries, weirs or traps and 11% at spawning grounds or along migration routes. One-third of all recaptures were at hatcheries in the Wind, Little White Salmon and Deschutes rivers and another 13% were in those tributaries at locations other than hatcheries. Twelve percent of all recaptures in 1996 were in the Snake River drainage, 18% were in the mid-Columbia or its tributaries upriver from McNary reservoir, and 13% were in the Columbia River downstream from McNary Dam.

Our best estimate of the final fate for all radio-tagged spring and summer Chinook salmon in 1996 was 6.2% downstream from Bonneville Dam, 59.6% between Bonneville and McNary dams, 19.2% in the mid-Columbia upstream from McNary Dam, and 14.7% in the Snake River basin. Returns to the lower Columbia River were mostly spring Chinook salmon, while summer Chinook salmon returned mostly to the mid- Columbia and Snake rivers. Escapements were 37% to tributaries and 22.6% to hatcheries; when we included fish that passed over Priest Rapids Dam and the Lower Granite trap, total escapement was 68.5%. About 10.6% were recaptured in sport or tribal fisheries, 2.3% of transmitters were found in non-spawning areas, and 18.3% were unaccounted for.

Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated transmitters that were not recovered or located, may have entered tributaries undetected, may have spawned at main stem locations, or may have died and were not detected as mortalities. More than 95% of the unaccounted for fish with transmitters were last recorded in the hydrosystem downstream from Lower Granite and Priest Rapids dams, and 92% were spring Chinook salmon.

Adult Chinook salmon and steelhead fallbacks versus spill at Bonneville Dam in 2000

Bjornn, Peery, Jepson, Tolotti, Ringe, Lee, Stuehrenberg, Matter Technical Report 2001-3

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

Migration of adult steelhead past Columbia and Snake River dams, through reservoirs and distribution into tributaries, 1996

Keefer, Bjornn, Peery, Tolotti, Ringe, Keniry, Stuehrenberg Technical Report 2002-2

Abstract: We captured 770 steelhead *Oncorhynchus mykiss* in the adult trapping facility at Bonneville Dam in 1996, released them with radio transmitters, and studied their passage past dams, through reservoirs and into tributaries. Radio receivers were set up at Columbia and Snake River dams and at the mouths of major tributaries to monitor movements of steelhead. Recaptures of steelhead at hatcheries, weirs and traps, and data from mobile tracking were used to complete the migration history.

Of 765 steelhead with transmitters released downstream from Bonneville Dam, 487 were classified as A-group steelhead (tagged before 29 August) and 278 as B-group steelhead (tagged after 29 August). We believe 739 fish retained transmitters beyond the release site and migrated upstream. Of the 739 fish, >99%

passed through the tailrace and reached Bonneville Dam and 97.4% were known to have passed the dam. Seventy- nine percent of the 739 fish passed The Dalles Dam, 62% passed John Day Dam, 53% passed McNary Dam, 43% passed Ice Harbor Dam, 35% passed Lower Granite Dam, and 2% passed Priest Rapids Dam.

Median times for steelhead to pass individual lower Columbia River dams ranged from 0.43 d at McNary Dam to 0.85 d at John Day Dam. Median passage times at the lower Snake River dams were between 0.61 d at Ice Harbor Dam and 1.08 d at Lower Granite Dam, where operation of the adult trap extended passage times for fish diverted into the trap. Adult steelhead passed most tailrace receiver sites throughout the day and night, but typically moved through fishways and past top-of-ladder receivers during daylight hours. Most fish that were in fishways at nightfall did not pass the dam until the next day.

Median passage rates through reservoirs were between 24 and 43 km/d through the lower Columbia River pools, which included time steelhead temporarily strayed into tributaries. Median times to pass through reservoirs ranged from 1.2 d to 2.9 d. From first passage of the tailrace at Bonneville Dam, median passage times past multiple dams were 16.1 d to the top of McNary Dam, 26.2 d to the top of Ice Harbor Dam, 35.0 d to the top of Lower Granite Dam, and 22.0 d to the top of Priest Rapids Dam.

B-group steelhead tended to migrate more rapidly than A-group steelhead, with median passage times past multiple projects about half those for A-group steelhead. However, median passage times past some individual dams and reservoirs were shorter for A-group fish.

In 1996, peak counts of steelhead at dams occurred during no-spill conditions. When spill did occur, it did not significantly affect passage times at dams. Total flow and turbidity also had limited impact on passage times, although there was a tendency for times to increase with increased flow. Passage times at dams decreased with increasing water temperature, but correlations between passage times and temperatures were low.

Cumulative passage times past multiple projects were best predicted by the time steelhead temporarily strayed into lower Columbia River tributaries. The date fish were released was also correlated with passage time, with early migrating fish migrating at lower rates than those later in the migration. The number of times steelhead fell back over dams was also a good predictor of passage times, because fish with one or more fallbacks during their migration had significantly longer migration times. Exits from fishways into tailrace areas also contributed to longer times to pass upriver. Turbidity, spill, and flow at lower Columbia River dams explained relatively low proportions of the variability in passage times past multiple dams.

The incidence of marine mammal injuries or descaling at time of tagging had a limited impact on fish passage times. Marine mammal and descaling injuries did not appear to have a detectable effect on fallback rates.

At least 143 steelhead, 20% of the fish with transmitters that passed Bonneville Dam, fell back at Bonneville or other dams 207 times in 1996 or 1997 before spawning. Most fallback events occurred at John Day (25%), The Dalles (19%), or Bonneville (18%) dams. About 22% of A-group and 16% of B-group steelhead fell back. Between 4.9 and 10.1% of fish fell back at lower Columbia River dams, and 5.6 to 8.4% fell back at Ice Harbor and Lower Granite dams; none fell back at Priest Rapids Dam. Fallback rates tended to be higher during high flow and spill, but correlations were not strong; most analyses were qualitative due to small sample sizes. Although most steelhead passed dams during no- spill conditions, a disproportionate number of fallback events occurred during spill, especially at lower Columbia River dams.

Fallbacks at any dam added significantly to overall passage time past multiple dams. Using median passage times, one or more fallbacks at any dam added 12 to 21 days to most overall passage times when compared to fish that did not fall back, differences that were significant. Differences in median passage times past multiple dams between fish that did and did not fall back were slightly greater for B-group steelhead than for A-group steelhead. Fish that fell back multiple times had the longest median passage times.

About 57% of steelhead that fell back subsequently reascended all dams where they fell back. Of fish that did not reascend, about 37% subsequently entered tributaries downstream from the location of the fallback. About 56% of steelhead that fell back at lower Columbia River dams eventually returned to tributary sites up- or downstream from the dam where they fell back. Less than 40% of those that fell back at lower

Snake River dams returned to tributaries. Steelhead that fell back escaped to tributaries at lower rates than fish that did not fall back, but differences were not strongly significant.

Fish that fell back over dams and then reascended ladders added mostly positive biases to fish counted at the dams. Using weighted adjustment factors, steelhead counts reported in the USACE annual fish passage report were inflated by an estimated 6,000 to 12,700 fish at The Dalles, John Day, and McNary dams. Positive biases were 7,800 to 8,300 fish at Ice Harbor and Lower Granite dams. Passage through the navigation lock at Bonneville Dam more than compensated for fallback and reascension behavior at the dam; the estimated escapement was about 1,300 higher for Bonneville Dam than that reported by USACE. Weighted escapement adjustment factors for counts at dams were from 0.93 to 1.01 at lower Columbia River dams, 0.92 at Ice Harbor Dam, and 0.91 at Lower Granite Dam.

About 5% of the steelhead that passed Bonneville Dam had mainstem overwintering behavior. A significantly higher proportion of B-group fish overwintered than A-group fish. Overwintering fish fell back at significantly higher rates than fish that did not overwinter, temporarily strayed into lower Columbia River tributaries at relatively high rates, and tended to move downstream during the overwintering period. We estimated average overwintering times to be around 140 d. The highest number of fish overwintered at least some of the time between The Dalles and John Day dams; overall, 73% spent overwintering time in the lower Columbia River, 41% spent time in the lower Snake River, and 25% spent some time overwintering in lower Columbia River tributaries other than their final destination. A significantly higher proportion of overwintering fish were unaccounted for than fish that did not overwinter in the mainstem hydrosystem. The steelhead that did not overwinter in the Columbia and Snake rivers hydrosystem (95% of the radio-tagged steelhead) entered tributary streams or passed Priest Rapids and Lower Granite Dam reservoir before the onset of winter.

Migrations into individual tributaries started during July of 1996 and continued through April of 1997. Median arrival dates were in August and September at most lower Columbia River tributaries, in October at the John Day, Yakima, and Snake River tributaries, and were in November or December at the Umatilla and Walla Walla rivers. Fish were first recorded at tributary mouths mostly during daylight.

In 1996, about 48% of A-group steelhead with transmitters were last recorded in the lower Columbia River and its tributaries and 28% were last recorded in the Snake River basin upstream from Lower Granite Dam. About 48% of B-group steelhead were last recorded upstream from Lower Granite Dam and 42% were last recorded in the lower Columbia River or its tributaries.

About 65% of steelhead that passed Lower Granite Dam and 61% that passed Priest Rapids Dam made temporary excursions into one or more lower Columbia River tributaries. Snake River fish mostly entered the Little White Salmon (32%), Deschutes (30%), and White Salmon (23%) rivers. A significantly higher proportion of Snake River A- group fish (74%) entered lower Columbia tributaries than B-group fish (55%). Fish stayed in tributaries for a median of 7.7 d (mean = 11.6 d). A-group fish stayed in tributaries significantly longer (median = 15.3 d) than B-group fish (4.7 d), and fish without fin clips stayed significantly longer (20.7 d) than fin-clipped fish (6.0 d). Peak proportions of Snake River fish were in lower Columbia River tributaries when mainstem water temperatures were high (20 C or higher) and tributary temperatures were relatively low in late August. Between 22 and 43% of Snake River fish were in lower river tributaries from early August through mid-September.

Fish bound for lower and mid-Columbia River tributaries also strayed into tributaries other than their final destinations. The proportion temporarily straying was 50% for the steelhead that ended up in the Deschutes (67%), John Day (81%), Umatilla (100%), Yakima (50%), and Walla Walla (50%) rivers. Less than 8% of the fish that entered the Wind, Little White Salmon, and White Salmon rivers were last recorded at those sites.

Reach survival estimates within the mainstem Columbia/Snake river hydrosystem were lowest through the Bonneville-The Dalles reach (0.920), and through the Lower Granite pool (0.901). Reach survival estimates in the remaining lower Columbia River reaches were approximately 0.94, and the estimate from the top Ice Harbor Dam to the top of Lower Granite Dam was 0.922.

Although there were limitations in our ability to monitor detectable escapement to tributaries, we calculated that approximately 63% of all steelhead that retained transmitters ended up in tributary streams, a

rate that included fish recaptured in tributary fisheries. Tributary return rates were similar for A-group and B-group fish and for fin-clipped and unclipped fish. Of 261 fish (37% of those that retained transmitters after release) that did not enter tributaries, about 27% were recaptured in mainstem fisheries and reported to us, and the fates of the remaining 73% (27% of all steelhead that retained transmitters) were mostly unknown.

About 32% of tagged fish were reported recaptured in fisheries, at hatcheries, weirs or traps (not including the Bonneville or Lower Granite traps), at spawning grounds, or their transmitters were found along river corridors. Forty-six percent of reported recaptures were in sport fisheries, 21% in tribal fisheries, 26% at hatcheries, weirs or traps and 19% at spawning grounds or along migration routes. About 47% of all recaptures were in the Snake River basin, 45% were in the lower Columbia River or its tributaries, and 8% were upstream from Priest Rapid Dam.

Our best estimate of the final fate for all radio-tagged A-group and B-group steelhead in 1997 was 6.0% downstream from Bonneville Dam, 44.4% between Bonneville and McNary dams, 8.2% in the mid-Columbia upstream from McNary Dam, and 41.3% in the Snake River basin. Escapements were 37.9% in tributaries (excluding tributary harvests) and 5.2% to hatcheries; when we included fish last recorded upstream from Priest Rapids Dam, at or near Ringold Trap, or at Lower Granite Trap without transmitters, total escapement was 47.5%. About 21% were reported recaptured in mainstem and tributary sport or tribal fisheries, 6.9% of transmitters were known or presumed regurgitated in non- spawning areas, and 24.8% were unaccounted for. We found no significant differences in escapement rates or unaccounted-for rates for A-group and B-group fish. Fish without fin clips escaped at higher rates than fin-clipped fish, probably because a significantly lower proportion of unclipped fish (8.8%) were harvested compared to fin-clipped fish (23.3%).

Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated transmitters that were not recovered or located, may have entered tributaries undetected, may have spawned at mainstem locations, or may have died and were not detected as mortalities. The largest proportion of unaccounted for fish were last detected between Bonneville and The Dalles dams. About two-thirds of unaccounted for fish were A-group steelhead, but we found no significant differences in the overall proportion of unaccounted for A-group or B-group fish; we also found no differences in unaccounted for rates for fin-clipped and unclipped fish.

Passage of radio-tagged adult salmon and steelhead at John Day Dam with emphasis on fishway temperatures: 1997-1998

Keefer, Peery, Burke **Technical Report 2003-1**

Abstract: To better understand the effects of elevated fishway temperatures at John Day Dam on passage of adult salmonids, we examined and compared behavior of radio-tagged adult Chinook salmon, sockeye salmon and steelhead at both John Day and The Dalles dams in 1997 and 1998. We calculated passage times through tailraces, fishways, transition pools and ladders and overall dam passage times, as well as the proportions of each run that exited fishways into tailrace areas and fishway exit rates.

Fish from all runs passed the dams more quickly as water temperatures increased each year, but median passage times at John Day Dam were longer than at The Dalles Dam for all groups. In almost all months of all years, fish that exited a fishway into a tailrace had significantly longer passage times than fish that moved straight through and exited from the tops of ladders. Far more fish exited John Day Dam fishways than exited fishways at The Dalles Dam. Proportionately more fish exited John Day Dam fishways into the tailrace as daily ladder temperatures increased. Exit rates at John Day Dam tended to be higher from the OR-shore fishway, which typically had warmer water than the WA-shore fishway. Exit rates from both John Day Dam fishways were strongly correlated with mean and maximum ladder water temperatures. However, exit rates were higher at John Day Dam than at The Dalles Dam during a wide range of temperature conditions, suggesting that factors other than temperature alone contribute to slow adult passage at John Day Dam.

Water temperatures and passage of adult salmon and steelhead in the lower Snake River
Peery, Bjornn, Stuehrenberg **Technical Report 2003-2**

Abstract: We used recently collected and historic data to evaluate effects of water temperatures on passage of adult salmon and steelhead in the lower Snake River, especially in relation to temperature exposures in fishways. Similar to the findings of others, we found little evidence that water temperatures have increased over time at the mouth of the Snake River (downstream from Ice Harbor Dam) but temperatures in the forebay of Ice Harbor Dam have trended upwards in the fall (September and October) since 1962. The latter trend can be explained at least in part by an increase in air temperatures during August and September in the region since 1948.

Water temperatures collected in and near fishways at Ice Harbor and Lower Granite dams for the four years 1995 to 1998 routinely exceeded 20°C. Warmest water temperatures typically occurred during July and August during the nadir between the summer and fall Chinook salmon runs and before onset of the bulk of the steelhead run. However, during warm years, such as occurred in 1998, warm water conditions can persist at the dams into October. Another potential problem was a temperature discontinuity that typically occurred at the base of fishways where water flowing down the ladder from the forebay surface met potentially cooler water pumped into the fishway from the tailrace, most notably at Lower Granite Dam when flows were released from Dworshak reservoir. Water released from Dworshak reservoir was effective at cooling summertime water temperatures near the forebay surface and in fishways by an estimated 1 to 3˚C at Lower Granite Dam. Cooling effects from Dworshak releases were diminished at Ice Harbor Dam because of warming and degree of mixing that occurred as water masses moved downstream, and were difficult to quantify. Best results through the lower Snake River appeared to occur when Dworshak flows were set at 20 kcfs or more, or 50 to 60% of the Snake River flow as measured at Lower Granite Dam.

There was evidence from monitoring radio-tagged adult salmon and steelhead that some fish had longer travel times into the lower Snake River, and some fish took longer to travel between Ice Harbor and Lower Granite dams, during unfavorable water temperature conditions. There was a significant trend for later arrival of salmon and steelhead at Ice Harbor Dam during years with warm summertime water temperatures.

Effect of the shad fishery on passage of adult Chinook through the Oregon-shore fishway ladder at The Dalles Dam - 2002
Jepson, Williams, Peery, Moser **Technical Report 2003-4**

Abstract: A fishery for American shad Alosa sapidissima at the exit of the Oregon-shore ladder at The Dalles Dam in the spring of 2002 had the potential to disrupt passage of adult Chinook salmon Oncorhynchus tshawytscha through the ladder. We evaluated the effects of the shad fishery on passage by monitoring Chinook salmon with radio transmitters as they passed through the Oregon-shore fishway. Passage times for 33 radio-tagged Chinook salmon that exited the ladder during the period the shad fishery were compared to passage times for 60 radio-tagged Chinook salmon that passed the dam prior to the shad fishery. We found that median time for Chinook salmon to pass through and exit the ladder before the shad fishery was significantly shorter than the median passage time observed during the shad fishery. However, the median time for Chinook salmon to pass on fishery days when the trapnet was deployed was not significantly different from the median time observed on fishery days when the trapnet was not deployed. Similarly, the effect of the fishery on passage rates was confounded with cooler mean daily water temperatures observed in the forebay of the dam during the fishery.

Adult spring and summer Chinook passage through fishways and transition pools at Bonneville, McNary, Ice Harbor and Lower Granite Dams

Keefer, Bjornn, Peery, Tolotti, Ringe, Stuehrenberg Technical Report 2003-5

Abstract: Evaluation of fishway entrances used, and passage through the fishways by Chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss at dams in the lower Columbia and Snake rivers was an objective of the adult salmon and steelhead passage project. In 1996, we monitored passage through the fishways by outfitting Chinook salmon with radio transmitters and installing full antenna/receiver coverage at Bonneville, McNary, Ice Harbor, and Lower Granite dams. Critical parameters studied were times for a fish to first approach the dam and first enter a fishway, total time to pass over the dam, which entrances were approached, where fish entered and exited the fishways, and their passage through transition pools and over the dams.

In 1996, 853 spring and summer Chinook salmon were outfitted with radio transmitters at the adult trapping facility adjacent to Bonneville's Washington-shore fishway and then released ~10 km downstream from the dam at Dodson and Skamania landings. Of these fish, 834 were subsequently recorded at Bonneville Dam, 307 were recorded at McNary Dam, 127 were at Ice Harbor Dam and 106 were at Lower Granite Dam. Median passage times from release after tagging to first record at the four dams were 0.8, 11.1, 16.2, and 25.1 d.

After passing a tailrace receiver, median times for Chinook salmon to first approach fishways was 1.7 to 3.1 hours (h) for all dams monitored in 1996. Median times to first enter fishways were 9.7 to 10.7 h at Bonneville, McNary, and Ice Harbor dams and 6.5 h at Lower Granite Dam. Median times from tailrace receiver to exit from the top of a ladder were 17.5 h at Ice Harbor, 23.1 h at Bonneville, 25.4 h at McNary, and 38.2 h at Lower Granite dams. The longer passage time at Lower Granite Dam was likely caused by trapping of the tagged fish in the adult trap in the ladder.

First approaches to fishways by Chinook salmon occurred at all entrances, with a tendency toward shoreline entrances, particularly at Ice Harbor and Lower Granite dams. The highest numbers of first approaches at Bonneville Dam were at Powerhouse I sluice gates and at shoreline entrances. At McNary Dam, the highest number of first approaches were at orifice gates at the southern end of the powerhouse and at north-shore entrances. Median numbers of approaches to fishway entrances by Chinook salmon in 1996 were 19 to 25 at Bonneville, McNary, and Ice Harbor dams and 50 at Lower Granite Dam.

Entrances used by Chinook salmon in 1996 were more restricted than entrances approached. The highest number of first and subsequent entries at Bonneville Dam were at the north-shore, south-spillway, and south-shore entrances. At McNary Dam, most first and subsequent entries were at shoreline entrances, and at both Ice Harbor and Lower Granite dams, most first and subsequent entries were at shoreline and north-powerhouse entrances. Median numbers of entries by Chinook salmon in 1996 were one at Ice Harbor, two at Bonneville and McNary, and three at Lower Granite Dam.

At most fishway entrances more fish entered than exited. Salmon that exited the fishways from the collection channels did so mostly at shoreline and powerhouse entrances closest to the bottoms of ladders and at entrances adjacent to spillways. Overall, however, the shoreline and powerhouse entrances had the highest net number of entries, in part because they were larger entrances, had greater depths, and higher flows. Although many Chinook salmon approached orifice and sluice gates, relatively few used them to enter or exit fishways.

We also analyzed behavior in the fishways and passage time for Chinook salmon that passed Bonneville Dam, fell back over the dam, and subsequently reascended. Overall, 110 fish fell back a total of 130 times, of which 82% initially passed the dam via the Bradford Island fishway. Of the 110 fish, 102 reascended ladders and passed the dam a second time. Fish that had fallen back moved through fishways more quickly, and with fewer entrances and exits from the fishway, on their second passage.

In 1996, entries, exits, movements in, and passage through the transition pools were analyzed for 679 Chinook salmon outfitted with transmitters at Bonneville Dam, 294 at McNary Dam, 86 at Ice Harbor Dam, and 85 at Lower Granite Dam. From 55% to 60% of the Chinook salmon at McNary and Ice

Harbor dams passed through transition pools on the first attempt, without exiting to a collection channel or to the tailrace. At Bonneville Dam, 36% passed through on the first attempt, and at Lower Granite Dam 20% passed the transition pool on the first attempt. Four to 25% turned around in transition pools and moved downstream into the collection channel but did not exit into the tailrace. At McNary and Ice Harbor dams, 27% and 35% of the Chinook salmon monitored turned around in the transition pool, moved downstream, exited the fishway into the tailrace, and then reentered the fishway at least once before passing the dam; at Bonneville and Lower Granite dams, 53 to 55% exited transition pools into the tailrace.

Median time for Chinook salmon with transmitters to first enter a transition pool after entering a fishway ranged from 4 to 11 min at all fishways, except at Lower Granite Dam where median time to first enter the transition pool was 50 min. Median times for all fish from the first entry into a transition pool to entry into a ladder were 35 min to 1.29 h at Bonneville, McNary and Ice Harbor dams and was 3.82 h at Lower Granite Dam. Median times for all Chinook salmon to ascend ladders from a transition pool were 2.1 to 2.9 h at Bonneville, McNary and Ice Harbor dams and was 9.15 h at Lower Granite Dam. Median times for all fish from first fishway entry to exit from the top of a ladder were 8.51 h at Bonneville, 5.62 h at McNary, 3.75 h at Ice Harbor and 25.99 h at Lower Granite dams.

For Chinook salmon that passed through transition pools on their first attempt, median times to pass through the pools ranged from 13 to 23 min (0.22 to 0.38 h) at each dam. Median times for Chinook salmon that moved back into collection channels, but did not exit into the tailrace, were 0.43 to 1.56 h; for Chinook salmon that exited to a tailrace, median passage times through transition pools ranged from 2.00 h at Ice Harbor Dam to 9.19 h at Bonneville Dam. Passage rates differed between individual fishways and pools at each dams based on fishway configuration, but in all cases fish that exited pools into the tailrace had the longest passage times through pools. Median times for all Chinook salmon with transmitters to ascend ladders were between 2.1 and 2.9 h at Bonneville, McNary, and Ice Harbor dams. At Lower Granite Dam, median time to ascend the ladder was 9.2 h.

Median times to pass from first fishway entry to exit from the ladders were 2.52 to 3.95 h for Chinook salmon that moved straight through a transition pool at Bonneville, McNary and Ice Harbor dams and was 20.83 h at Lower Granite Dam. For fish that moved downstream in a transition pool at these two dams but did not exit to a collection channel or tailrace, median times to pass a dam were 3.08 to 4.47 h at the three lower dams and was 22.84 h at Lower Granite Dam. Fish that exited to a collection channel at Bonneville, McNary, and Ice Harbor dams had median times to pass from first fishway entry to exit from the top of a ladder from 3.96 to 4.81 h; for fish that exited to a tailrace at these dams, median times to pass were 7.86 h at Ice Harbor, 22.29 h at McNary, and 17.31 h at Bonneville dams. At Lower Granite Dam, median times to pass from first fishway entry to exit from the ladder were approximately 45 h for fish that did not exit the fishway after exiting the transition pool, and 29 h for fish that exited to the tailrace.

Passage time comparisons based on behavior in transition pools showed that Chinook salmon that exited into the tailrace from transition pools were delayed 7 to > 36 h at Bonneville, 7 to 24 h at McNary, 5 to 20 h at Ice Harbor Dam, and 6 to 8 h at Lower Granite dams. Chinook salmon that moved through pools on their first attempt had the shortest passage times through fishways and past dams in 1996.

We also evaluated behavior in transition pools for 89 Chinook salmon that passed Bonneville Dam, fell back over the dam, and then reascended. Eighty-one had complete transition pool records on both first and second passages of the dam, and for most measures of transition pool passage, median times were shorter on the second passage than on the first. Chinook salmon that fell back had median passage times from first fishway entry to exit from the top of a Bonneville ladder of 8.55 h on the first passage and 5.17 h on the second passage. Fewer fish exited the fishway into the tailrace and more passed through transition pools into ladders on their first attempt than on their second passage of the dam.

Temperature influenced migratory behavior and use of thermal refuges by upriver bright fall Chinook salmon, 1998 and 2000

Goniea, Peery, Bennett **Technical Report 2003-6 Draft**

***Abstract*:** Correlations between lower Columbia River water temperatures and run timing, migration behavior, and tributary use by fall Chinook salmon *Oncorhynchus tshawytscha* were studied using historic counts and radio telemetry data. Over the past 70 years, mean August and September water temperatures recorded at Bonneville Dam have increased, often exceeding the estimated optimal migration temperature for fall Chinook salmon. We found median run passage dates from historic fall chinook count data at Bonneville, The Dalles and McNary dams were positively correlated with mean August water temperatures at Bonneville Dam, suggesting later adult migration timing in warm years.

In 1998 and 2000, we radio-tagged and released 1,032 and 1,118 fall Chinook salmon at Bonneville Dam and monitored their upstream migration. Mean water temperatures in August and September were 1.9°C warmer in 1998 than in 2000, and upriver bright (URB) fall Chinook salmon migrated significantly slower in the warmer year. Lower migration rates in 1998 were due in part to temporary straying by radio-tagged fish: 30.2% of URB salmon were recorded for more than 12 h in lower Columbia River tributaries in 1998, versus 14.5% in 2000. Tagged fish were observed holding in and around the Little White Salmon, White Salmon, Klickitat, and Deschutes rivers, but not at other monitored tributaries. The four tributaries used by tagged fish had relatively high discharges, were 4 to 12°C cooler than ambient Columbia River temperatures during the migrations and entered the Columbia River at sites where cool-water plumes were likely to be encountered by migrating salmon. During both years, use of tributaries was significantly correlated with Columbia River water temperatures. URB fall Chinook salmon that delayed in tributaries for longer than 12 h, and those that fell back at any of the study area dams, were significantly less likely to escape to mid-Columbia or Snake River sites.

An evaluation of adult Chinook salmon and steelhead behavior at counting windows and through vertical-slot weirs of Bonneville Dam using radiotelemetry: 2001-2002

Jepson, Nauman, Peery, Tolotti, Moser **Technical Report 2004-2**

Abstract: We used radio telemetry to evaluate the behavior of spring–summer Chinook salmon, fall Chinook salmon, and steelhead swimming past counting windows and through vertical-slot weirs of the Bradford Island and Washington shore fishways at Bonneville Dam during 2001 and 2002.

Median times to pass a counting window ranged from 2.0 to14.7 min among all run/year/fishway groups (n=12) and were consistently highest for run/year groups initially recorded at the Bradford Island counting window. Ratios of counting window passage times to total dam passage times (first record in tailrace to last record at ladder exit) for individual fish were ≤ 1.0% based on median values, and ≤6.7% based on mean values, of all year/run/fishway groups. The maximum proportion of fish swimming downstream to a transition pool after being recorded at a counting window was for spring–summer Chinook salmon at the Bradford Island counting window in 2001 (2.4%, n=340). The median counting window passage times for all fish that swam to a transition pool after being detected at a counting window was approximately 30 h (n=24).

Proportions of fish recorded upstream of a counting window and then downstream of a counting window (‘up-and-back’ behavior) were consistently highest for steelhead among all run/year groups with a maximum of 11.5% (n=295) at the Bradford Island counting window during 2001. Of the 4,277 unique fish recorded downstream from a counting window during the two study years, 272 (6.4%) exhibited up-and-back behavior and their median counting window passage time was 43 min.

Among all run/year groups, median times to pass through the vertical-slot weirs of the Bradford Island fishway ranged from 26.5 to 33.5 min and 39.7 to 51.8 min for the Washington-shore fishway.

Direct comparisons of passage times between vertical-slot weir sections of the Bradford Island and Washington shore fishways were precluded because of differences in antenna configurations and varying distances between the first vertical-slot weir of each fishway and its corresponding ladder exit.

Based on median values among all run/year groups, ratios of vertical-slot weir passage times to total dam passage times for individual fish were ≤3.8% (mean ≤ 7.3%) for groups initially recorded in the Bradford Island vertical-slot weirs and ≤4.8% (mean ≤9.0%) for the Washington shore vertical-slot weirs. The maximum proportion of fish recorded swimming to a transition pool after being recorded at a vertical-slot weir was for fall Chinook salmon at the Bradford Island fishway in 2001 (1.5%, n=204). Overall, 0.6% of fish (n=4,277) swam to a transition pool after being detected in a set of vertical- slot weirs and their median passage time was 95.3 h. Six fish (0.1%) were recorded in a set of vertical-slot weirs, swam to a transition pool, and did not pass the dam.

On average, the combined passage of count windows and vertical-slot weirs at termini of the Bonneville fishways accounted for 6.9 to11.8% of total dam passage times among all run/year/fishway groups and 2.8 to 5.6% based on median values.

Analyses assessing the degree of association between counting window or vertical- slot weir passage times and total dam passage times suggested the correlations were positive, but weak. Linear regression models using median weekly passage times as dependent variables and mean daily fish counts (during corresponding weeks) as predictors suggested that steelhead were slightly more likely than Chinook salmon to have increased passage times during periods of high fish counts. On balance, however, any effects of high fish abundance on counting window or vertical-slot weir passage times were believed to be small.

Evaluation of fallback of adult salmon and steelhead via juvenile bypass systems at Bonneville, John Day, McNary, John Day, and Ice Harbor Dams: 2001-2002

Jepson, Bjornn, Peery, Keefer, Tolotti, Moser **Technical Report 2004-3**

Abstract: We used radiotelemetry techniques to assess the fallback behavior of adult spring, summer, and fall Chinook salmon and steelhead via juvenile bypass systems (JBS) at Bonneville, John Day, McNary, and Ice Harbor dams in 2000 and 2001. Of the 868 fallback events recorded at the four dams during the two study years, 77 (8.9%) were via a JBS; 22 by spring-summer Chinook salmon, four by fall Chinook salmon, and 51 by steelhead. Sixty-one percent of all JBS fallback events occurred in 2001. Fifty-six percent of them occurred at McNary Dam. The median JBS residency time was 10.4 h based on minimum estimates and 60.2 h based on maximum estimates.

Sixty-one percent of all JBS fallback events were followed by reascension while 70% of all fallback events via other routes were followed by reascensions. Of those fish that did not reascend the dam after a JBS fallback, 67% (n=6) of the spring-summer Chinook salmon, 0% (n=2) of the fall Chinook salmon, and 57% (n=23) of the steelhead were recorded entering a downstream tributary or were recaptured at a downstream hatchery. We believe some JBS fallback events may have been attributed to fish that overshot their natal tributaries and returned downstream to enter them.

JBS fallback proportions for spring-summer Chinook salmon were consistently higher at all dams in 2001 than in 2000. We believe the higher JBS fallback proportions in 2001 may have been associated with low spillway discharge volumes. We discerned no pattern between JBS fallback proportion and spill when we made similar comparisons for fall Chinook salmon or steelhead and speculate this may have been because the majority of their migrations occurred during periods of relatively little or no spill in both years.

Of the 76 unique fish with transmitters that experienced a JBS fallback event at one of the four dams during the two study years, 28 (37%) were recorded passing Lower Granite or Priest Rapids Dam, 21

(27%) were last recorded entering a tributary downstream of Lower Granite or Priest Rapids Dam, two (3%) were captured in a mainstem fishery, and we could not account for 25 (33%).

Adult Chinook salmon and steelhead fallback at Bonneville Dam, 2000-2001

Boggs, Keefer, Peery, Moser **Technical Report 2004-4**

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

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

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

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

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

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

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

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

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

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

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

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

An evaluation of the effects of spill basin drilling on salmon and steelhead passage at Lower Monumental Dam in 2002 using radio-telemetry

Jepson, Joosten, Peery, Moser **Technical Report 2004-6**

Abstract: Construction work associated with a new spill basin bottom occurred during the evening hours (1600-0230 hrs) on 46 of the 61 days between 19 August and 18 October 2002 at Lower Monumental Dam. We monitored the movements of adult fall Chinook salmon Oncorhynchus tshawytscha and steelhead O. mykiss outfitted with radio transmitters and determined the time they used to make their first approach and first entrance at a monitored fishway opening, and their total time to pass the dam. We compared values from 2002, when construction occurred, with those from the preceding two years, prior to construction. We additionally compared the proportionate use by salmon and steelhead of the three available openings (orifice gates were closed in 2000-2002) to first approach and first enter the dam. We also examined proportionate use of the two fish ladders to pass the dam. All of these comparisons were made across the three years to evaluate any changes in adult fish behavior that may have been associated with construction activity.

We found no significant difference among years in the median times fall Chinook salmon required to first approach, first enter, or pass Lower Monumental Dam. We did find significant differences among years in the proportionate use of the three openings to first approach the fishways at the dam and in proportionate use of the two ladders to pass the dam, but found no significant difference among years in the proportionate use of the openings to first enter fishways at the dam. While there were no significant differences among years in the median times to first approach, first enter, or pass the dam, the highest proportionate use of the north shore entrance (NSE) to first approach, and the north shore ladder (NSL) to pass the dam, occurred in 2002. This may have been associated with salmon avoiding the construction area, which was closer to the south powerhouse entrance (SPE) and south spillway entrance (SSE).

We found significant differences among years in the median times steelhead used to first approach, first enter, and pass Lower Monumental Dam but the highest median times to first approach and first enter a fishway did not occur during 2002. The median time for steelhead to pass Lower Monumental Dam was highest in the year with construction (2002) but it was not significantly different from the median time observed in 2000. We also found significant differences among years in the proportionate use of the three fishway openings by steelhead to first approach and first enter the fishways, and in use of the two ladders to pass the dam. As with fall Chinook salmon, we believe this may have been associated with steelhead avoiding the construction area.

We concluded that construction activity at Lower Monumental Dam in 2002 did not significantly retard fall Chinook salmon passage, may have mildly impeded steelhead passage, and may have caused an increased proportion of fish to use the opening and ladder on the north shore to preferentially approach, enter, and pass the dam.

Migration behavior of adult Chinook salmon and steelhead released in the forebay of Bonneville Dam, 2000-2001

Boggs, Keefer, Tolotti, Peery, Bjornn, Stuehrenberg **Technical Report 2004-7**

Abstract: In 2000 and 2001, we evaluated the efficacy of potential sites for a new or modified Bradford Island fishway exit to reduce fallback of adult salmon and steelhead at Bonneville Dam. Radio-tagged salmon and steelhead were released on the Oregon shore just upstream from the navigation lock, on the north and south (2000 only) sides of the downstream end of the navigation lock guidewall and at the upstream end (2001 only) of the navigation lock guidewall. Telemetry records were used to determine migration routes through the forebay and the number and type of fallback events by fish released at these sites, we also documented the fallback behavior of radio-tagged fish released downstream from the dam that passed the Bradford Island fishway.

In 2000, forebay migration routes were determined for 131 spring–summer Chinook, 253 fall Chinook and 260 steelhead released in the forebay and 462 spring–summer, 330 fall Chinook and 328 steelhead released downstream from the dam that passed the Bradford Island fishway. Most (72-82%) fish released at the three forebay sites were only recorded by telemetry receivers located on the Oregon shore or the south side of Bradford Island (south shore migrants) as they migrated out of the forebay. The remaining 18-28% of forebay- released fish were recorded in the forebay of the spillway or along the Washington shore. By comparison, significantly higher proportions (50-61%) of downstream-released fish that exited the Bradford Island fishway were recorded in the spillway forebay or along the Washington shore. Fallback rates for spring–summer Chinook and steelhead released in the forebay were significantly lower than rates of fish that exited the Bradford Island fishway. Fall Chinook released in the forebay fell back at significantly higher rates than those that passed the Bradford Island fishway; most fallbacks by forebay-released fall Chinook were through the navigation lock.

In 2001, forebay migration routes were determined for 297 spring–summer Chinook, 360 fall Chinook and 297 steelhead released in the forebay and 307 spring–summer, 170 fall Chinook and 265 steelhead released downstream from the dam that passed the Bradford Island fishway. Most (59-68%) fish released at the three forebay sites were determined to be south shore migrants; the remaining 32-41% were recorded in the spillway forebay or along the Washington shore. Between 48 and 70% of downstream-released fish that exited the Bradford Island fishway were recorded in the forebay of the spillway or along the Washington shore. These proportions were significantly lower for spring–summer Chinook released at all three forebay release sites and for steelhead released at one of three sites. Fallback rates for forebay-released fish were in all cases significantly higher than rates for fish that passed the dam via the Bradford Island fishway; most fallbacks by forebay-released fish occurred through the navigation lock.

Migration depths of adult spring-summer Chinook salmon in the Lower Columbia and Snake Rivers in relation to dissolved gas supersaturation

Johnson, Clabough, Peery, Bennett, Bjornn, Stuehrenberg Technical Report 2004-8

Abstract: Dissolved gas supersaturation in the Columbia and Snake rivers routinely occurs during the spring and summer freshet as a result of water spilling over dams and can be lethal to fish. Measurable plumes of high dissolved gas extend downstream of dam spillways and create gas supersaturated conditions that do not equilibrate in reservoirs. Based on modeling results, the extent of the dissolved gas plume downstream from Bonneville Dam before dissipating is at least 10 km and the lateral position of the plume is highly dependent on dam powerhouse operation and spill volume.

During the spring and summer of 2000, 228-adult Chinook salmon Oncorhynchus tshawytscha were tagged at Bonneville Dam with archival radio data storage transmitters (RDSTs) that recorded depth of migration every 5 s and water temperature every 1 min. Migration depth is instrumental in determining levels of exposure due to the effects of hydrostatic pressure that provides compensation that limits the effects of supersaturation (hydrostatic compensation). We evaluated the swimming depths of 131 fish with RDSTs to determine in situ swimming depths in relation to water with elevated dissolved gas concentrations as they migrated from the Bonneville Dam tailrace upstream to Lower Granite Dam. Migration paths of 54 individual fish were monitored in the tailraces of Bonneville and Ice Harbor dams and collaborated with output from a two-dimensional dissolved gas model to estimate exposure levels.

We found that adult spring–summer Chinook salmon spent a majority of their time at depths deeper than 2 m (providing at least 20% hydrostatic compensation), and only several minutes at a time at depths shallower than 2 m. The most successive time an individual fish was observed shallower than 1 and 2 m deep was 1.3 h and 19.5 h, respectively. These behaviors suggest that adult salmon exposure to elevated levels of dissolved gas should have been minimal in 2000.

Based on analysis of locations of 54 fish and dissolved gas model results downstream of Bonneville and Ice Harbor dams, uncompensated exposure based on modeled dissolved gas levels (typically less than 130% TDGP) was estimated to be 4.1% of the time fish spent in the Bonneville tailrace and 11.9 % of the time spent in the Ice Harbor tailrace. Less than 1% of this exposure was at or higher than 115% which is considered a conservative level of exposure known to cause GBD and mortality. Adult spring–summer Chinook salmon tended to migrate near the shoreline with approximately equal proportions of fish entering or leaving areas of the river with elevated dissolved gas levels. No significant association existed between crossing the river and the position of the dissolved gas plume downstream of Bonneville Dam. Statistical associations were also weak between dissolved gas concentrations and the percent and duration of time fish occupied near-surface waters.

We recommend that efforts should be made to direct higher dissolved gas water from the spillway away from shorelines to minimize the potential for exposure. Additional research is needed to quantify the effects of short but frequent exposure to supersaturated dissolved gas conditions on reproductive potential and survival.

Migration of adult sockeye salmon past Columbia River dams, through reservoirs and distribution into tributaries, 1997

Naughton, Keefer, Bjornn, Jepson, Peery, Tolotti, Ringe, Keniry, Stuehrenberg

Technical Report 2004-10

Abstract: We captured 577 sockeye salmon Oncorhynchus nerka in the adult trapping facility at Bonneville Dam in 1997, released them with radio transmitters, and studied their passage past dams, through reservoirs and into tributaries. We set up radio receivers at Columbia and Snake river dams and at the mouths of major tributaries to monitor movements of salmon. Recaptures of salmon at hatcheries, weirs and traps, and data from mobile tracking were used to complete the migration history.

We believe 570 fish retained transmitters beyond the release site and migrated upstream. Of the 570 fish, 100% returned to the Bonneville Dam tailrace and 98.6% were known to have passed the dam. Eighty-six percent of the 570 fish passed The Dalles Dam, 82% passed John Day Dam, 80% passed McNary Dam, 76% passed Priest Rapids Dam, 75% passed Wanapum Dam, 73% passed Rock Island Dam and 42% passed Rocky Reach Dam.

Median times for sockeye salmon to pass individual Columbia River dams ranged from 0.3 d at The Dalles Dam to 1.4 d at Rocky Reach Dam. Median passage rates through reservoirs ranged from 36.4 km/d through the McNary pool to 64.7 km/d through the John Day pool. Median times to pass through reservoirs ranged from 0.6 d to 4.6 d. The median migration rate through the unimpounded Hanford Reach on the mid-Columbia River was 28.2 km/d. From first passage of the tailrace at Bonneville Dam, median passage times past multiple dams were 6.9 d to the top of McNary Dam, 17.3 d to the top of Rock Island, and 19.0 d to the top of Rocky Reach Dam.

In 1997, sockeye passed Bonneville Dam from late May through late August, with peak counts occurring in early and mid-July. Passage times for tagged fish at individual dams, were not strongly correlated with flow, spill, or turbidity. Cumulative passage times past multiple projects was negatively correlated with the date fish first passed the Bonneville Dam tailrace, with later migrating fish migrating at faster rates than those earlier in the migration. However, the relationship was weak with r2 values < 0.3. Turbidity, spill, and flow at lower Columbia River dams explained relatively low proportions of the variability in passage times past multiple dams.

The incidence of marine mammal injuries, descaling, and head injuries at time of tagging varied significantly during the migration. Injuries, however, appeared to have a limited impact on fish passage times. Marine mammal and descaling injuries also did not appear to affect fallback rates, but fish with head injuries fell back at dams at significantly higher rates than fish without head injuries.

At least 164 sockeye salmon, 29% of the fish with transmitters that passed Bonneville Dam, fell back over or through Bonneville or other dams 181 times in 1997. Forty-three percent of all fallback events occurred at Bonneville Dam. One to seven percent of the fish that passed The Dalles, John Day and McNary dams fell back; 2 to 7% fell back at Priest Rapids, Wanapum, Rock Island and Rocky Reach dams. Fallbacks at any dam added to overall passage time past multiple dams. Using median passage times, one or more fallbacks at any dam added 1 to 7 days to overall passage time when compared to fish that did not fall back, differences, that were significant at lower Columbia River dams, but not at middle Columbia River Dams. Fish that fell back multiple times had the longest median passage times.

About 87% of sockeye salmon that fell back subsequently reascended all dams where they fell back. Of fish that did not reascend, about 27% subsequently entered tributaries downstream from the location of the fallback and probably did not reach spawning areas. From 63 to 100% of sockeye salmon that fell back at Columbia River dams eventually returned to tributary sites up- or downstream from the dam where they fell back. At most individual dams, sockeye salmon that fell back escaped to tributaries at significantly lower rates than fish that did not fall back.

Migrations into individual tributaries were typically spread over 6 to 8 weeks. Because we did not monitor some mid-Columbia River tributaries with fixed receivers, sockeye arrival at the first dam downstream was used as a surrogate for arrival at those sites. The median date sockeye salmon passed Rock Island Dam was 19 July for Wenatchee River stocks. The median first date at Wells Dam was 20

July for Methow and Okanogan river stocks, including those fish last recorded at Wells Dam. The median passage date at Bonneville Dam was 29 June for both Wenatchee and Okanogan river stocks. Reach survival estimates within the main stem Columbia/Snake river hydrosystem exceeded 96% for all sampled reaches. Reach survival estimates in the lower Columbia River were between 96% and 98% and estimates were > 97% through the mid-Columbia River reaches.

About 17% of tagged fish were reported recaptured in fisheries, at hatcheries, weirs or traps, at spawning grounds, or their transmitters were found along river corridors. Sixty-eight percent of reported recaptures were in tribal fisheries, 22% at spawning grounds, 7% at weirs or traps, and 3% in sport fisheries. About two-thirds of all recaptures were in the lower Columbia River and one-third was in the mid-Columbia River basin.

Our best estimate of the final fate for all radio-tagged sockeye salmon in 1997 was 2.8% downstream from Bonneville Dam, 18% between the top of Bonneville Dam and the McNary Dam tailrace, 5% between the top of McNary Dam to the Priest Rapids Dam tailrace, 37% in the Columbia River between the top of Priest Rapids Dam to Wells Dam, and 38% upstream from Wells Dam. Escapements were 68.5% in tributaries,12.1% were reported recaptured in main stem tribal or sport fisheries and one fish (0.2%) was reported captured in tributary sport fishery, 3.1% of transmitters were known or presumed regurgitated in non-spawning areas, and 16.1% were unaccounted for. Most notably, only a single sockeye salmon of 27 (3.7%) tagged at Bonneville Dam during the period 24 July – 5 August successfully reached a spawning tributary.

Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated transmitters that were not recovered or located, may have entered tributaries undetected, may have spawned at main stem locations, or may have died and were not detected as mortalities. The largest proportion of unaccounted-for fish (16.1%) were last recorded between the top of Rocky Reach Dam and the tailrace of Wells Dam. Another 15% were last recorded between the top McNary Dam and the tailraces of Priest Rapids and Ice Harbor dams.

An Evaluation of adult Chinook salmon and steelhead behavior at counting windows of McNary Dam during 2002 & 2003 and the north shore counting window at Ice Harbor Dam during 2003

Jepson, Nauman, Peery, Dick, Burke

Technical Report 2004-11 Draft

Abstract: We used radio telemetry to evaluate the behavior of adult spring–summer Chinook salmon, fall Chinook salmon, and steelhead swimming past counting windows and through adjustable overflow weirs of the Oregon and Washington shore fishways at McNary Dam during 2002 and 2003. Similarly, we evaluated their behavior at the counting window and through the vertical-slot weirs of the North shore fishway at Ice Harbor Dam during 2003.

At McNary Dam, median times to pass a counting window ranged from 5.9 to19.1 min among all run/year/fishway groups (*n*=12) and were consistently highest for run/year groups initially recorded at the Washington shore counting window. Among all year/run/fishway groups, ratios of counting window passage times to total dam passage times (first record in tailrace to last record at ladder exit) for individual fish were ≤ 4.1% based on median values and ≤13.4% based on mean values. The maximum proportion of fish swimming downstream to a transition pool after being recorded at a counting window was for fall Chinook salmon at the Washington shore counting window in 2002 (9.5%, *n*=242). The median counting window passage times for all fish that swam to a transition pool after being detected at a counting window was approximately 23 h (*n*=99).

The median counting window passage times at the North shore fishway of Ice Harbor Dam ranged between 9.9 min for spring–summer Chinook salmon (*n*=30) and 21.2 minutes for fall Chinook salmon (*n*=4). Ratios of counting window passage times to total dam passage times for individual fish were ≤ 2.4% based on median values and ≤ 4.7% based on mean values. No fish swam to a transition pool from the North shore counting window (*n*=57).

Proportions of fish recorded upstream from a counting window and then downstream from a counting window ('up-and-back' behavior) were typically highest for steelhead among all run/year groups with a maximum of 4.5% (*n*=156) at the Washington shore counting window at McNary Dam during 2002. Of the 3,243 unique fish recorded downstream of a counting window at McNary Dam during the two study years, 63 (1.9%) exhibited up-and-back behavior at a counting window and their median time to pass a counting window was 42.9 min. Twenty-three percent of the spring–summer Chinook salmon recorded at Ice Harbor Dam (*n*=30) exhibited up-and-back behavior but their median window passage time was slightly less than for fish that did not exhibit the behavior.

Among all run/year groups at McNary Dam, median times to pass the adjustable overflow weirs ranged from 14.2 to 21.8 min for the Oregon-shore fishway and 12.1 to 19.0 min for the Washington-shore fishway. Median times to pass the vertical-slot weirs at Ice Harbor Dam ranged from 10.3 to 13.4 min based on median values and 15.0 to 47.7 min based on means.

Among all run/year groups, ratios of median adjustable overflow weir passage times to total median dam passage times for individual fish were ≤3.0% (*mean* ≤ 5.5%) for groups initially recorded in the Oregon shore adjustable overflow weirs and ≤2.6% (*mean* ≤ 4.5%) for those first recorded at the Washington shore adjustable overflow weirs. Passing the vertical-slot weirs at Ice Harbor Dam comprised ≤ 2.2% of total dam passage times (medians) and ≤ 6.2% (means) among runs.

Overall, 0.2% of fish (*n*=3,152) swam to a McNary Dam transition pool after being detected in a set of adjustable overflow weirs and their median passage time was approximately 22 h (n=6). At Ice Harbor Dam, two fish were recorded swimming downstream to a transition pool from the vertical-slot weirs in the North shore fishway and they ultimately passed the dam via the South shore ladder.

The combined passage of counting windows and adjustable overflow weirs at termini of the McNary Dam fishways accounted for 3.1 - 8.5% of total dam passage times based on medians, and 5.1 -17.3% of total dam passage times (means) among all run/year/fishway groups. The combined passage of the counting window and vertical-slot weirs at the North shore fishway of Ice Harbor Dam accounted for 3.2 - 5.6% of total dam passage times based on medians (means = 5.4 – 14.7%).

Analyses assessing the degree of association between counting window or weir passage times and total dam passage times suggested the correlations were positive, but weak. Linear regression models using median weekly passage times as dependent variables and mean daily fish counts (during corresponding weeks) as predictors suggested that effects of high fish abundance on counting window or weir passage times were small.

Escapement, harvest, and unaccounted for loss of radio-tagged adult Chinook salmon and steelhead in the Columbia-Snake River hydrosystem, 1006-2002

Keefer, Peery, Daigle, Jepson, Lee, Boggs, Tolotti, Bjornn, Burke, Moser, Stuehrenberg

Technical Report 2005-2

Abstract: Accurate estimates of escapement by adult anadromous salmonids are difficult, especially in large, multi-stock river systems. We used radiotelemetry, a fishery reward program, and help from cooperating agencies and hatcheries to calculate escapement, harvest, and unaccounted-for loss rates for 10,498 adult Chinook salmon (Oncorhynchus tshawytscha) and 5,324 steelhead (O. mykiss) during six migration years in the Columbia River basin. Mean annual escapements to spawning sites, hatcheries, or the upper bounds of the monitored hydrosystem (top of Lower Granite or Priest Rapids dams) were 73.4% (spring–summer Chinook salmon), 61.3% (fall Chinook salmon) and 62.6% (steelhead). Mean reported harvest rates were 8.7% (spring–summer Chinook), 22.0% (fall Chinook) and 15.1% (steelhead) within the mainstem hydrosystem, and 5.9, 3.4 and 5.7%, respectively, in lower hydrosystem tributaries. Harvest-adjusted escapement means for the monitored hydrosystem were 87.5% (spring–summer Chinook), 86.7% (fall

Chinook), and 83.4% (steelhead). On average, 12 to 17% of each run had unknown fates within the mainstem hydrosystem.

Escapement, harvest, and loss varied significantly between runs and years, within annual runs, among known-source (PIT-tagged) stocks, and between inter-dam river reaches. Reach escapements tended to be lowest through the Bonneville-The Dalles reach, and increased as fish progressed upstream through the lower Columbia River. Reach escapements were highest in the lower Snake River. Escapement differences among known-source stocks—and between known-source and the randomly-collected unknown-source groups—were statistically significant in some years.

Fallback at dams had a consistently negative impact on escapement. For randomly- collected groups, decreases in harvest-adjusted escapement averaged 6.5% for spring– summer Chinook salmon, 19.5% for fall Chinook salmon, and 13.2% for steelhead that fell back. Fallback impacts on known-source groups were generally similar to the randomly-collected groups, except decreases were higher for Snake River spring– summer Chinook (mean = 15.8% decrease). Fallback was associated with negative population-level impacts on escapement ranging from 1 to 4%. Annual spring–summer Chinook salmon escapement was negatively correlated with Columbia River discharge, but not temperature. In contrast, fall Chinook and steelhead escapements were not correlated with either discharge or temperature metrics.

This multi-year quantitative assessment should provide managers a comprehensive review of adult salmonid fates within the federal hydrosystem. The results reduce uncertainty, clarify inter- and intra-annual variability, and can help managers better evaluate fisheries, operate the hydrosystem, identify conservation priorities, and help protect evolutionarily significant populations.

Adult salmon and steelhead passage times through hydrosystem and riverine environments of the Columbia River Basin, 1996-2002

Keefer, Peery, Jepson, Bjornn, Stuehrenberg **Technical Report 2005-3**

Abstract: We assessed upstream migration rates of more than 12,000 radio-tagged adult spring–summer and fall Chinook salmon (*Oncorhynchus tshawytscha)* and steelhead (*O. mykiss*) past Columbia and Snake river dams, reservoirs and longer hydrosystem reaches that included multiple dams and reservoirs. Passage rates were also calculated for 1,800 spring–summer Chinook salmon as they passed through 12 unimpounded reaches and tributaries. Most radio-tagged fish from all runs passed mainstem Columbia and Snake River dams in less than two days. Migration behavior in reservoirs and through multiple dam/reservoir reaches varied substantially within and between years and between species. Within years, spring– summer Chinook salmon migrated more rapidly as water temperature and date of migration increased; between years, spring–summer Chinook salmon migrated quickly in low-discharge years and slowly in high-discharge years. Steelhead migrations slowed dramatically when summer water temperatures peaked within each year then increased as rivers cooled in fall. Mean summer temperatures explained more between-year variation in steelhead passage rates than did differences in discharge. Fall Chinook salmon also slowed migration through the mainstem Columbia River during warm water periods. Protracted passage times within the hydrosystem were most likely for fish from all runs that fell back over and reascended dams, and for steelhead that sought thermal refugia by straying temporarily into coldwater tributaries. In tributaries and unimpounded reaches, migration date explained the most variance in spring–summer Chinook salmon migration rates while river discharge, migration year and migration reach were secondary. Both within and between years, spring–summer Chinook salmon migrated more rapidly as migration date increased and more slowly when discharge was high.

Straying rates of known-origin adult chinook salmon and steelhead within the Columbia River Basin, 2000-2003

Keefer, Peery, Firehammer, Moser **Technical Report 2005-5**

Abstract: As part of a large-scale radiotelemetry study of Columbia River adult salmon and steelhead (*Oncorhynchus* spp.), we investigated permanent inter-basin straying by several important known-origin stocks. From 2000 to 2003 we radio-tagged 1,588 spring–summer Chinook salmon, 166 fall Chinook salmon, and 1,414 steelhead at Bonneville Dam that had been PIT-tagged as juveniles in tributaries, at hatcheries or at Snake or Columbia River dams. The largest samples were from the Snake River basin, including about 49% of spring–summer Chinook salmon, 73% of fall Chinook salmon, and 64% of steelhead. Between 16 and 33% of the samples were from the Columbia River basin upstream from Priest Rapids Dam, and 14% of the spring–summer Chinook were from the Yakima River.

Overall, 2.2% of spring–summer Chinook salmon, 4.2% of fall Chinook salmon, and 6.8% of steelhead strayed into non-natal tributaries. Rates varied somewhat between years, but most inter-annual differences were not statistically significant. Among spring–summer Chinook salmon, fish from the Wind River basin strayed at the highest rate (9.7%), while stray rates for Yakima, Snake, and upper Columbia stocks were between 0.4 and 2.1%. Steelhead from upper Columbia and Snake River sites strayed at comparable rates (5.6 and 7.0%), but Snake River fish tended to stray into Oregon-shore tributaries and upper Columbia fish mostly strayed into Washington-shore tributaries. Strays mostly entered cold- water tributaries, particularly the Little White Salmon, Deschutes and White Salmon rivers. Many strays from the Snake River also entered the John Day River.

Fish of certain hatchery origin (with fin clips) and those that were transported as juveniles were consistently more likely to stray. Adult fallback at dams was also strongly associated with increased straying, particularly among fish that fell back multiple times. Early-migrating steelhead were more likely to stray than later migrants, likely reflecting differential exposure to high water temperatures in the lower Columbia River. Results should be useful for managers responsible for monitoring inter-basin straying, measuring adult salmon and steelhead escapement, and aiding recovery of listed Columbia River populations.

Fallback, reascension and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake River dams, 1996-2003

Boggs, Keefer, Peery, Stuehrenberg, Burke **Technical Report 2005-6**

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.

Adult steelhead passage through fishways and transition pools at Bonneville, McNary, and Lower Granite Dams -1996

Stuehrenberg, Keefer, Peery, Tolotti, Ringe, Bjornn, Burke **Technical Report 2005-7**

Abstract: Evaluation of fishway entrances used and passage through fishways by steelhead *Oncorhynchus mykiss* at dams in the lower Columbia and Snake rivers were objectives of the adult salmon and steelhead hydrosystem passage project. In 1996, we monitored passage through the fishways by outfitting steelhead with radio transmitters and installing full antenna/receiver coverage at Bonneville, McNary, and Lower Granite dams. Critical parameters studied were passage times for a fish to first approach the dam and first enter a fishway, total time to pass over the dam, which entrances were approached, where fish entered and exited the fishways, and their passage through transition pools and over the dams.

In 1996, 765 steelhead were outfitted with radio transmitters at the adult trapping facility adjacent to Bonneville's Washington-shore fishway and then released ~10 km downstream from the dam at Dodson and Skamania landings. Of these fish, 735 were subsequently recorded at Bonneville Dam tailrace monitors or in the Bonneville Dam fishways, 401 were recorded at McNary Dam, and 264 were at Lower Granite Dam. Median passage times from release after tagging to first tailrace record at the four dams were 0.3, 20.0, and 41.8 d.

After passing a tailrace receiver, median times for steelhead to first approach fishways in 1996 were 2.47 h at Bonneville Dam, 2.35 h at McNary Dam, and 2.04 h at Lower Granite Dam. Median times from tailrace receivers to first enter fishways were 3.62 h at Bonneville, 3.34 h at McNary, and 5.06 h at Lower Granite dams. Median times from tailrace receiver to exit from the top of a ladder were 17.02 h at Bonneville, 10.39 h at McNary, and 25.97 h at Lower Granite Dam. The longer passage time at Lower Granite Dam was likely caused by trapping of the tagged fish in the adult trap in the ladder.

First approaches to fishways by steelhead occurred at all entrances, with a tendency toward shoreline entrances. The highest number of first approaches at Bonneville Dam were at shoreline entrances and entrances adjacent to the spillway. At McNary and Lower Granite Dams, the highest number of first approaches were at orifice-gate and shoreline entrances. Median numbers of pre- fallback approaches to fishway entrances by steelhead in 1996 were 9 at Bonneville and McNary dams and 10 at Lower Granite Dam.

Entrances used by steelhead in 1996 were more restricted than entrances approached. The highest number of first and subsequent entries at Bonneville Dam were at the powerhouse 2 north-shore entrance, the south-spillway, and the powerhouse 1 south-shore entrances. At McNary and Lower Granite dams, most first and subsequent entries were at south-shoreline entrances and the north end of the powerhouse. Median number of entries by steelhead in 1996 was two at Bonneville and one at McNary and Lower Granite dams. At most fishway entrances more fish entered than exited. Steelhead that exited the fishways from the collection channels did so mostly at the large entrances at the ends of the powerhouse collection channels, at shoreline entrances and at the entrances closest to the bottoms of ladders. Overall, the net number of entries were positive. Although many steelhead approached orifice and sluice gates, relatively few used them to enter or exit fishways.

We also analyzed behavior in the fishways and passage time for steelhead that passed Bonneville Dam, fell back over the dam, and subsequently reascended. Overall, 37 fish fell back a total of 40 times, of which 84% initially passed the dam via the Bradford Island fishway. Of the 37 fish, 29 (78%) ascended ladders and passed the dam a second time. Fish that fell back moved through fishways more slowly, but had fewer entrances and exits from the fishway, on their second passage.

In 1996, entries, exits, movements in, and passage through the transition pools were analyzed for

615 steelhead outfitted with transmitters at Bonneville Dam, 316 at McNary Dam, and 192 at Lower Granite Dam. The most efficient passage through a transition pool occurred at McNary Dam where about 51% of the steelhead passed through on the first attempt, without exiting to a collection channel or to the tailrace. At Bonneville Dam, 45% passed through on the first attempt, and at Lower Granite Dam 29% passed the transition pool on the first attempt. Of the steelhead that turned around in transition pools, 8 to 23% moved downstream into the collection channel but did not exit into the tailrace. Between 41 and 48% of the steelhead monitored at the dams turned around in transition pools, moved downstream, exited the fishway into the tailrace, and then reentered the fishway at least once before passing.

Median time for all steelhead with transmitters to first enter a transition pool after entering a fishway ranged from 4 to 7 min at all dams. Median times from the first entry into a transition pool until final entry into a ladder were 37 to 50 min for all fish. Median times for all steelhead to ascend ladders from a transition pool were 2.38 h at Bonneville, 2.23 h at McNary, and 7.32 h at Lower Granite dams. Median times from first fishway entry to exit from the top of a ladder were 4.26 h at McNary, 6.17 h at Bonneville, and 17.55 h at Lower Granite dams.

For steelhead that passed through transition pools on their first attempt, median times to pass through the pools ranged from 7 to 26 min (0.12 to 0.44 h) at each dam. Median times for steelhead that moved back into collection channels, but did not exit into the tailrace, were 0.34 to 1.09 h; for steelhead that exited to a tailrace median passage times through transition pools ranged from 3.98 h at McNary Dam to 10.40 h at Lower Granite Dam. Passage rates differed between individual fishways and pools at each dams based on fishway configuration, but in all cases fish that exited pools into the tailrace had the longest passage times through pools.

Median times to pass from first fishway entry to exit from the ladders were 2.68 to 2.91 h for steelhead that moved straight through a transition pool at Bonneville and McNary dams. For fish that moved downstream in a transition pool at these two dams but did not exit to a collection channel or tailrace, median times were 3.31 to 3.49 h, and for fish that exited to a collection channel at Bonneville and McNary dams, median times to pass from first fishway entry to exit from the top of a ladder were 3.53 to 4.26 h. For fish that exited to a tailrace at these dams, median times to pass ranged from 7.36 to 13.94 h. At Lower Granite Dam, median times to pass from first fishway entry to exit from the ladder were approximately 11.46 h for fish that did not exit the fishway after exiting the transition pool, and 23.89 h for fish that exited to the tailrace at Lower Granite Dam.

Passage time comparisons based on behavior in transition pools showed that steelhead that exited into the tailrace from transition pools were delayed 3 to 23 h at Bonneville, 2 to 15 h at McNary, and 8 to 16 h at Lower Granite dams. Steelhead that moved through pools on their first attempt had the shortest passage times through fishways and past dams in 1996.

Energy use, migration times, and spawning success of adult spring-summer Chinook salmon returning to spawning areas in the South Fork Salmon River in Central Idaho, 2002 and 2003

Pinson, Peery, Congleton, Moser **Technical Report 2005-8 Draft**

*Abstract***:** Adult salmon do not feed during the spawning migration and rely on lipid and protein stores for energy to swim upstream and spawn. Behavior during migration, the rate at which energy is depleted, and ultimately reproductive success may be affected by river conditions (temperature and flow) and dam operations (e.g., spill, proportion of powerhouse flow, etc.) occurring during the spawning migration. Adult Chinook salmon, *Oncorhynchus tshawytscha*, must pass eight hydroelectric dams and reservoirs and migrate over 1000 river kilometers to reach spawning areas in the South Fork Salmon River in central Idaho. The goal of this study was to determine relationships between estimates of energy use, migration time, and reproductive success of adult Chinook salmon.

Chinook salmon originating in the South Fork Salmon River were sampled at four stages of migration: the nominal start of migration (arrival at Bonneville Dam 235 km upstream from the mouth of the Columbia River), arrival at the South Fork Salmon River, after pre-spawning death and after post-spawning death in the South Fork Salmon River. The lipid and protein reserves of the skin, muscle, viscera, and gonad tissue of all study fish were quantified to determine how these reserves were utilized to meet the costs of migration and reproduction. Energy content was compared for each stage. Energy content and reproductive costs were related to fish length (fork length) for both sexes. Energy for migration and for gamete development during migration was supplied primarily by lipid reserves. In addition, female Chinook salmon used protein reserves to some degree prior to completion of migration. More than half of the initial energy reserves were used during migration. After arrival at the spawning stream, energy for final gamete development and reproductive behavior was obtained largely from metabolism of protein reserves. Females expended up to 90% and males up to 80% of initial energy reserves from the beginning of the spawning migration to the completion of spawning. The observed decrease in energy reserves during migration and spawning was in the upper range of that reported for other salmonid stocks making long migrations in unimpounded rivers. The relatively large proportion of initial energy reserves used during migration and high total energetic requirements of migration and spawning suggest that increases in energetic expenditures during migration or reductions in initial reserves caused by changing ocean conditions could affect reproductive success during some years.

A non-lethal method for determining the energy content of individual fish during the spawning migration at several sampling locations was developed to relate migration patterns, energy use and reproductive success. Three non-destructive methods (morphometrics, bioelectrical impedance analysis [BIA], and biopsy) were assessed using linear and quadratic regression. Morphometrics alone estimated lipid and energy content with reasonable accuracy ($R^2 = 0.90$). Measures of BIA were poor to reasonable estimators of water content: single variable regressions accounted for 12 to 72% of the variance in water content. However, BIA measures did not contribute significantly to multiple regression models that also included morphometrics. Using muscle biopsy, percent muscle lipid was estimated from percent muscle moisture of a small tissue biopsy with quadratic regression ($R^2 = 0.75$). We concluded that morphometric data (including body mass) provided the best non-lethal method to estimate energy condition of live fish in the field. This method could be improved by using standardized photographs of fish in the field; morphometrics could then be determined at a later time, reducing handling of fish. Morphometrics should prove to be a useful, non-lethal tool for further investigations into the relationship between energy expenditure, migration behavior, and reproductive success of adult Chinook salmon. Continued use of morphometrics and other recently developed technologies to monitor the initial condition of adults as they enter the hydrosystem will help determine to what degree variation among individuals in initial energetic conditions is associated with migration success. Comparisons of mean initial condition among years should also assist managers in forecasting in-river performance by adults, assuming a causal relationship between energetic condition and migration and reproductive success exists.

Migration times and rates for radio-tagged and PIT-tagged Chinook salmon migrating upstream to spawning grounds on the SFSR were compared with indices of energy condition and spawning success. The migration time (d) from Bonneville to Lower Granite Dam was negatively correlated with the mass specific energy content of PIT-tagged fish upon arrival at the spawning stream: slower migrating fish expended 39% of mass-specific somatic energy to develop gametes and migrate to the SFSR, while faster migrating fish expended only 29%. In some cases, percentage muscle lipid was similar for pre-spawning and post-spawning mortalities (males in 2002) suggesting that energy content was a factor for pre-spawning death. However, understanding the relationship between energy use and spawning success is complicated by variations in run timing, time spent in the spawning stream, reproductive behavior, and the limited number of fish returning to a single population. Small sample sizes, thus far, limit the ability to reach robust conclusions. Overall, patterns observed are consistent with the results of the population-level energetic work described above, patterns between passage time and migration success in the Columbia-Snake system, and recent studies on Sockeye salmon in the Fraser River system. Clearly, a mechanistic understanding of the relationships between initial condition, migration behavior, migration success, and reproductive success are needed given recent observations of high pre-spawn mortality on spawning grounds and the potential for future increases in the energetic costs of migration.

An evaluation of adult Chinook salmon and steelhead behavior at the north-shore counting window of Lower Monumental Dam using radiotelemetry: 2004

Jepson, Peery, Burke **Technical Report 2006-1**

Abstract: We used radiotelemetry to evaluate the behavior of adult steelhead and spring, summer, and fall Chinook salmon swimming past the counting window and its first upstream pool in the north-shore fishway at Lower Monumental Dam during 2004. We combined spring and summer Chinook runs for these analyses. Salmon and steelhead used for this evaluation were outfitted with radio transmitters at either Bonneville or Ice Harbor Dam.

The median time to pass the counting window for all radio-tagged fish was 14.3 min (*n* =325) but the median passage times for runs released from Ice Harbor Dam were consistently higher than for runs released from Bonneville Dam. The median time to pass the pool upstream from the window for all radio-tagged fish was 3.8 min (*n*=321). The median time to pass the counting window and upstream pool combined was 18.9 min (*n*=324). On median, passing the counting window and upstream pool combined accounted for 3.5% of total dam passage times for fish with complete sets of detections (tailrace, downstream from window, upstream from pool, and ladder exit) and the median dam passage time for these fish was 10 h (*n*= 298).

Slightly more than four percent of radio-tagged fish were recorded swimming downstream to a transition pool after being detected immediately downstream from the window (*n*=349). The median time to pass the north-shore window for these fish (with complete sets of detections) was1, 181 minutes, or approximately 19.7 h (*n* = 10). Approximately four percent of all radio-tagged fish exhibited up-and-back behavior at the counting window (*n*=349).Spring–summer Chinook salmon exhibited the highest percentage of up-and-back behavior among the runs (8.7%, *n*=150). The maximum window passage time for any spring–summer Chinook salmon which exhibited up-and-back behavior was 40.3 min. Four steelhead exhibited up-and-back but we do not believe their downstream movements were directly attributable to the window or pool.

Radio-tagged salmon and steelhead initially recorded downstream from the counting window at night had higher median counting window passage times than fish initially recorded there during the day. Analyses assessing the degree of association between counting window passage times and total dam passage times suggested the correlations were positive, but weak. Linear regression models using median weekly passage times as dependent variables and mean daily fish counts (during corresponding weeks) as predictors suggested that effects of high fish abundance on counting window or weir passage times were small.

We conclude that one can expect a relatively small percentage of adult migrants to swim downstream after being detected at a counting window or in its upstream pool (and thereby have relatively higher total dam passage times) but it is unclear as to what steps might be taken to minimize these events since no window or pool modifications were experimentally evaluated for this study.

Non-direct homing by adult spring-summer Chinook salmon: tributary overshoot, overshoot fallback, and temporary non-natal tributary use in the Columbia River Basin

Keefer, Boggs, Caudill, Peery, Moser **Technical Report 2006-2**

Abstract: Homing movements of adult salmon and steelhead in the Columbia River system is a poorly understood aspect of migration, yet has important ecological and management implications. In this study, three migration behaviors—overshoot of natal tributaries, fallback at dams upstream from natal tributaries, and temporary non-natal tributary use—were evaluated for more than 5200 radio-tagged spring–summer Chinook salmon *Oncorhynchus tshawytscha*. Over seven years, from 1% to almost 80% of eleven Columbia River study stocks initially overshot natal tributaries and were recorded at upstream Columbia or Snake River dams (*mean* = 29%). Smaller proportions of each stock were recorded falling back at upstream dams (*range* = 0–49%, *mean* = 17%). The contribution of overshoot fallback to total fallback by salmon that returned to tributaries was approximately 20% at The Dalles, John Day, and Ice Harbor dams and was about 40% at McNary Dam. Proportions that temporarily entered non-natal tributaries ranged from 8% to 42% (*mean* = 22%) of each stock. Overshoot, overshoot fallback, and temporary tributary use behaviors were greatest when spawning tributaries and/or dams were in close geographic proximity. For example, 39% of Klickitat River salmon fell back at The Dalles Dam, 49% of Umatilla River salmon fell back at McNary Dam, and salmon from Bonneville pool tributaries were most likely to temporarily use nearby tributaries. In multivariate models, hatchery origin, fish sex, migration timing, and fallback at both upstream and downstream dams were also associated with non-direct homing behaviors. Overshoot and temporary tributary use events were complex and inter- related, likely reflecting a combination of active searching for olfactory cues from natal tributaries, behavioral thermoregulation, and geographic proximity among sites.

Water temperatures in adult fishways at mainstem dams on the Snake and Columbia rivers: phase 2-biological effects.

Caudill, Clabough, Naughton, Peery, Burke **Technical Report 2006-3**

Abstract: Impoundments on the Columbia, Snake and Clearwater rivers have strong effects on the environment encountered by adult salmonids as they migrate upstream. Reservoirs influence seasonal temperature regimes and spatial heterogeneity in temperature, key factors affecting salmonid behavior. We hypothesized that temperature gradients in fish ladders caused by thermal layering in reservoirs and dam forebays represent potential thermal barriers impeding passage of adult salmonids. As a preliminary step in quantifying the biological effects of ladder temperature gradients on adult salmonids, we examined associations between fish passage behaviors and the difference between fish ladder exit and transition pool temperatures (ΔT) at the time of the first detection of fish at the base of fishways. Study sites included McNary Dam and the four lower Snake River dams and this report includes data collected from 2000 to 2003.

Throughout the run season, ladder ΔT values frequently exceeded 1˚C during fish passage events. Ladder temperature differences increased in frequency and magnitude during the warmest periods of the year and were largest at Lower Granite Dam, with few fish passing during periods of $\Delta T > 4°C$. The proportion of the run experiencing ladder $\Delta T \geq 1.0$ ˚C during the four-year study was lowest for spring Chinook salmon (8.4-15.5%) and highest for summer Chinook salmon (20.3-68.7%), and again,

proportions were generally highest at Lower Granite Dam. Importantly, the estimated proportions experiencing $\Delta T \geq 1.0$ ˚C were probably underestimated for summer Chinook salmon and steelhead because of tagging restrictions during warm water temperatures, while the proportions for spring Chinook may represent overestimates.

Passage time estimates consistently suggested that ladder temperature gradients increased ladder passage time, in some cases by a factor of two or more. In many cases, total dam passage time also increased with increasing ladder ΔT. The proportion of fish overnighting—those fish passing one or more days after arriving in the tailrace—also consistently increased with ΔT. Detailed examination of passage routes revealed that more fish switched between ladders prior to passing during periods with ladder temperature gradients at McNary Dam but not Ice Harbor or Lower Monumental dams. The observed effects of ΔT on passage behavior did not appear to be solely caused by correlated factors such as high river temperatures. For instance, tailrace passage times were not related to ladder ΔT. Finally, comparison of ladder exit temperature and adult body temperature at the time of exit demonstrated that adult salmonid body temperature had equilibrated to the surrounding ladder water temperature by the time of ladder exit. Adult salmonids' body temperature increases during ladder passage were also positively, though more weakly, related to ladder ΔT.

Collectively, the results suggest ladder temperature differences represent a migration obstacle that slows adult passage at McNary and the lower Snake River dams, especially at Lower Granite Dam. Passing through ladder temperature gradients may have physiological consequences because fish body temperature increases in proportion to ΔT during passage and many passage events occurred at or near temperatures thought to be stressful to migrating adult salmon and steelhead (> 18-20°C). Improvements to the thermal regime in ladders, particularly those that reduce temperatures at ladder exits and temperature differences between the tops and bottoms of ladders during warm summer months, could provide improvements to adult passage conditions. However, we recommend that any ladder modification should provide adequate thermal conditions between the ladder exit and cool waters at depth in the forebay during summer to prevent the formation of sharp thermal gradients at the interface between the ladder exits and forebay surface waters.

Adult Chinook salmon and steelhead dam passage behavior in response to manipulated discharge through spillways at Bonneville Dam

Caudill, Peery, Daigle, Jepson, Boggs, Bjornn, Joosten, Burke, Moser

Technical Report 2006-5

Abstract: The river conditions encountered at dams in the Columbia-Snake River Basin by returning adult salmonids are strongly affected by discharge over dam spillways (spill) during spring run-off. In recent years, dam operators have altered hydrosystem operations to continue spilling through the summer in an effort to improve survival of downstream migrating smolts. However, this action may slow the migration of adults through a number of mechanisms. During 2000, 2002, and 2003, spill levels at Bonneville Dam were alternated between low (~75 kcfs) and high (85-160 kcfs) spill volume conditions to determine the effects of spill on adult upstream migration behavior. We monitored daily dam counts and the migration of radio-tagged adult spring, summer, and fall Chinook salmon and steelhead as they passed the dam during these two treatments.

Daily dam counts of adults were 16.5-32.0% lower during high spill conditions than during low spill conditions. Individual radio-tagged fish could not be assigned or restricted to single treatments, and many of those requiring more than one day to pass the dam experienced both treatment conditions while in the dam tailrace. Among fish experiencing no change in treatments, a greater proportion of spring Chinook salmon and steelhead passed through the tailrace under low spill treatments. Among fish experiencing a switch in treatment during dam passage, a greater proportion of spring Chinook salmon entered the tailrace under the high spill treatment and entered fishways after a switch to low spill treatment than vice versa, suggesting an increase in fishway entrance rates as spill decreased. Cox proportional hazards regression models accounted for the changing treatment and environmental conditions and revealed that individuals in all stocks were 14 - 16% less likely to enter fishways under high than low spill treatments, though the effect was not significant for fall Chinook salmon. Minimum estimates of the difference in median passage time between high and low treatments were 8.64-8.68 hours in spring Chinook salmon in 2002-3, 3.33 hours for fall Chinook salmon in 2002, and 3.85 hours in steelhead in 2002. However, these estimates almost certainly underestimate the effects of constant high spill because of treatment switching. There was no evidence that the differences in median passage time between treatments increased at relatively high spill levels within the high spill treatment. Comparisons of behaviors in the spillway and tailrace between the two treatments supported the hypothesis that migration routes though the tailrace were less direct during high spill. Fallback by spring Chinook salmon was also related to spill and to inter-annual differences in powerhouse priority. The observed relationships between spill and passage behavior were probably related to flow conditions and increased turbulence in the tailrace rather than the result of exposure to high dissolved gas conditions.

The recent observation of a relationship between slow dam passage and delayed mortality upstream in adult salmonids suggests that slow migration may have negative effects on adults. Overall, the results highlight the need for mechanistic understanding of how behavior at individual dams and the cumulative experience of adults in the hydrosystem affects survival and reproductive success.

Experimental evaluation of fishway modifications on the passage behavior of adult Chinook salmon and steelhead at Lower Granite Dam, Snake River 2000-2002

Peery, Bjornn, Peery, Tolotti, Stuehrenberg **Technical Report 2006-6**

Abstract: In 2000, the five downstream weirs in the transition pool at Lower Granite Dam were modified so that a 0.3 m (1ft) head could be maintained at each weir to increase velocities through submerged orifices. We hypothesized that with higher flows through the underwater orifices, fish would more readily locate the submerged orifices and move into the ladder without delay. A framework for vertical panels was added, allowing for the addition of panels as needed to reduce the width of the overflow section.

It is unclear however, if faster passage times in 2000 were related to the weir modifications or to better flow and passage conditions (lower and less turbid flow). Therefore, in 2001 and 2002, we conducted an experiment to determine if the faster transition pool times we found in 2000 were due to modification of the panels in the transition pool. In 2001 and 2002, we manipulated the slotted aluminum panels of the first two downstream weirs in the fish ladder by alternately raising (control) and lowering (treatment) panels to manipulate flow through the weirs.

During the experiment we monitored radio-tagged adult Chinook salmon and steelhead to determine passage routes and times through the transition pool. The weir treatment increased the number of spring–summer Chinook salmon passing straight through the transition pool compared to those exiting the transition pool to the collection channel or tailrace. Mean passage times through the transition pool differed among routes and were significantly lower during treatment periods for the exit-to-collection channel route in spring–summer Chinook salmon, but not for other routes. Passage times among routes differed in steelhead, but there was no evidence of treatment effects on route use or passage time. Fall Chinook exhibited similar trends in route use and passage time to spring–summer Chinook, but differences were not significant, perhaps because of relatively small sample size. Total dam passage times did not differ by treatment or route for any run. Fish depth during passage of the transition pool suggested that most fish passed through submerged orifices and supported the hypothesis that increased water velocity through these orifices caused the increase in straight-through passage in spring–summer Chinook. Collectively, the results suggested the weir modifications provided improvement to passage through the transition pool for spring–summer Chinook and no evidence of negative effects on other runs. The results from this study were used to develop new design criteria and modifications of the Lower Granite Dam fishway.

Effects of transport during juvenile migration on behavior and fate of returning adult chinook salmon and steelhead in the Columbia-Snake hydrosystem, 2000-2003

Keefer, Caudill, Peery, Lee, Burke, Moser **Technical Report 2006-7**

Abstract: We used radiotelemetry to examine the effects of juvenile transportation on adult fate and migration behaviors of 1,184 Snake River spring–summer Chinook salmon and steelhead. All study fish were collected and tagged with passive integrated transponder (PIT) tags as juveniles at Lower Granite Dam on the Snake River from 1998-2002 and returned as adults during 2000-2003. Approximately 60% of the adults radio-tagged in this study were transported in barges as juveniles from Snake River dams to release sites downstream from Bonneville Dam on the Columbia River. Juveniles that were not transported migrated downstream in-river.

Adult homing was significantly lower and unaccounted loss and permanent straying into non-natal basins was higher for both spring–summer Chinook salmon and steelhead that were barged as juveniles. On average, adult fish barged as juveniles homed to Lower Granite Dam at rates about 10% lower than fish that had migrated in-river. Homing to Lower Granite Dam differed between juvenile release years for both species, reflecting differences in treatments and river environment during both juvenile and adult migrations. The presence of fin clips (certain hatchery origin) was not significantly associated with Chinook salmon homing, while unclipped steelhead returned to Lower Granite Dam at significantly lower rates than fin-clipped fish. Straying rates in both species were higher among groups barged as juveniles. When compared to in-river migrants, barged Chinook salmon were 1.9 times more likely and barged steelhead were 1.3 times more likely to fall back at dams as adults. Among fish that fell back, a significantly greater proportion of barged fish also experienced multiple fallback events than in-river migrants.

Decreased homing, increased fallback, and increased straying rates by transported fish were interrelated and linked to hatchery origin in some cases. The results were consistent between species and years, strongly suggesting that juvenile transport impaired adult orientation of both hatchery and wild fish during return migration. Streams-of-origin and hatcheries-of-origin were unknown for most fish and differences among sub-basin stocks may have influenced results. However, there were clear associations between adult behavior and transport history, despite the potential presence of underlying sub-basin variation. Future studies are needed to isolate the effects migration timing, of origin, and of in-stream residence times upstream from Lower Granite Dam from those of transport history for Snake River salmon and steelhead. Overall, the results suggest that the benefits of barging juveniles may be reduced due to negative effects on returning adults. These effects are typically difficult to quantify and may include both adult losses and significant changes to population genetic structure caused by increased straying.

Run-timing, escapement and harvest of upriver bright fall Chinook salmon in the Columbia River, 1998 and 2000-2005

Jepson, Keefer, Naughton, Peery, Burke **Technical Report 2006-8**

Abstract: During 1998 and 2000-2005, we radiotagged a total of 6,079 adult fall Chinook salmon *Oncorhynchus tshawytscha* at Bonneville Dam and monitored them as they migrated to upstream spawning sites in the Columbia and Snake River basins. We divided the 'upriver bright' (URB) stock of fall Chinook salmon into five subgroups: the Deschutes, Yakima, and Snake rivers, the Hanford Reach, and sites upstream from Priest Rapids Dam. We calculated run-timing statistics past Bonneville Dam during 15-day intervals and estimated annual escapement and harvest values for each subgroup.

The relative abundance of adult fish returning to sites upstream from Priest Rapids Dam was as much as half of the run during early August but decreased steadily during the remainder of each migration season. Deschutes, Yakima, and Snake river subgroups typically comprised small (≤13%), but relatively constant proportions of fall Chinook salmon throughout each migration season. During all years, Hanford Reach fish made up increasingly large proportions of the run at Bonneville Dam as each migration season progressed, averaging over three-quarters of the run in early October.

Fall Chinook salmon from the Hanford Reach were estimated to be the most abundant of the five URB subgroups. All URB subgroups increased in abundance compared to estimated 1998 levels; the Snake River subgroup increased by as much as five times by 2004. Escapement estimates for the Hanford, Snake River, and 'above Priest Rapids' subgroups were estimated to have declined from 2004 to 2005 while those for the Deschutes and Yakima subgroups were estimated to have increased. The minimum coefficients of variation about escapement estimates were observed for the Hanford and 'above Priest Rapids Dam' subgroups, averaging approximately four and six percent, respectively, for the seven study years. Coefficients of variation about escapement estimates averaged approximately 10% for the Snake River subgroup, 18% for the Deschutes River subgroup, and 20% for the Yakima River subgroup.

Harvest estimates ranged between 5 and 41% among all year-subgroup combinations. With all years averaged, nearly one-third of most URB subgroups that passed Bonneville Dam were estimated to have been harvested in a mainstem Columbia River fishery. Fall Chinook salmon returning to sites upstream from Priest Rapids Dam were estimated to have been harvested at a lower mean rate (20%) during the seven study years, probably because of its relatively early run- timing, coupled with the start of the mainstem fishery in late August each year.

Fishway entrance use and passage times of adult spring-summer Chinook salmon at Lower Monumental Dam, with an emphasis on effects of spillway deflectors: 2000-2004

Keefer, Peery, Tolotti, Jepson, Burke **Technical Report 2006-10 Draft**

Abstract: We monitored the passage behaviors of 1,679 radio-tagged adult spring–summer Chinook salmon at Lower Monumental Dam from 2000-2004. Over the five years, 99.7% of the monitored fish successfully passed the dam. Under most conditions, the majority of tagged fish passed via the north-shore ladder.

Passage times at the dam (annual medians) ranged from 1.4 to 2.2 h from time of tailrace entry to first approach a fishway, from 1.5 to 3.5 h from first approach to first fishway entry, and from 9.2 to 13.3 h to pass the dam. Ladder ascension times were rapid, with relatively little variability among years (medians 3.5-3.7 h). In all passage environments, salmon slowed upstream migration at night.

Full-dam passage times were only weakly correlated with environmental conditions, including flow, spill, and water temperature. In general, passage times were longer during higher flow and spill and when water temperatures were either relatively high (> 17º C) or low (< 10º C). Full-dam passage times were more strongly correlated with fishway use behaviors: times were longer when fish approached fishway entrances multiple times and when fish entered and exited the fishway more than once. Numbers of approaches and entries were correlated, indicating these measures were inter-related. Times also varied somewhat with where fish first approached and entered fishways, possibly reflecting differences in fishway entrance configurations and/or the ease of use.

Orifice gates were closed in all study years. Use of the south-shore, south-powerhouse, and north-shore entrances varied significantly among years. Patterns were related, at least in part, to environmental conditions fish encountered. Use of the south-shore entrance, adjacent to the spillway, increased as flow and spill increased, presumably because attraction flows to this side of the river were greater at higher discharge. Ratios of fishway approaches to fishway entries also varied among years, and there was some evidence that conditions near some fishway entrances (especially the south-powerhouse entrance) became more difficult for adult fish to negotiate during periods of higher flow and spill.

Particular attention was given to the effects of spillway deflectors, which were installed in the Lower Monumental end bays in the winter of 2002-2003. Previous hydraulic modeling had indicated that deflectors may increase turbulence near adult fishway entrances. In general, however, there was limited evidence that deflectors had a negative impact on adult spring–summer Chinook passage at the dam. Deflectors were associated with some possible shifts in fishway use patterns, but overall dam passage metrics indicated that negative effects were limited. Given below-average flow and spill conditions in the study years, further evaluation of deflector effects is recommended during years with higher discharge.

Evaluation of fishway modifications to improve passage of adult Chinook salmon and steelhead through the transition pool at Lower Granite Dam, 2006

Clabough, Naughton, Jepson, Caudill, Peery, Burke **Technical Report 2007-1**

Abstract: Previous studies of Pacific salmonid passage over Snake River dams indicated slowed passage at transition pools in adult fishways. In 2001 and 2002, we conducted an experiment to determine if modified weirs affected adult salmon and steelhead passage times and route selection through the Lower Granite Dam transition pool. Attraction flows through weir orifices were experimentally manipulated using removable aluminum panels. Results from these studies indicated a greater proportion of radio-tagged spring– summer Chinook salmon passed straight through the transition pool when the panels were deployed, and mean transition pool passage times were significantly lower. Based on these results, the U.S. Army Corps of Engineers modified the fish ladder at Lower Granite Dam in 2006. Modifications included narrowing the junction pool walls and increasing the weir crest height of the lower eleven weirs. To evaluate the effectiveness of the modifications, we radio-tagged and monitored adult spring–summer and fall Chinook salmon and steelhead as they passed Little Goose and Lower Granite dams and compared their performance to that measured during previous years without modifications in place. Transition pool passage times at Lower Granite Dam for spring– summer Chinook were significantly faster in 2006 than in 2003 and 2004 (non-modified years) and the other runs exhibited similar, though not statistically different responses. The frequency of downstream exits out of the transition pool back to the collection channel or tailrace for spring-summer Chinook salmon at Lower Granite Dam in 2006 were lower than in 2003 and 2004. We also compared the relative passage times by individual fish at Little Goose and Lower Granite dams in an effort to statistically control for interannual variation river environment. For all runs, we found that passage time was relatively faster at Lower Granite Dam compared to Little Goose Dam in 2006 versus 2003 and 2004. While the results generally support the hypothesis that the weir modifications improved passage and provide no evidence that the modifications worsened passage conditions, we caution that rigorous conclusions can not be made because behaviors were made for only one year post-modification and inter-annual variability in pool passage times can be high.

Adult salmon and steelhead passage through fishways and transition pools at the Dalles Dam, 1997-2001

Keefer, Peery, Bjornn, Jepson, Tolotti, Ringe, Stuehrenberg **Technical Report 2007-2**

Abstract: Evaluation of fishway entrance use and passage through fishways by spring–summer Chinook salmon Oncorhynchus tshawytscha, steelhead O. mykiss, and sockeye salmon O. nerka at The Dalles Dam were objectives of the adult salmon and steelhead passage project in 1997, 1998, 2000 and 2001. Critical parameters studied were times for a fish to first approach the dam and first enter a fishway, total time to pass over the dam, which entrances were approached, where fish entered and exited fishways, and fish passage through transition pools and over the dam. We report here on study results from four years of spring–summer Chinook salmon data, three years of steelhead data and one year of sockeye salmon data.

After entering the tailrace, fish of all three species first approached a fishway entrance within 2.5 to 5.3 h (medians); median times to first enter a fishway were 2.5 h for sockeye salmon, 6.1 to 6.8 h for steelhead and 6.2 to 16.1 h for Chinook salmon. Median dam passage times, from first tailrace record to exit from the top of a ladder, were 7.9 h for sockeye salmon, 13.3 to 16.4 h for steelhead and 20.4 to 31.2 h for Chinook salmon. Median passage times for all segments decreased for Chinook salmon as migrations progressed. Flow and spill levels had limited influence on most passage time calculations compared to behaviors in the fishways and transition pools. Chinook salmon approached fishways more often (median = 4 to 6 times, mean = 6 to 8 times) than steelhead (median = 2 to 3 times, mean = 4 to 6 times) or sockeye salmon (median= 1 time, mean = 2 times). Fish from all species approached all fishway entrances. Chinook salmon and steelhead tended to first approach shoreline entrances, and Chinook salmon increasingly approached the North Ladder Entrance (NLE) as spill increased. Steelhead approached the NLE two to four times more frequently during periods of spill, and preferred the East Ladder Entrance (ELE) or South Spillway Entrance (SSE) during periods of no-spill. The majority of sockeye salmon first approached the NLE, followed by the ELE.

All species entered fishways a median of one time; means were 2 to 4 times for Chinook salmon, 2 to 3 times for steelhead, and 1.5 times for sockeye salmon. Chinook salmon and steelhead mostly entered the ELE at low spill levels, and increasingly entered the NLE and SSE as spill increased. Sockeye salmon mostly entered the NLE first, followed by the ELE.

In all years, 30 to 54% of the fish from all species exited a fishway into the tailrace. The percentage of Chinook salmon that exited increased as migrations progressed each year while exit rates for steelhead tended to be lower in fall than in summer months. Fish that exited fishways had significantly longer passage times than those that did not exit. An exit typically resulted in dam passage delays of 8 to 20 h for all species during all parts of the migrations. Delays related to exiting a fishway were greatest for Chinook salmon in 1997. The highest numbers of exits by Chinook salmon and steelhead were via the SSE, and were at the NLE and West Powerhouse Entrance (WPE) for sockeye salmon. Many of the fish that exited fishways migrated upstream as far as transition pools before turning around and exiting to the tailrace. Very few fish exited after migrating up ladders.

More fish from all species passed the dam via the OR-shore fishway than via the WA-shore fishway; 52 to 61% of Chinook and sockeye salmon and > 85% of steelhead passed via the OR- shore.

Most fish of all species entered transition pools almost immediately after entering fishways. Median times to first enter a pool were < 3 min for all species in all years; medians were 0.3 to2.3 h for fish that entered the OR-shore pool via the SSE or WPE entrances.

Fish behavior in transition pools fell into four categories: fish that moved straight through with no downstream movement, fish that delayed (moved downstream) in a pool but did not exit, fish that exited the OR-shore pool into the collection channel but not the tailrace, and fish that exited a pool into the tailrace. Fourteen to 21% of Chinook salmon, 22 to 49% of steelhead and 29% of sockeye salmon moved straight through, while 32 to 57% of Chinook and sockeye salmon and 22 to 32% of steelhead delayed. Two to 8% of all species exited to the OR-shore collection channel. Between 22 and 49% of Chinook salmon, 26 to 45% of steelhead and 24% of sockeye salmon exited to the tailrace in each year.

Passage times from first transition pool record to exit a pool into a ladder were significantly different for the four groups for most species–years. Median pool passage times (all species) were < 0.25 h for fish that moved straight through, 0.4 to 2.1 h for fish that delayed, 2.0 to 5.2 h for fish that exited into the collection channel, and 8.4 to 23.4 h for fish that exited into the tailrace. Steelhead and sockeye salmon times tended to be lower than Chinook salmon times. Between 18 and 53% of fish (all species) that exited into the tailrace took > 1 d to pass through a pool versus ≤ 2% of fish that did not exit.

The proportions of Chinook salmon that exited transition pools into the tailrace increased as migrations progressed. Water temperature was the best predictor of transition pool exit behavior for Chinook salmon, with the highest exit rates occurring at the highest temperatures. Tailwater elevation was a secondary predictor of transition pool exit rates.

Fish of all species that exited either transition pool to the tailrace had significantly longer median dam passage times (tailrace to exit from top of ladder) than fish that moved straight through or delayed in a pool in most months of most years. Dam passage times for Chinook salmon and steelhead that exited transition pools into the tailrace were 9 to 22 h longer than those for fish that did not exit; delays for sockeye salmon that exited were 5 to 9 h longer than fish that moved straight through or delayed in a pool.

Fish of all species ascended ladders relatively quickly throughout the migrations. Median times were 1.6 to 2.4 h, with sockeye salmon and steelhead ascending ladders slightly faster than Chinook salmon.

The fastest-migrating Chinook salmon passed the dam mostly during June and July, significantly later than those fish that passed the dam slowest. The longest Chinook salmon passage times occurred in spring 1997, coincident with the highest flow and spill levels recorded during the study. While flow and spill may affect dam passage times, water temperature and migration timing appeared to be more important factors for Chinook salmon. Environmental conditions and date of passage for the fastest- and slowest-migrating steelhead were similar, except in 2001 when the slowest-migrating fish tended to pass the dam in summer and faster fish passed in fall. Flow and spill were significantly lower for the fastest-passing sockeye salmon. Chinook and sockeye salmon—but not steelhead— that passed the dam fastest tended to first approach and first enter the dam at the NLE.

The fastest-migrating fish were far less likely to exit from fishways or transition pools into the tailrace. Significantly fewer of the fastest Chinook salmon exited fishways in all years except 1997, and significantly fewer exited from transition pools in all years. Among steelhead, 81 to 91% of the slowest fish exited fishways compared to 11 to 13% of the fastest fish. The proportions of the slowest steelhead that exited transition pools were 7 to 18 times higher than the proportions of the fastest fish. Just four percent of the fastest sockeye salmon exited either a fishway or transition pool, compared to 86% and 61% of the slowest fish, respectively.

Orifice gate entrances were open and unmonitored at the dam in 1997 and 1998 and closed in 2000 and 2001. We did not experimentally test for differences in fish behavior with gates open and closed, but made retrospective comparisons between years. Total dam passage times for Chinook salmon were longer in most months of 1997 than in 2000 and 2001, though in-river conditions (near record low flow in 2001, very high flow in 1997) may have affected passage times more than orifice gate closures. Chinook passage times in 1998 were longer than in 2001 but not 2000. Conversely, steelhead dam passage times were significantly shorter in 1997 (gates open) than in 2000 or 2001; differences were inconsistent between individual months.

In each year, 3.6 to 8.9% of Chinook salmon, 2.5 to 3.4% of steelhead and 2.8% of sockeye salmon recorded at the dam did not pass. Pooling across years, 32% of Chinook salmon, 56% of steelhead and 79% of sockeye salmon that did not pass were recaptured in fisheries near the dam or downstream in the Bonneville pool. Twenty-five percent of Chinook salmon and 13% of steelhead that did not pass were last recorded in tributaries downstream from the dam; 33% of Chinook, 28% of steelhead and 21% of sockeye were unaccounted for and were presumably mortalities or unreported harvest.

An Evaluation of adult Chinook salmon behavior in the presence of pinniped exclusion gates, hazing, and acoustic deterrents at Bonneville Dam: 2005-2006

Jepson, Keefer, Tolotti, Peery, Burke **Technical Report 2007-4 Draft**

Abstract: We used radiotelemetry to evaluate the behavior of adult summer Chinook salmon in the presence of sea lion exclusion devices (SLEDs) intermittently deployed at four fishway openings at Powerhouse 2 of Bonneville Dam during 2005. Radio-tagged salmon that first approached at a SLED had the highest median time from first approach to first entry (1.3 h) among groupings (i.e., spillway, Powerhouse 1, and Powerhouse 2 w/ no SLED), suggesting the SLEDs mildly impeded fishway entry for some tagged salmon. However, we found no significant difference in the spatial distribution of first approaches or first entrances of radio-tagged salmon in the presence or absence of SLEDs during 2005.

Based on time-to-event analyses and Cox Proportional Modeling, tagged salmon were 21% more likely to first approach Powerhouse 2 entrances at any given time when the SLEDs were deployed than when they were not. In contrast, tagged salmon were 19% less likely to first enter a Powerhouse 2 fishway at any given time when the SLEDs were deployed than when they were not. Neither difference was statistically significant.

Significantly higher total PIT and total visual counts recorded on days when SLEDs were deployed at Powerhouse 2 but we concluded that using daily count data to make inferences about any effects of the SLEDs, ADDs, or hazing was not robust when we used passage histories of radio-tagged salmon as surrogates.

In 2006, SLEDS were deployed at all main fishway openings and we evaluated the behavior of radio-tagged spring Chinook salmon in response to sea lion hazing and acoustic deterrent treatments. Deterrents were applied in a paired-treatment, randomized block design during 2006. Blocks were four days long and consisted of two days each with or without hazing and ADD applications. We considered both hazing and ADD applications to be parts of a single treatment for these analyses.

We ln-transformed passage times from a) first tailrace record to first approach, b) first tailrace record to first entry, c) first approach to first entry, and d) first tailrace record to last record at the ladder top to meet the normality assumption of ANOVA. We tested for any treatment and/or block effects using the model: Passage time = Treatment + Block + error. We found no significant treatment effects but the block term was significant for all passage time metrics except the time from first approach to first entry. Passage times were typically higher during late April and early May than during the latter part of May, likely a reflection of faster fish passage when water temperatures were higher.

We also used Cox Proportional Hazard Modeling to test for any effects of the ADDs/Hazing on passage times from the tailrace to first fishway approach and first fishway entry. Fish were 10% and 17% more likely to first approach and first enter fishways, respectively, at any given time during the ADD/Hazing treatment than during the No ADD/Hazing treatment, but neither difference was statistically significant. In summary, both parametric and non-parametric analyses suggested that the combined effect of hazing and ADDs did not impede the passage of radio-tagged adult spring Chinook salmon during 2006.

Finally, we performed an *ad hoc* evaluation of any SLED effects by comparing passage times from April-May 2006 during periods with no ADDs/Hazing, to passage times from April-May in 2003 and 2004, when no SLEDs were deployed. Median passage times from 2006 were consistently lower than those from the years with no SLEDs, circumstantially suggesting the SLEDs alone did not impede the passage of radio-tagged adult spring Chinook salmon during 2006.

Migration depths of adult steelhead in the lower Columbia and Snake Rivers in relation to dissolved gas exposure, 2000

Johnson, Clabough, Peery, Bjornn, Stuehrenberg **Technical Report 2008-1**

Abstract: High spill volume at dams can create supersaturated dissolved gas conditions that may have negative effects on fishes. Water spilling over Columbia and Snake River dams during the spring and summer freshet creates plumes of high dissolved gas that extend downstream of dam spillways and creates gas supersaturated conditions that do not equilibrate in reservoirs. During 2000, 201-adult steelhead Oncorhynchus mykiss were tagged at Bonneville Dam with archival radio data storage transmitters (RDSTs) that recorded depth and water temperature as they migrated through tailraces and reservoirs of lower Columbia and Snake River dams. Migration depth plays a central role in the development and expression of gas bubble disease because hydrostatic compensation reduces the effects of exposure at greater depths. Swimming depths from 115 of the 201 adult steelhead tagged with RDSTs were used to estimate the degree of exposure to various dissolved gas conditions in the lower Columbia and Snake rivers. Migration paths of 28 individual fish tagged with RDSTs were monitored in the tailraces of Bonneville and Ice Harbor dams and combined with output from a two-dimensional dissolved gas model to estimate the degree of uncompensated dissolved gas exposure.

We found that adult steelhead, like Chinook salmon, spent a majority of their time at depths deeper than 2 m, providing at least 20% hydrostatic compensation, interspersed with periods lasting minutes at depths shallower than 2 m. The longest successive time an individual fish was observed shallower than 1 and 2 m was 17 h and 8.5 d, respectively. Steelhead spending the longest durations of time near the surface (< 2 m) were likely near the mouth of a Columbia River tributary based on body temperatures obtained from RDST data that were cooler than the mainstem Columbia River.

Depth uncompensated exposure based on model results was estimated to be 7.1% of the time in the Bonneville tailrace and 0% of the time spent in the Ice Harbor tailrace. Most (87%) of the uncompensated exposure was less than 115% total dissolved gas supersaturation (TDGS) which is considered a conservative level of exposure known to cause gas bubble disease (GBD) and mortality. Adult steelhead tended to migrate near the shoreline with approximately equal proportions of fish entering or leaving areas of the river with elevated dissolved gas levels. No significant association existed between crossing the river and the position of the dissolved gas plume downstream of Bonneville Dam.

Although degree of dissolved gas exposure was not considered lethal, dams could be operated during periods of potential high levels to direct water away from shorelines to minimize the potential for encountering water with high TDGS levels. Additional research is needed to confirm the effects of short but frequent exposure to supersaturated dissolved gas conditions on reproductive potential and survival.

Migration depths of adult Chinook salmon and steelhead in the Lower Columbia and Snake Rivers in relation to dissolved gas exposure, 2002

Johnson, Clabough, Peery, Bjornn, Stuehrenberg **Technical Report 2008-2**

Abstract: High spill volume at dams can create supersaturated dissolved gas conditions that may have negative effects on fishes. During 2002, 184 adult Chinook salmon *Oncorhynchus tshawytscha* and 231 steelhead *Oncorhynchus mykiss* were tagged at Bonneville Dam with archival radio-data storage transmitters (RDSTs) that recorded depth and water temperature as they migrated through dams and reservoirs of the lower Columbia and Snake rivers. These data were used to estimate the degree of exposure to gas supersaturated conditions. Migration depth plays a role in the development of gas bubble disease because hydrostatic compensation reduces the effects of exposure to supersaturation at greater depths. We found that adult spring and summer Chinook salmon and steelhead spent a majority of their time at depths deeper than 2 m (providing at least 20% hydrostatic compensation). However, migration depths below 2 m were interspersed with periods lasting several minutes at depths shallower than 2 m. Statistical associations were weak between dissolved gas concentrations and the percent and duration of time fish occupied near-surface waters. Based on the observed migration depths and dissolved gas conditions in the river, biological effects resulting from depth uncompensated exposure to dissolved gas were likely minimal in 2002.

Body temperature during migration in adult Chinook salmon and steelhead through the Lower Columbia and Snake Rivers, 2000 and 2002

Clabough, Caudill, Keefer, Jepson, Stuehrenberg **Technical Report 2008-3**

Abstract: Temperature is a major environmental factor affecting salmonid physiology, behavior, reproduction, and life history, yet the range of temperatures experienced by adult Pacific salmon and steelhead during their upstream migration in the Columbia and Snake rivers has not been well documented. Here, we present temperature histories for 261 spring-summer Chinook salmon, 64 fall Chinook salmon, and 302 steelhead that were tagged with radio data storage tags (RDSTs) and released near Bonneville Dam. Sixty-seven percent of all fish released with RDSTs were recaptured and 60% of the recaptured tags were recovered at Lower Granite Dam adult fish trap. The remaining 40% were tags returned from fisheries, hatcheries, and spawning ground surveys. RDSTs were programmed to record temperature at 1 minute intervals over a 40-day period.

River temperatures during the two study years (2000 and 2002) were near or below the 10-year average conditions during the migration seasons.

Few (2%) spring Chinook salmon experienced temperatures considered to be stressful (≥ 20 °C) in either year. In contrast, 13% of summer Chinook salmon, 81% of fall Chinook salmon, and 75% of steelhead experienced temperatures ≥ 20 ºC (both years combined). Fall Chinook salmon experienced the highest average percentage of time at temperatures ≥ 20 ºC (45% of time), followed by steelhead (22%), and summer Chinook (20%). Steelhead experienced the longest periods with consecutive records ≥ 20 ºC during upstream migration (mean = 12.1 h), followed by summer Chinook salmon (10.5 consecutive hours), and fall Chinook salmon (9.6 consecutive hours).

In general, salmon and steelhead experienced the highest temperatures in fish ladders at dams, although they spent less time there (range of median passage times = 1.5-3.2 hours) than in tailraces (range =0.04-0.8 days) or reservoirs (range=0.6-6.3 days). On average, Chinook salmon and steelhead experienced higher temperatures in reservoirs than in tailraces.

Overall, the results demonstrate that adult salmonids migrating through the Columbia-Snake River hydrosystem frequently experience body temperatures widely considered to be physiologically stressful, even in years with moderate river temperatures. Exposure to high temperatures during migration may hinder salmon and steelhead recovery by increasing the metabolic costs of migration, increasing exposure and susceptibility to disease, decreasing reproductive potential, and contributing to delayed effects such as upstream *en route* or prespawn mortality. Current conditions and predicted climate warming suggest water temperature will continue to be an important environmental factor in the management of summer- and fall-run salmonid stocks.

Adult salmon and steelhead passage through fishways and transition pools at John Day Dam, 1997-2001

Keefer, Peery, Bjornn, Jepson, Tolotti, Lee, Stuehrenberg **Technical Report 2008-4**

Abstract: Evaluation of fishway entrance use and passage through fishways by spring–summer Chinook salmon *Oncorhynchus tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka* at John Day Dam were objectives of the adult salmon and steelhead passage project in 1997, 1998, 2000, and 2001. Critical parameters studied were times for a fish to first approach and first enter a fishway, total time to pass over the dam, which entrances were approached, where fish entered and exited fishways, and fish passage through transition pools and over the dam. We report here on study results from four years of spring–summer Chinook salmon data, three years of steelhead data, and one year of sockeye salmon data.

After entering the tailrace, fish of all three species first approached a fishway entrance within 1.6 to 2.6 h (medians); median times to first enter a fishway were 1.9 h for sockeye salmon, 2.8 to 3.8 h for steelhead and 4.7 to 8.6 h for Chinook salmon. Median dam passage times, from first tailrace record to exit from the top of a ladder, were 13.3 h for sockeye salmon, 16.9 to 20.3 h for steelhead and 26.1 to 35.8 h for Chinook salmon. Median passage times for all segments decreased for Chinook salmon as migrations progressed. Flow and spill levels had limited influence on most passage time calculations compared to behaviors in the fishways and transition pools.

Chinook salmon approached monitored fishway entrances more often (*median* = 7 to 15 times, *mean* = 15 to 26 times) than steelhead (*median* = 5 to 13 times, *mean* = 9 to 19 times) or sockeye salmon (*median* = 4 time, *mean* = 5 times). Fish from all species approached all fishway entrances. Chinook salmon and

steelhead tended to first approach entrances adjacent to the shorelines, and Chinook salmon increasingly approached the North Ladder Entrance (NLE) as spill increased. When all approaches were considered, Chinook salmon favored the North Powerhouse Entrance (NPE), steelhead and sockeye salmon approached most often at the South Ladder Entrance (SLE).

Fish from all runs entered fishways a median of 2 to 5 times (*mean* = 3 to 9 times). Chinook salmon and steelhead mostly first entered the SLE, and increasingly entered the NLE as spill increased. In contrast, sockeye salmon first entered the NLE preferentially, but were more likely to enter the SLE as spill increased.

In all years, 56 to 83% of Chinook salmon, 67 to 85% of steelhead, and 70% of sockeye salmon exited a fishway into the tailrace. The proportion of Chinook salmon that exited increased as migrations progressed each year while exit rates for steelhead tended to be highest in summer months. Fish that exited fishways had significantly longer dam passage times than those that did not exit. An exit typically resulted in dam passage delays of 8 h to more than a day for all species during all parts of the migrations. Delays related to exiting a fishway were greatest for Chinook salmon in 1997. The highest numbers of exits by Chinook salmon and steelhead were via the SLE, and were at the NLE and SLE for sockeye salmon. Many of the fish that exited fishways migrated upstream as far as transition pools before turning around and exiting to the tailrace. Very few fish exited fishways after migrating up ladders.

More fish from all species passed the dam via the OR-shore fishway than via the WA-shore fishway; 52 to 74% of Chinook salmon, 61 to 82% of steelhead, and 55% of sockeye salmon passed via the OR-shore.

Most fish of all species entered transition pools quickly after entering fishways. Median times to first enter the WA-shore transition pool were < 3 min for all species in all years. Median times to first enter the OR-shore pool ranged from 0.6 to 2.0 h for Chinook salmon, from 0.2 to 0.4 h for steelhead, and was 2.5 h for sockeye salmon.

Fish behavior in transition pools were apportioned into four categories: fish that moved straight through with no downstream movement, fish that delayed (moved downstream) in a pool but did not exit, fish that exited the OR-shore pool into the collection channel but not the tailrace, and fish that exited a pool into the tailrace. Seven to 15% of Chinook salmon, 6 to 17% of steelhead and 23% of sockeye salmon moved straight through, while 19 to 42% of Chinook and sockeye salmon and 12 to 23% of steelhead delayed in a pool. Two to 7% of all species exited to the OR-shore collection channel. Between 41 and 68% of Chinook salmon, 57 to 79% of steelhead and 48% of sockeye salmon exited to the tailrace in each year.

Passage times from first transition pool record to exit a pool into a ladder were significantly different for the four groups for most species–years. Median pool passage times (all species) were < 0.25 h for fish that moved straight through, were 0.1 to 1.6 h for fish that delayed in a pool but did not exit to the collection channel, and were 0.6 to 6.4 h for fish that exited to the collection channel but not the tailrace. Fish that exited transition pools into the tailrace had the longest median pool passage times: 20.6 to 37.0 h for Chinook salmon, 12.5 to 13.2 h for steelhead, and 12.2 h for sockeye salmon. Between 24 and 64% of fish (all species) that exited into the tailrace took > 1 d to pass through a pool versus ≤ 2% of fish that did not exit.

The proportions of Chinook salmon that exited transition pools into the tailrace increased as migrations progressed. Water temperature was the best predictor of transition pool exit behavior for Chinook salmon, with the highest exit rates occurring at the highest temperatures. Sockeye salmon were also more likely to exit at higher temperatures. Fish from all species were significantly more likely to exit from the WA-shore transition pool to the tailrace than from the OR-shore pool, but only in some years.

Fish of all species that exited either transition pool to the tailrace had significantly longer median dam passage times (tailrace to exit from top of ladder) than fish that moved straight through or delayed in a pool in most months of most years. Overall, full-dam passage times for Chinook salmon transition pools into the tailrace were 19 to 37 h longer than those for fish that did not exit to the tailrace. Steelhead that exited had median times that were 12 to 15 h longer than non-exiting fish, and delays for sockeye salmon were about 12 h.

Fish of all species ascended ladders relatively quickly throughout the migrations. Median times were 2.5 to 3.1 h for all runs.

In a multivariate analysis of total dam passage time, an exit from a transition pool into the tailrace was the most influential predictor for fish from almost all runs. Time of day was important in some cases, because most fish that entered the tailrace late in the day passed the dam the following day. Water temperature and/or passage date was also predictive, particularly for Chinook salmon passage times: later migrants encountered warmer temperatures and tended to pass the dam more quickly. While flow and spill had some influence on dam passage times, fish behavior and migration timing appeared to be more important factors.

In each year, 3 to 6% of Chinook salmon of the salmon and steelhead recorded at the dam did not pass. On average, 22% of Chinook salmon, 34% of steelhead, and 6% of sockeye salmon that did not pass were recaptured in fisheries near or downstream from John Day Dam. Twenty percent of Chinook salmon and 24% of steelhead that did not pass were last recorded in downstream tributaries. Between 31 and 65% of those that did not pass were unaccounted for and were presumably mortalities or unreported harvest.

Adult salmon and steelhead passage through fishways and transition pools at Bonneville Dam, 1997-2002

Keefer, Joosten, Williams, Nauman, Jepson, Peery, Bjornn, Ringe, Tolotti, Lee, Stuehrenberg, Moser, Burke **Technical Report 2008-5**

Executive Summary: Evaluation of fishway entrance use and passage through fishways by spring–summer Chinook salmon *Oncorhynchus tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka* at Bonneville Dam were objectives of the adult salmon and steelhead passage project in 1997, 1998, 2000, 2001, and 2002. Critical parameters studied were times for a fish to first approach and first enter a fishway, total time to pass over the dam, which openings were approached, where fish entered and exited fishways, and fish passage through transition pools and over the dam. We report here on study results from five years of spring–summer Chinook salmon data, four years of steelhead data, and one year of sockeye salmon data.

Passage times for spring Chinook salmon were consistently longer than for summer Chinook salmon and steelhead. Sockeye salmon passed most rapidly. After entering the tailrace, median times to first approach a fishway entrance were 2.3 to 9.6 h for spring–summer Chinook, 2.5 to 3.3 h for steelhead, and 2.2 h for sockeye salmon. Median times from tailrace entry to first fishway entry were 9.6 to 1.75 h for spring-summer Chinook, 5.1 to 7.9 h for steelhead, and 3.0 h for sockeye salmon. Total times to pass Bonneville Dam (tailrace entry to first exit from the top of a ladder) were 23.8 to 41.1 h for spring–summer Chinook, 17.4 to 24.2 h for steelhead, and 15.0 h for sockeye salmon. Fish from all species ascended ladders rapidly.

Median passage times for all segments decreased for spring–summer Chinook salmon as migrations progressed. Time of day was also influential, with longer passage times for fish that entered a passage segment later in the day. Powerhouse II priority in later years appeared to slow total passage times for Chinook salmon and steelhead. By comparison to the above factors, flow and spill levels had relatively limited influence on most passage time calculations compared to behaviors in the fishways and transition pools.

Chinook salmon approached monitored fishway entrances more often (*median* = 7 to 15 times, *mean* = 11 to 24 times) than steelhead (*median* = 6 to 9 times, *mean* = 13 to 17 times) or sockeye salmon (*median* = 7 times, *mean* = 12 times). Fish from all species approached all fishway entrances. Fish from all runs favored the larger shoreline entrances. Total spill volume affected the distribution of approaches, but considerably less so than powerhouse priority. Movements between fishways was extensive for all species in all years.

Fish from all runs entered fishways a median of 1 to 2 times (*mean* = 2 to 4 times). Fish from all runs entered all fishway entrances, again favoring shoreline entrances for first entries. Sockeye salmon were somewhat more likely than the other runs to use Powerhouse I entrances. Chinook salmon were more likely to use the spillway entrances. As with fishway approaches, the distributions of fishway entrances was related to powerhouse priority, with fish attracted to the side of the river with greater discharge.

In all years, 36 to 63% of Chinook salmon, 43 to 64% of steelhead, and 62% of sockeye salmon exited a fishway into the tailrace at least once. Fish from all runs were more likely to exit from openings at Powerhouse II than at other fishways. The proportion of Chinook salmon that exited increased as migrations progressed each year while exit rates for steelhead were more variable.

Fish that exited fishways had significantly longer dam passage times than those that did not exit. An exit typically resulted in considerable dam passage delays for all species during all parts of the migrations. Based on monthly median passage times, minimum delays associated with fishway exit were 3 to 13 h for spring–summer Chinook salmon and steelhead; maximum delays were 15 to 45 h for Chinook salmon and 7 to 38 h for steelhead. Exiting a fishway added 10 to 15 h to the total passage time of sockeye salmon. Many fish exited fishways after entering transition pools, while very few fish exited fishways after migrating up ladders.

Most fish of all species entered transition pools quickly after entering fishways. After transition pool entry, however, behaviors were quite variable and this section of the fishway appeared to create the most confusion for adults. Fish behavior in transition pools were apportioned into four categories: fish that moved straight through with no downstream movement, fish that delayed (moved downstream) in a pool but did not exit, fish that exited the pools into collection channels but not the tailrace, and fish that exited a pool into the tailrace. Transition pool behaviors were quite consistent across species. From 12 to 27% of each run moved straight through pools, 25 to 45% delayed briefly in pools before passing, 6 to 14% exited pools into collection channels, and the rest (25 to 49%) exited pools into the tailrace. Generally, fish were more likely to exit the Washington-shore transition pool than other pools.

Passage times from first transition pool record to exit a pool into a ladder were significantly different for the four groups for most species–years. Median pool passage times (all species) were rapid (most < 1.0 h) for fish that had any of the first three behaviors. Those that exited to the tailrace had much longer passage times for this segment (medians ranged from ~ 5 h to >24 h) for fish that exited from each pool. Fish of all species that exited either transition pool to the tailrace had significantly longer median dam passage times (tailrace to exit from top of ladder) than fish that did not exit a pool in most months of most years.

Multivariate analyses identified several factors that influenced transition pool exit. Fish that first entered the Washington-shore pool were more likely to exit, exit rates were higher in years with higher tailwater elevation, exit rates increased with water temperature (particularly for spring–summer Chinook salmon), and fish that entered a pool late in the day were more likely to exit to the tailrace.

Multivariate analyses of total dam passage time (tailrace entry to top of ladder) indicated that an exit from a fishway and water temperature were the most influential predictors. Times were consistently longest for fish that exited fishways, while passage times decreased as water temperatures rose within each year, especially for spring–summer Chinook salmon. Exit from a transition pool was also influential, though this variable was strongly correlated with fishway exit. Steelhead passed more slowly when spill was high. Analyses of the shorter passage segment from first fishway entry to exit from the top of a ladder indicated that fishway exit and time of day were most influential. Passage through the tailrace was most influenced by water temperature, with slow passage during cool periods and again at the highest temperatures. Time of tailrace entry was also influential. For both Chinook salmon, use of the Washington-shore fishway and transition pool contributed to longer passage times, and this led to longer passage times in years with Powerhouse II priority.

In each year, 1 to 2% of Chinook and sockeye salmon and 2 to 3% of steelhead recorded at Bonneville Dam did not pass. Most of these fish were only recorded in the tailrace, though some were recorded inside fishways and transition pools. The majority had unknown fates (were unaccounted for) downstream from the dam, and a portion of these were almost certainly mortalities from pinnipeds or other factors. Some fish likely regurgitated transmitters and small numbers were reported harvested or were recorded in downstream tributaries or hatcheries.

Energy use, migration times, and spawning success of adult spring-summer Chinook salmon returning to spawning areas in the South Fork Salmon River in Central Idaho: 2002-2007

Mann, Peery, Pinson, Anderson **Technical Report 2009-4**

Abstract: The accuracy and feasibility of multiple methods for determining energy condition in Chinook salmon were determined. These results were compared to proximate analysis of fish tissues, which represented the true value of energy content for these fish. Although all estimate methods produced results that were significantly correlated with proximate analysis, bioelectrical impedance and condition factor were less accurate than morphometrics and the Distell Fatmeter. Bioelectrical impedance did not seem to be as accurate in salmon as with other fish species, and is generally considered of better use for mammals. Although condition factor was included as a factor in many models to predict energy condition, its lipid estimation qualities by itself are suboptimal. From a series of 12 morphometric measures, breadth at anus, hump height and mideye to hyperal length together provided the best method for determining lipid content. These three measures were used in subsequent years. Although morphometrics proved to be the most accurate method for estimating energy condition, the Distell Fatmeter was also accurate, and had the added benefit of a reduced handling time. Either of these two methods are recommended to be used in further research when a quick and accurate measure of lipid content is needed.

Spawning success as it relates to energy condition and migration experience were studied over multiple years for a single population of summer Chinook salmon returning to the South Fork of the Salmon River (SFSR) in Central Idaho. In combination, about 400 salmon were radio-tagged at Bonneville Dam across six years in order to record migration histories and spawning success. Additional fish were PIT-tagged and many more were sampled on spawning grounds on the SFSR. In 2002, muscle lipid, mass-specific somatic energy, and mass-specific total energy were higher for females that died prior to spawning (pre-spawning fish) compared with fish that died after spawning, suggesting that pre-spawn mortality was not directly associated with the exhaustion of energy reserves. Pre-spawn mortality did seem to be correlated with high temperature periods in the SFSR in early years of the study.

A series of logistic regression models which related spawning success to a multitude of factors of energy condition and migration success were built in 2005-2006. The most parsimonious model included only energetic condition of fish upon river entrance and total passage time. Every factor measured, however, did appear in at least one significant model suggesting spawning success is complex and potentially controlled my many factors. It is important for the successful management of this species to have accurate methods to determine the mean condition of stocks as they enter the river and the relative costs of migrating through the Hydrosystem in years with different environmental and operational conditions. This is especially true in the face of changing climate and river environments in the Pacific Northwest.

Adult Chinook salmon passage behavior at Bonneville Dam in relation to structural modifications to the Cascades Island fishway-2009

Jepson, Keefer, Caudill, Burke **Technical Report 2010-1**

Abstract: We conducted a radiotelemetry study of spring–summer Chinook salmon at Bonneville Dam to evaluate if modifications made at the Cascades Island (CI) fishway to facilitate passage of adult Pacific lamprey and reduce maintenance requirements adversely affected passage of adult salmon. This report compares Bonneville Dam passage time metrics and CI entrance use and passage efficiency metrics collected in April-May 2009 with similar metrics calculated using spring Chinook salmon data collected in 1997-1998, 2000-2004, and 2006-2007. It also compares passage time metrics and CI entrance use and

passage efficiency metrics from June 2009 with similar metrics from summer Chinook salmon radio-tagged in June 2002–2004.

Results indicated some behavioral differences near the CI entrance in 2009 relative to previous years. Specifically, a relatively low percentage of spring Chinook salmon that approached the CI fishway opening subsequently entered through it and those that did enter took a relatively longer time to do so in 2009. While river conditions explained some of the differences, there was also some evidence that the modified CI opening may have contributed to the decline in entrance efficiency. We speculate that hydraulic conditions created by the new variable-width weir and/or altered olfactory conditions related to the modifications contributed to the longer salmon passage times. Because effects on salmon appeared to occur principally outside the fishway, we conclude that the hydraulic effects of the floor-mounted bollards and the new lamprey passage structure (LPS) inside the CI fishway had insignificant effects on salmon passage behavior.

This study will be repeated in 2010 to augment the 2009 conclusions and to further evaluate any effects of the CI modifications on adult spring–summer Chinook salmon passage.

Passage behavior of adult spring Chinook salmon at Bonneville Dam including evaluations of passage at the modified Cascades Island fishway, 2010

Jepson, Keefer, Caudill, Burke **Technical Report 2011-1**

Abstract: In 2010, we conducted a second year of radiotelemetry studies of spring–summer Chinook salmon at Bonneville Dam to evaluate if modifications made at the Cascades Island (CI) fishway to facilitate passage of adult Pacific lamprey and reduce maintenance requirements adversely affected passage of adult salmon. This report compares Bonneville Dam passage time metrics and CI entrance use and passage efficiency metrics collected in April-May 2010 with similar metrics calculated using spring Chinook salmon data collected in 1997-1998, 2000-2004, 2006-2007 (pre-modification years), and 2009 (post-modification). It also compares these same metrics from June 2010 with results from summer Chinook salmon radio-tagged in June 2002–2004 and 2009.

Results from 2009 indicated some behavioral differences near the CI fishway opening relative to pre-modification years but the 2010 results were less conclusive. Specifically, a relatively low proportion of spring Chinook salmon that approached the CI fishway opening subsequently entered through it in 2009 and those that did enter took a relatively longer time to do so. In contrast, the entrance efficiency estimate in 2010 was 0.90, at the high end of the range from the pre-modification years (range = 0.56-0.98). The median CI approach- entrance time in 2010 was 42 minutes, also within the range of median times from pre- modification years (*range* = 2-46 min). For summer Chinook salmon, the entrance efficiency estimate was 0.70 in 2009 and 0.71 in 2010, the two lowest efficiencies of the five study years but similar to 2004. Median CI approach-entrance times for summer Chinook salmon in 2010 was < 1 minute, compared to 6-12 minutes in pre-modification years.

While river conditions explained some of the differences in 2009, there was also some evidence that hydraulic conditions created by the new CI variable-width weir and/or altered olfactory conditions related to the modifications contributed to the low entrance efficiency and longer salmon passage times that year. We conclude that any adverse effects associated with the modifications were reduced in magnitude in 2010 compared to 2009. We speculate that the concentration of any disruptive olfactory cues originating from the modification has declined since 2009 and the new structures may have "seasoned" by leaching and by the accumulation of biofilms. Because effects on salmon appeared to occur principally outside the fishway in both years, we conclude that the hydraulic effects of the floor-mounted bollards and the new lamprey passage structure (LPS) had negligible effects on salmon passage behavior inside the CI fishway.

Behavior of radio-tagged adult spring-summer Chinook salmon at the Dalles Dam in relation to spill volume and the presence of the bay 8/9 spill wall, and at John Day Dam in relation to North Shore Ladder modifications, 2010.

Jepson, Keefer, Caudill, Burke. Technical Report 2011-2

Abstract: The construction of a ~145 meter spill wall at The Dalles Dam was completed in April 2010 and was designed to improve the survival of spillway-passed juvenile salmonids by directing them toward deep water with fewer predators. We evaluated how the new spill wall, spill volume, and a spill pattern, which directs most water though the northern-most spillbays, may have affected behaviors and passage times of radio-tagged adult spring–summer Chinook salmon in 2010.

Tagged salmon had little apparent difficulty locating and using the north fishway at low (0-50 kcfs) and medium (>50-100 kcfs) spill volumes. At high spill volumes (>100-150 kcfs), tagged salmon used the north fishway less frequently. Entrance efficiency decreased from 95% at low and medium spill volumes to 67% at high spill volumes. Approach routes taken by tagged salmon initially recorded on spillway receivers during low and medium spill volumes were generally consistent with the hypothesis that salmon were swimming upstream along the north shore and subsequently approached the north fishway. During periods of high spill, telemetry records suggested that the majority of adults swimming up the north shore encountered the spillway discharge and subsequently crossed the river to the south prior to approaching a powerhouse fishway opening. This was consistent with the high percentage of salmon that first approached powerhouse fishways, the low entrance efficiency at the north fishway, and the low daily Chinook salmon counts at the north ladder during periods of high spill.

The new spill wall and the spill pattern employed in 2010 did not appear to impede the ability of tagged salmon to seek and find alternate passage routes when spill volumes were high or when approaches at the north fishway did not result in a fishway entry. Dam passage times for radio-tagged Chinook salmon in 2010 were the fastest among all comparison years (median = 12.1 h, n = 285), perhaps because approximately two-thirds of the tagged salmon passed the dam by 1 June 2010, a period when mean daily spill volumes were less than 100 kcfs. Our findings did suggest, however, there may be some justification for concerns that smaller fish may be unable to successfully use the north fishway when most or all spill volume is directed through spillbays 1-8.

The counting window at the north fishway at John Day Dam underwent structural modifications in spring 2010. Radio-tagged Chinook salmon consistently used less time to pass the counting window in 2010 compared to monthly median passage times recorded in 1998, the lone comparison year. The available data suggest the modifications had little or no adverse affects on adult salmon passage.

Radio-tagged Chinook salmon and steelhead passage behavior at Lower Monumental, Little Goose, and Lower Granite Dams-2013

Clabough, Jepson, Lee, Keefer, Caudill, Martinez-Rocha, Renner, Erdman, Sullivan, Hatch

Technical Report 2014-3

Executive Summary: The Biological Opinion (BiOP) for the operation of the Federal Columbia River Power System specifies management goals for survival rates of adult salmon and steelhead during upstream migration. Recent data from PIT-telemetry monitoring indicates survival rates are lower than BiOp targets. We conducted a multiple objective study in 2013 using radiotelemetry and environmental monitoring to: 1) characterize general adult migration behavior and passage metrics at lower Snake River dams and reservoirs upstream of Ice Harbor Dam forebay, 2) test for associations between behavior of adult spring–summer Chinook salmon during passage of Little Goose Dam and dam operations and river environmental conditions; and 3) monitor adult salmonid passage in relation to temperature conditions in the Lower Granite Dam fishway and forebay near the fishway exit.

We radio-tagged and monitored movements of three samples of Chinook salmon: 600 adult spring–summer Chinook collected and trapped at Bonneville Dam, 300 jack Chinook salmon collected and tagged at Bonneville Dam, and 300 adult Chinook salmon collected and tagged at a new trap in the Ice Harbor Dam south fishway. Inclusion of adults tagged at Bonneville Dam increased sample size and allowed tests for short-term tagging effects in the Ice Harbor-tagged sample, though we note that differences in tagging schedules between the locations complicated direct comparison between the two adult samples. The primary sources of environmental data were from strings of temperature loggers deployed in the forebay of Lower Granite Dam and operational and river environmental data collected at dams by USACE. Prior to estimation of passage metrics, we assessed the potential for operation of the new trap at Ice Harbor Dam to affect passage of adults in the fishway downstream of the trap. These analyses revealed no strong or consistent evidence the operation of the trap delayed adults downstream, though we note that most comparisons had small sample sizes that prevented statistical comparison.

We estimated conversion rates of radio-tagged adults for seven reaches between the base of Lower Monumental Dam and the top of Lower Granite Dam. Comparisons among release groups differed ($P< 0.05$, $\chi 2$ tests) for two reaches: Ice Harbor-tagged adults had lower conversion from the base of Lower Monumental dam past Lower Monumental Dam (0.901 versus 0.982 for Bonneville adults and 1.000 for Bonneville jacks) and from the base of Lower Monumental Dam past Lower Granite Dam (0.860 versus 0.969 for Bonneville adults and 0.974 for Bonneville jacks). These results suggest a likely short-term handling effect for Ice Harbor-tagged fish prior to passage of Lower Monumental Dam. There were no statistically meaningful differences among tag groups in any reach upstream from Lower Monumental Dam. When the combined radiotelemetry and PIT detection data were considered, 95.2% of Bonneville adults, 97.4% of Bonneville jacks, and 84.0% of Ice Harbor adults were considered to have passed Lower Granite Dam. The groups of fish that did not pass Lower Granite Dam were last detected at a variety of Snake River sites, but primarily in dam tailraces and fishways.

Evaluation of passage behavior at Lower Monumental, Little Goose and Lower Granite dams provided estimates of the distribution of adults approaching and entering different fishways, the number of approaches, entries, and exits, and estimates of entry and passage efficiency. Excluding the apparent tag effects in the Ice Harbor-tagged adult group, these analyses revealed relatively high entrance and passage efficiency (> ~95%). Median tailrace-fishway exit passage times were more rapid at Lower Monumental (12.1-18.6 h) and Little Goose (11.1-19.7 h) dams than at Lower Granite Dam (19.8-24.1). Fallback percentages ranged from 2.9-7.9% among the dams and three sample groups.

We used Cox proportional hazards regression to test for associations between Chinook salmon passage time and operational conditions at Little Goose Dam, while statistically controlling for several time-varying factors such as time of day and temperature. The models indicated increases in the rate of passage during periods of increased discharge from turbine units 1 and 3 and decreased passage rate with increased discharge through spillbays 1 and 6.

Temperature monitoring at Lower Granite Dam revealed forebay surface waters within 122 m of the fishway exit were above 20 ºC in the upper water column (< 6.1 m) from 1 July through 25 September, whereas temperatures remained near 18 ºC at depths >18 m. The warmer surface water resulted in warmer temperatures in the ladder from the transition pool to the exit than in the forebay and fishway entrance, and the difference in temperature was > 2 ºC from mid-July to mid-September. Relative few radio-tagged salmon passed during this period, preventing statistical evaluations, but the results were qualitatively consistent with previous observations showing longer passage times during periods with high fish ladder water temperature differences.

Evaluation of adult salmon passage behavior in relation to fishway modifications at Bonneville Dam-2013

Johnson, Clabough, Keefer, Caudill, Lee, Garnett, Layng, Dick, Jepson, Burke, Frick

Technical Report 2014-10

Executive Summary: In 2013, we evaluated the passage and migration behavior of radio-tagged spring and summer Chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) in relation to the installation of the Lamprey Flume System (LFS) at the north downstream entrance (NDE) of the powerhouse 2 (PH2) fishway at Bonneville Dam. We also conducted a third year of radiotelemetry studies of spring–summer Chinook salmon at Bonneville Dam to evaluate if modifications made at the Cascades Island (CI) fishway in winter 2008-2009 to facilitate passage of adult Pacific lamprey (*Entosphenus tridentatus*) and improve hydraulics at the entrance for salmon adversely affected passage of adult salmon. Our primary study objective was to compare passage times and behaviors from pre-modification years to those from post-modification years while considering inter-annual variation in environmental, operational, and ecological conditions using a set of 5-7 quantitative passage metrics. The metrics included: entrance efficiency, exit ratio, approach-to-entry time, entry-to-ladder base time, proportion of adults requiring > 1 hour to pass these segments. We also compared behaviors at NDE and CI to similar sites (PH2 south downstream entrance and Bradford-Island B- Branch entrance).

A total of 600 adult spring-summer Chinook, 300 jack spring-summer Chinook, and 400 adult sockeye salmon were collected and radio-tagged at the adult fish facility at Bonneville Dam in 2013. All tagged fish were released below Bonneville Dam near Dodson, OR or Skamania, WA. Movements of radio-tagged salmon were monitored with aerial and underwater antennas attached to fixed-site radio receivers in the tailrace and at the dam. Data were compared to results from 1996-1998, 2000-2004, 2005 (summer Chinook only), 2006 (spring Chinook), 2007 (spring Chinook), 2009, and 2010; no previous data were available for jack Chinook salmon and data from a single year (1997) were deemed unsuitable for comparison to 2013 results for sockeye salmon due to large differences in environmental conditions.

Inter-annual variation in passage metrics collected at the NDE of Bonneville Dam PH2 was high in pre-modification years. Some variation was attributable to differences in environmental factors and operations among years. For instance, 1996-1998 were relatively high flow, cool years and 2000-2001 were low flow years with warm temperatures. Slightly below average discharge and spill levels and above average temperatures were observed in 2013. For adult spring Chinook salmon, mean entrance efficiencies at NDE were slightly lower and entrance times were slightly longer in 2013 than in pre-modification years. In contrast, mean entrance efficiencies were higher and entrance times were faster than values from pre-modifications years for spring and summer jack Chinook and sockeye salmon. Differing results in the same passage metrics among runs and species suggest the observed values were not directly related to the newly-constructed LFS. Exit ratios, times from the PH2 NDE entrance to the base of the ladder, and the ratio of fish approaching and entering the NDE versus the SDE were within the range of values observed in pre-modification years. Taken together, observed differences in passage metrics between 2013 and pre-modification years suggest that any effects of the LFS installation were small relative to environmental factors, the presence of sea lions in the tailrace, and other unmeasured factors.

At the CI fishway opening, exit ratios, times from entry to the base of the ladder, and the proportion of fish taking longer than 1 h to pass through the lower CI fishway in 2013 suggested that the modifications made in 2008-2009 were not adversely affecting spring Chinook salmon passage. The 2013 CI entrance efficiency for adult spring Chinook salmon (67%) was similar to values from both pre- and post-modification years. However, lower entrance efficiencies were observed for summer Chinook salmon in 2013 (47%) vs. pre-modification years (*mean* = 83%). Sockeye salmon entrance efficiency was 61% in 2013. Times to enter the CI fishway opening for Chinook salmon in post-modification years were collectively higher than those from pre-modification years but the times were lower in 2010 and 2013 compared to 2009. Slower approach-to-entry times in 2009 (the first post-modification year) may have been produced by changes in hydraulic or olfactory conditions outside the Cascades Island entrance directly caused by the modifications and/or other conditions in the fishways. Since then, potentially disruptive olfactory cues may have declined as the new structures have "seasoned" by leaching and the accumulation of biofilms.

Passage evaluation of radio-tagged Chinook and sockeye salmon after modifications at The Dalles and John Day Dams, 2013

Burke, Frick, Garnett, Jepson, Keefer, Caudill **Technical Report 2014-11**

Executive Summary: At The Dalles Dam, construction of a ~145-m spill wall was completed in April 2010 and was designed to improve the survival of spillway-passed juvenile salmonids by directing them toward deep water with fewer predators. We evaluated how behavior and passage time of radio-tagged adult and jack spring-summer Chinook salmon *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka* in 2013 were affected by three factors: 1) a new spill wall, 2) changing spill volumes, and 3) a spill pattern that directs most water though the northern-most spillbays. We focused analyses on fish size and use of the north fishway.

Radio-tagged salmon used the north side of the river less frequently than the south side; this trend intensified as fish migrated from the tailrace to the base of The Dalles Dam. In 2010, a majority of tagged adults swimming up the north shore crossed the river to the south before approaching a powerhouse fishway opening, particularly during periods of higher spill. In 2013, we did not estimate how far fish migrated on the north shore prior to switching sides, but over 85% of salmon that were on the north shore switched to the east fishway prior to approaching the dam. Our results indicated that fish size is related to use of the north ladder, as is spill and temperature. However, we did not find an interaction between fish size and spill. Unlike Jepson et al. (2011), who found low entrance efficiency at the north fishway opening, entrance efficiency in 2013 was high for all groups at both fishways.

The new spill wall and the 2013 spill pattern did not appear to impede the ability of tagged salmon to seek and find alternate passage routes, even when approaches at the north fishway did not result in a fishway entry. Salmon recorded on the north shore that subsequently switched sides had median fishway entry times similar to those of fish that did not switch (adult Chinook salmon that switched entered 1 h faster while sockeye salmon that switched were 0.6 h slower than those that did not switch). Dam passage times for radio-tagged Chinook salmon in 2013 (median = 12.1 h, *n* = 285) were about average relative to those in the 11 years for which comparison data are available. When data were separated by month, fish passing in June were the slowest among the 11 years, while fish passing in July were the fastest (on median).

At ***John Day Dam***, several structural modifications were made to the north fishway entrance in winters 2012 and 2013 in order to improve passage of adult salmonids and Pacific lamprey *Entosphenus tridentatus*. These modifications included the removal of lower fishway weirs; closure of one of two entrance slots; and installations of a variable-width entrance weir, a bollard field, and a lamprey passage system (LPS).

Structural modifications were also made to the upper north ladder in 2010 that included the removal of concrete weirs; replacement of a bulkhead, crowder, light box, and picket leads near the count window; and the installation of a window washer on the count window. We evaluated how these modifications may have affected behaviors and passage times of radio-tagged adult and jack spring-summer Chinook salmon by comparing behavior and passage time data from 2013 to those collected in pre-modification years 1997-1998 and 2000-2006.

Use of the John Day north fishway by spring and summer Chinook salmon in 2013 was consistent with patterns of use observed in pre-modification years. Entrance efficiencies and fishway passage efficiencies in 2013 were either within the range of pre-modification values or were higher. Fishway exit ratios (i.e., exit to the tailrace) for 2013 adult Chinook salmon were similar to exit ratios in prior years; jack Chinook salmon had considerably lower exit ratios than adults. We also found that salmon passage times were similar to or faster than those estimated prior to the north fishway modifications. Approach-to-entrance times were significantly faster in 2013 than in most pre-modification years, while entrance-to-ladder base times were similar to previous results. The percentage of Chinook salmon that required more than 1 h to complete these passage segments was much lower in 2013 than in most pre-modification years.

Salmon passage up the north ladder (from the base to the ladder exit) was significantly shorter for adult spring Chinook salmon in 2013 than in previous years; ladder passage times for adult summer Chinook salmon in 2013 were similar to pre-modification ladder times. Jacks passed the ladder more slowly than adults in both spring and summer. All of the passage metric results suggest that the recent north fishway modifications had no adverse effect on the passage behavior of Chinook salmon.

Reach conversion rates of radio-tagged Chinook and sockeye salmon in the Lower Columbia River, 2013

Keefer, Jepson, Clabough, Johnson, Caudill, Burke, Frick Technical Report 2014-12

Executive Summary: Our primary objective in this 2013 study was to estimate upstream migration survival (i.e.,'conversion rates') of adult salmon and steelhead from release downstream from Bonneville Dam, through dam-to-dam reaches, and past McNary Dam. Radiotelemetry was used to help estimate final fates of tagged fish and to monitor fish behaviors at dams, in reservoirs, and as they entered lower Columbia River tributaries. Radiotelemetry was selected to provide more explicit spatial and temporal accounting for adults that did not successfully pass through the lower Columbia River Hydrosystem.

We collected and double-tagged (radio + PIT) 400 adult sockeye salmon and 900 spring– summer Chinook salmon (600 adults, 300 jacks) at Bonneville Dam and released them downstream. Final detections indicated that 83% of sockeye salmon, 69% of adult Chinook salmon, and 83% of jack Chinook salmon passed McNary Dam; majorities of these fish were ultimately detected in the Snake or upper Columbia River basin. Self-reported main stem harvest rates using a transmitter reward program from release to McNary Dam were 2.8% (sockeye), 4.5% (adult Chinook), and 0.3% (jack Chinook); these were minimum indicators of harvest rates given presumed low transmitter return rates. Tributary turnoff estimates were 8.2% (adult Chinook) and 10.3% (jack Chinook). No sockeye were detected in the Deschutes River, the only potential lower Columbia River source of returning adult sockeye. The unaccounted-for percentages downstream from McNary Dam were: 13.5% (sockeye), 17.7% (adult Chinook), and 5.0% (jack Chinook). An unknown portion of the unaccounted-for fish was almost certainly harvested but with no transmitter return.

Reach-specific conversion rates were estimated for five reaches: (1) release downstream from Bonneville Dam past Bonneville Dam; (2) from the top of Bonneville Dam past The Dalles Dam; (3) from the top of The Dalles Dam past John Day Dam; (4) from the top of John Day Dam past McNary Dam; and (5) the cumulative conversion from the top of Bonneville Dam past McNary Dam. Cormack-Jolly-Seber (CJS) survival models were used to estimate detection probabilities and a suite of four conversion rates that differentially accounted for tributary turnoff and self-reported harvest of radio-tagged fish.

Conversion rate estimates from release past Bonneville Dam were ≥0.966 for all three study groups. Rates in dam-to-dam reaches were lowest between Bonneville and The Dalles dams, the reach with the highest fisheries effort. Conversion rates were generally highest between John Day and McNary dams. Unadjusted conversion estimates through the Bonneville-McNary reach were: 0.858 (sockeye), 0.728 (adult Chinook), and 0.887 (jack Chinook). Conversion estimates that censored known tributary turnoff and harvest were: 0.883 (sockeye), 0.828 (adult Chinook), and 0.966 (jack Chinook).

Conversion rates varied seasonally, with lower survival from Bonneville to McNary for late-migrating sockeye and adult Chinook salmon, but not for jack Chinook salmon. Conversion rate estimates for adult summer Chinook salmon were 3-11% lower than for adult spring Chinook salmon, depending on how harvest and tributary turnoff were accounted for. Hatchery Chinook salmon had lower conversion rates than their wild (i.e., no fin clips) counterparts in both age classes. Fish from all runs that fell back downstream past dams were considerably less likely to survive through the study reaches.

This report summarizes data from the first of a two-year study. Future reports will include conversion estimates for summer steelhead and additional evaluation of the factors that impact adult survival, including potential population effects identified using genetic stock identification (GSI) analyses.

Evaluation of salmon passage behavior in relation to fishway modifications at Bonneville Dam-2013-2014
Johnson, Clabough, Keefer, Caudill, Lee, Garnett, Layng, Noyes, Dick, Jepson, Burke, Frick
Technical Report 2015-6

Executive Summary: In 2013 and 2014, we evaluated the passage and migration behavior of radio-tagged spring and summer Chinook salmon (Oncorhynchus tshawytscha) and sockeye salmon (O. nerka) in relation to the installation of the Lamprey Flume System (LFS) at the north downstream entrance (NDE) of the powerhouse 2 (PH2) fishway at Bonneville Dam. We also conducted a fourth year of radiotelemetry studies of spring–summer Chinook salmon at Bonneville Dam to evaluate if modifications made at the Cascades Island (CI) fishway in winter 2008-2009 to facilitate passage of adult Pacific lamprey (Entosphenus tridentatus) and improve hydraulics at the entrance for salmon adversely affected passage of adult salmon. Our primary study objective was to compare passage times and behaviors from pre-modification years to those from post-modification years using a set of 5-7 quantitative passage metrics while considering inter-annual variation in environmental, operational, and ecological conditions. The metrics included: entrance efficiency, exit ratio, approach-to-entry time, entry-to-ladder base time, and proportion of adults requiring > 1 hour to pass these segments. We also compared behaviors at NDE and CI to similar sites: the PH2 south downstream entrance (SDE) and Bradford-Island B-Branch entrance, respectively.

A total of 1,200 adult spring-summer Chinook salmon, 600 jack spring-summer Chinook salmon, and 799 adult sockeye salmon were collected and radio-tagged at the adult fish facility at Bonneville Dam in 2013 and 2014. All tagged fish were released below Bonneville Dam near Dodson, OR, or Skamania, WA. Movements of radio-tagged salmon were monitored with aerial and underwater antennas attached to fixed-site radio receivers in the tailrace and at the dam. Data were compared to results from 1996-1998, 2000-2004, 2005 (summer Chinook salmon only), 2006-2007 (spring Chinook salmon only), and 2009-2010. No pre-modification data were available for jack Chinook salmon. Sockeye salmon data from a single year (1997) were deemed unsuitable for comparison to 2013-2014 results for sockeye salmon due to extreme high water conditions in 1997.

Inter-annual variation in passage metrics collected at the NDE of Bonneville Dam PH2 was high in pre-modification years. Some variation was attributable to differences in environmental factors and operations among years. For instance, 1996-1998 were relatively high flow, cool years and 2000-2001 were low flow years with warm temperatures. Slightly below average discharge and spill levels, and above average temperatures were observed in 2013-2014.

For adult lamprey, mean NDE entrance efficiencies were significantly lower ($P< 0.001$) in 2013 (0.26) and 2014 (0.23) compared to pre-modification years (1996-2010 mean = 0.37). Spring Chinook salmon NDE entrance times were slightly slower in 2013 and slightly faster in2014 than in pre-modification years; collectively, there was not a statistical difference in entrance times between pre- and post-modification years ($P = 0.927$). In contrast, mean entrance efficiencies for adult summer Chinook salmon were significantly higher ($P < 0.001$) and entrance times were faster ($P = 0.005$) than values from pre-modifications years. Differing results in the same passage metrics among runs and species suggest that the observed values were not directly related to the newly-constructed LFS. Adult Chinook salmon exit ratios, times from the PH2NDE entrance to the base of the ladder, and the ratio of fish approaching and entering the NDE versus the SDE were within the range of values observed in pre-modification years. Observed differences in passage metrics between pre- and post-modification years suggested that any effects of the LFS were small relative to environmental factors and other unmeasured factors.

The CI entrance efficiency for adult spring and summer Chinook salmon in 2013-2014 were significantly lower than in the average across pre-modification years. Pairwise comparisons among years were mixed with some higher and some lower between pre- and post-modification entrance efficiencies. Lower entrance efficiencies were observed after the modifications for spring Chinook salmon in 2009

(58%) and for summer Chinook salmon in 2013 (47%) vs. pre- modification years (means of 73% and 76%, respectively). Sockeye salmon entrance efficiency was 61% in 2013 and 65% in 2014. Jack spring Chinook salmon entrance efficiencies ranged from 50-74% and jack summer Chinook salmon entrance efficiencies ranged from 67-77%. Times to enter the CI fishway opening for adult spring and summer Chinook salmon in post- modification years were collectively higher than those from pre-modification years. Similar patterns of lower entrance efficiencies and longer entrance times were also observed for spring Chinook salmon at Bradford Island from 2009 to 2014. At the CI fishway opening, spring and summer Chinook salmon exit ratios and times from entry to the base of the ladder did not appear to be adversely affected by the modifications made in 2008-2009.

Passage evaluation of radio-tagged Chinook and sockeye salmon after modifications at The Dalles and John Day Dams, 2014

Frick, Burke, Garnett, Jepson, Keefer, Caudill **Technical Report 2015-7**

Executive Summary: Adult salmon and steelhead migrating to natal streams in tributaries of the Columbia River must pass up to nine dams: four in the lower Columbia and Snake Rivers and five in the mid-Columbia River. Losses and delays in migration at each dam must be minimized to maintain native fish runs and to achieve the recovery goals outlined by the Northwest Power and Conservation Council (NWPCC) and by the National Marine Fisheries Service (NMFS).

This study addressed research related to improving passage and survival of adult salmonids, a research priority identified by state fish and wildlife agencies, the U.S. Army Corps of Engineers, tribal fish and wildlife agencies, and NMFS. For the Columbia River Federal Power System (FCRPS), these priorities are enumerated in the 2008 biological opinion on recovery of threatened and endangered Columbia and Snake River salmon and steelhead (NMFS 2008, 8-15).

At The Dalles and John Day Dams, major and minor fishway modifications have been completed recently to improve passage of adult Pacific lamprey and/or adult salmonids. Structural and operational changes to improve juvenile salmonid survival were also completed recently. As with any significant changes, these modifications must be evaluated for effectiveness and to ensure that adult salmonid passage is not adversely affected.

At The Dalles Dam, construction of a ~145-m spill wall was completed in April 2010 and was designed to improve the survival of spillway-passed juvenile salmonids by directing them toward deep water with fewer predators. We evaluated behavior and passage time of radio-tagged adult and jack spring and summer Chinook salmon *Oncorhynchus tshawytscha* and sockeye salmon *O. nerka* in 2014. Passage metrics for these fish were compared with metrics in previous years to determine whether fish were affected by three factors: 1) a recently constructed spill wall, 2) changing spill volumes, and 3) a spill pattern that directs most water though the northern-most spillbays. We focused analyses on factors affecting use of the north fishway.

Radio-tagged salmon used the north side of the river less frequently than the south side; this trend intensified as fish migrated from the tailrace to the base of The Dalles Dam. In 2010, a majority of tagged adults swimming up the north shore crossed the river to the south before approaching a powerhouse fishway opening, particularly during periods of higher spill. In 2014, we did not estimate how far fish migrated on the north shore prior to switching sides, but over 84% of adult Chinook salmon that were on the north shore switched to the east fishway prior to approaching the dam.

This behavior pattern was also observed for 92% of jack Chinook salmon and 93% of sockeye salmon. Our results indicated that spill was the only factor related to use of the north ladder for all groups in 2014, and its influence was negative. Unlike Jepson et al. (2011), who found low entrance efficiency at the north fishway opening, we found high entrance efficiency for all groups at both fishways.

The new spill wall and 2014 spill pattern did not appear to impede the ability of tagged salmon to seek and find alternate passage routes, even when approaches at the north fishway did not result in a fishway entry. Salmon recorded on the north shore that subsequently switched sides had median fishway entry times similar to those of fish that did not switch sides. Adult Chinook salmon that switched sides entered a fishway 1 h faster on average, while sockeye salmon that switched were 0.6 h slower on average than those that did not switch.

Dam passage times for adult radio-tagged Chinook salmon in 2014 (median = 16.1 h, n = 393) were about average relative to those in the 11 years for which comparison data are available. When data were separated by month, fish passing in July were among the fastest of the 11 years.

At John Day Dam, several structural modifications were made to the north fishway entrance in winter 2012 and 2013 to improve passage of adult salmonids and Pacific lamprey *Entosphenus tridentatus*. These modifications included the removal of lower fishway weirs, closure of one of two entrance slots, and installation of a variable-width entrance weir, bollard field, and lamprey passage system (LPS). Structural modifications were also made to the upper north ladder in 2010 that included the removal of concrete weirs; replacement of a bulkhead, crowder, light box, and picket leads near the count window; and installation of a window washer on the count window.

We evaluated how these modifications may have affected behaviors and passage times of radio-tagged adult and jack spring and summer Chinook salmon by comparing behavior and passage-time data from post-modification years (2013-2014) to similar data collected in pre-modification years (1997-1998 and 2000-2006). Jack Chinook salmon sampling began in 2013; thus jack data was not available for pre-modification years.

Use of the John Day north fishway by spring and summer Chinook salmon in 2013-2014 was consistent with patterns of use observed in pre-modification years. Post-modification fishway entrance and passage efficiency were either within the range of pre-modification values or higher. For adult Chinook salmon, fishway exit ratios (exit to the tailrace) in 2013-2014 were similar to those in prior years for the spring run and lower than those in prior years for the summer run. Jack Chinook salmon had considerably lower exit ratios than adults.

We also found that salmon passage times were similar to or faster than those from estimates prior to the north fishway modifications. Approach-to-entry times were significantly faster in 2013-2014 than in pre-modification years, while entrance-to-ladder-base times were similar to previous results. The percentage of Chinook salmon that required more than 1 h to pass these segments was much lower in 2013-2014 than in most pre-modification years.

Salmon passage time through the north ladder (from base to ladder exit) was significantly shorter for adult spring and summer Chinook in 2013-2014 than in previous years. Jacks passed the ladder more slowly than adults in spring, but at rates similar to those of adults in summer. All of the passage metric results suggest that recent north fishway modifications had no adverse effect on the passage behavior of Chinook salmon, with some passage metrics indicating a benefit.

In 2013-2014, we also monitored sockeye salmon passage through the John Day north fishway. Limited pre-modification data exists for sockeye salmon passage, making evaluation of the north ladder modifications on sockeye salmon difficult. Nevertheless, we present data collected on sockeye salmon in the north ladder in 2013-2014 to serve as a baseline for any future modifications.

Entrance, fishway, and dam passage efficiencies for sockeye salmon passage in the John Day north fishway were all high (> 85%), while exit ratios were low (≤ 25%). Median passage times throughout the fishway were low, and few fish required more than 1 h to enter the fishway and migrate through lower sections of the ladder.

Reach conversion rates of radio-tagged Chinook and sockeye salmon and steelhead in the lower Columbia River, 2013-2014

Keefer, Jepson, Clabough, Johnson, Caudill, Burke, Frick Technical Report 2015-8

Executive Summary: Our primary objective in this two-year study was to estimate upstream migration survival (i.e., ‘conversion rates’) of adult salmon and steelhead from release downstream from Bonneville Dam, through dam-to-dam reaches, and past McNary Dam. Radiotelemetry was used to help estimate final fates of tagged fish and to monitor fish behaviors at dams, in reservoirs, and as they entered lower Columbia River tributaries. Radiotelemetry was selected to provide more explicit spatial and temporal accounting of adults that did not successfully pass through the lower Columbia River Hydrosystem. PIT tags were used as a secondary marker that provided additional detection information at Bonneville, The Dalles and McNary dams, at upstream dams, and at many tributary sites and collection facilities.

In 2013-2014, we collected and double-tagged (radio + PIT) 1,200 adult spring–summer Chinook salmon, 600 jack spring–summer Chinook salmon, 799 adult sockeye salmon, and 1,590 adult summer steelhead at Bonneville Dam in approximate proportion to the runs and released them downstream. The steelhead sample was separated into 'early' and 'late' groups, with oversampling of late-run fish to address overwintering objectives (reported separately). Genetic samples were collected for all adult and jack Chinook salmon and all steelhead.

Fish fates – Fish were assigned to one of four fate categories using telemetry records and recapture information: 1) upstream from McNary Dam; 2) entered a tributary downstream from McNary Dam; 3) fisher-reported harvest downstream from McNary Dam; and 4) unaccounted for downstream from McNary Dam. Final detections indicated that 65-69% of adult Chinook salmon, 76-83% of jack Chinook salmon, 81-83% of sockeye salmon, 45-46% of early steelhead, and 72-73% of late steelhead passed McNary Dam; majorities of these fish were ultimately detected in tributaries or at dams in the Snake or upper Columbia River basins. Entry into lower Columbia River tributaries varied considerably among groups: 8-15% (adult Chinook salmon), 10-11% (jack Chinook salmon), 0% (sockeye salmon), 30% (early steelhead), and 8% (late steelhead). Fisher-reported main stem harvest rates from release to McNary Dam were 5% (adult Chinook), <1-2% (jack Chinook), 2-3% (sockeye), 5-7% (early steelhead), and 4-5% (late steelhead); these were minimum indicators of harvest rates given evidence for low transmitter return rates from fisheries and discordance between adult and jack conversion rates. The unaccounted-for percentages downstream from McNary Dam were: 16-18% (adult Chinook), 5- 11% (jack Chinook), 13-18% (sockeye), 18-23% (early steelhead), and 15-16% (late steelhead). A portion of the unaccounted-for fish in each group was almost certainly harvested but was not reported to us.

Reach-specific conversion rates – Conversion rates were estimated for five reaches: (1) release downstream from Bonneville Dam past Bonneville Dam; (2) from the top of Bonneville Dam past The Dalles Dam; (3) from the top of The Dalles Dam past John Day Dam; (4) from the top of John Day Dam past McNary Dam; and (5) the cumulative conversion from the top of Bonneville Dam past McNary Dam. We calculated a suite of four conversion rates that differentially accounted for tributary turnoff and fisher-reported harvest of radio-tagged fish.

Conversion rate estimates for the aggregate samples from release past Bonneville Dam averaged 0.967 and ranged from 0.932 (2014 sockeye) to 0.982 (2014 early steelhead). Rates in dam-to-dam reaches were lowest between Bonneville and The Dalles dams, the reach with the most fisheries effort. Rates were generally highest between John Day and McNary dams. When tributary entry was treated as successful migration, conversion estimates through the multi-dam Bonneville-McNary reach were: 0.806-0.815 (adult Chinook), 0.907-0.966 (jack Chinook), 0.858-0.863 (sockeye), 0.738-0.771 (early steelhead), and 0.817-0.852 (late steelhead). Bonneville-McNary reach conversion estimates that accounted for known tributary turnoff and main stem harvest were slightly higher for all groups: 0.830-0.841 (adult Chinook), 0.911-0.966 (jack Chinook), 0.879-0.886 (sockeye), 0.719-0.773 (early steelhead), and 0.846-0.879 (late steelhead). By excluding tributary turnoff and main stem harvest, the latter estimates measured unknown loss in the main stem.

Conversion rates were statistically associated with a variety of covariates including fish traits (origin, size, sex), fish behaviors (fallback at dams), and seasonal environmental conditions. In general, lower reach conversion rates for adult Chinook salmon were associated with warm water temperature, fallback at downstream dams, and large size. The size effect may indicate some size-selective harvest. Hatchery adult Chinook salmon also had lower conversion than wild adults, but only through the Bonneville-The Dalles reach. There was little evidence for covariate effects on jack Chinook salmon, largely because jack conversion rates were consistently among the highest in this study. The only statistically significant covariate for jack Chinook salmon was year, as conversion rates were higher in 2013 than in 2014 through the Bonneville-The Dalles and the multi-dam Bonneville-McNary reaches.

Sockeye salmon conversion rates were lower for larger fish (possible harvest effect), for late- timed migrants that encountered relatively warm water, and for those that fell back at Bonneville Dam. There was also a year effect, with higher conversion in 2013 than in 2014 through the release-Bonneville and John Day-McNary reaches. There were few statistically significant covariate effects for early-run steelhead, except that larger steelhead were less likely to survive the Bonneville-The Dalles reach and fallback was surprisingly associated with higher survival in the Bonneville-McNary reach. A variety of covariates were associated with late-run steelhead conversion rates. Wild late-run steelhead and males had lower conversion rates than hatchery fish and females, respectively. Head injuries, marine mammal injuries, gillnet marks, and downstream fallback events were all associated with lower late-run steelhead survival.

Genetic assignments – We used parentage-based tagging (PBT) and genetic stock identification (GSI) to assign Chinook salmon and steelhead to specific hatcheries (PBT) or reporting groups (GSI). There were 16 Chinook salmon and 11 steelhead source hatcheries identified in the PBT analysis and 14 Chinook salmon and 12 steelhead GSI reporting groups. PBT assignments were possible for varying percentages of the tagged fish approximately in proportion to the abundance of Snake River hatchery fish in each sample: adult spring Chinook salmon (26-31% PBT assigned), adult summer Chinook salmon (2-5%), jack spring Chinook salmon (30-50%), jack summer Chinook salmon (21-38%), early-run steelhead (22-25%), and late-run steelhead (71-74%). Large majorities of each Chinook salmon and steelhead sample were assigned to GSI reporting groups.

The genetic assignments were used to calculate population-specific reach conversion rates for groups with adequate sample sizes and to estimate the origin of fish that were harvested or were unaccounted for downstream from McNary Dam. The genetic information was also used to identify fish that likely strayed from populations upstream from McNary Dam into tributaries between Bonneville and McNary dams.

Bonneville-McNary reach conversion estimates varied considerably among species and populations. Using the metric that treated main stem harvest, strays, and unaccounted for fish as unsuccessful, conversion estimates for PBT-assigned adult spring Chinook salmon were: 0.773-0.882 (Dworshak), 0.793-0.852 (Rapid River), 0.538-0.950 (McCall), and 0.857 (South Fork Clearwater). Estimates for PBT-assigned jack spring Chinook salmon were: 1.000 (Dworshak) 0.946-1.000 (Rapid river), and 0.778 (McCall). Estimates for PBT-assigned early-run steelhead were: 0.636-0.714 (Pahsimeroi) and 0.684-0.714 (Lyons Ferry). Estimates for late-run steelhead were: 0.857-0.897 (Pahsimeroi), 0.833-0.875 (Sawtooth), 0.762-0.818 (Dworshak), 0.583-1.000 (Wallowa), and 0.714 (Oxbow). Radio-tagged sample sizes varied widely among PBT groups.

The GSI assignments were less geographically precise than the PBT assignments, and some GSI reporting groups including a mixture of fish that potentially originated either upstream or downstream from McNary Dam. We used the GSI data to calculate reach conversion estimates only for those populations that primarily or exclusively originated upstream from McNary Dam. Using the Bonneville-McNary conversion metric described above, estimates for GSI-assigned adult spring Chinook salmon were: 0.864-0.870 (Yakima), 0.750-0.785 (Hells Canyon), 0.705-0.909 (South Fork Salmon), and 0.667-0.880 (upper Salmon). Estimates for adult summer Chinook salmon were: 0.692-0.738 (upper Columbia summer/fall) and 0.818 (South Fork Salmon). GSI-based estimates for jack Chinook salmon were consistently higher than for adults within the respective reporting groups. Bonneville-McNary conversion estimates for PBT- assigned early-run steelhead were: 0.818 (upper Columbia) and 0.639-0.737 (upper Salmon). Estimates for late-run steelhead were: 0.777-0.814 (South Fork Clearwater), 0.765-0.833 (upper Clearwater), and 0.804-0.848 (upper Salmon).

Using the PBT data from hatchery origin adults we estimated that stray rates from the Snake River into lower Columbia River tributaries were 3.0-3.3% (adult spring Chinook), 0.0% (adult summer Chinook), 0.0-1.0% (jack spring Chinook), 0.2-3.2% (jack summer Chinook), 3.6% (early steelhead), and 4.5-7.1% (late steelhead). These estimates were calculated across hatchery groups to increase sample size; estimates for individual hatchery samples were higher and lower than the aggregate estimates. Straying estimates based on GSI assignments were generally aligned with the PBT-based results. We note that some fish designated as strays were likely harvested and may not have been permanent, breeding strays in the absence of fisheries.

Conclusions – The combination of radiotelemetry and PIT-tag detection histories with genetically-based stock assignments allowed us to generate precise estimates of dam-to-dam and multi-dam reach conversion estimates for upstream-migrating salmonids in the lower Columbia River hydrosystem. The self-reported harvest, tributary turnoff, and straying rates reported in this study, along with the analysis of covariate effects, provide information needed for understanding why some groups do not survive at the performance standards mandated by the FCRPS Biological Opinion. A critical remaining uncertainty regards the fates of upstream migrants that were unaccounted for. We presume that many of these fish were harvested but not reported to us. Others were presumably prespawn mortalities and smaller numbers may have entered tributaries undetected or spawned at main stem sites.

Overwintering distribution and fallback behavior by adult radio-tagged steelhead in the Federal Columbia River Power System, migration years 2013-2014 and 2014-2015

Keefer, Clabough, Jepson, Caudill, Burke, Frick **Technical Report 2015-15**

Executive Summary: Our primary objectives in this two-year study were to: 1) estimate the percentages of adult summer steelhead (*Oncorhynchus mykiss*) that overwintered in the Federal Columbia River Power System (FCRPS); 2) summarize the spatial distribution of FCRPS-overwintering fish; 3) evaluate the timing, location, and routes of wintertime fallback events at FCRPS dams; 4) estimate overwintering steelhead survival to tributaries; and 5) summarize the downstream movements and FCRPS survival of post-spawn steelhead kelts.

We collected and radio-tagged 789 (2013) and 799 (2014) adult steelhead at Bonneville Dam and used radiotelemetry and PIT tags to monitor their behaviors and distribution. Each annual sample was split into two study groups: an early-run group that was collected from June through August, and a late-run group that was collected in September and October. The samples were weighted for late-run fish because they were more likely to overwinter in the FCRPS and because the late-run, ‘B-group’ steelhead are a management and conservation priority. A substantial portion of the run in late summer could not be sampled due to high temperatures in both years. Tissue samples were collected for all steelhead, and parentage-based tagging (PBT) and genetic stock identification (GSI) was used to help assign fish to tributary populations.

Overwintering estimates – The probability of FCRPS overwintering substantially increased as steelhead migration date at Bonneville Dam increased. We estimated that 5.8-7.7% of early-run steelhead and 21.8-27.4% of the late-run steelhead at least partially overwintered in the lower Columbia and lower Snake River portions of the FCRPS. Overwintering estimates were higher at 8.7-12.2% for the early group and 29.9-37.8% for the late group after we censored fish that were reported as harvested and that were unaccounted for in the FCRPS (many were presumably harvested but not reported to us). The genetic data indicated that majorities of the late-run samples were from the Clearwater River basin whereas early-run groups originated from a more geographically diverse set of locations. Population-specific overwintering estimates generally aligned with the aggregated estimates for early- and late-run groups.

FCRPS distribution – In both years, some steelhead at least partially overwintered in each of the monitored FCRPS reservoirs. The highest proportions of overwintering steelhead were in the Lower Granite reservoir in December, January, and February, reflecting the preponderance of Snake River – and especially Clearwater River – steelhead in the radio-tagged samples. Other FCRPS areas with relatively high overwintering abundance included The Little Goose to Lower Granite reach and the McNary reservoir reach. There was a general upstream movement by steelhead through the winter period and some overwintering steelhead exited the FCRPS into tributaries in each month. Large majorities of the overwintering fish in each reach had entered tributaries by 1 April. Population-specific distributions indicated that Clearwater River steelhead overwintered primarily in Snake River reservoirs while steelhead with genetic assignments to other tributaries (including other Snake River tributaries) were distributed more equally among FCRPS reaches, with relatively more fish in the lower Columbia River reaches.

Winter fallback – Fallback by pre-spawn steelhead occurred at almost all dams during the late fall and winter study period. Events were most frequent at The Dalles and McNary dams, and there was a nadir in fallback activity in January at most dams in both study years. There was considerable evidence that some winter fallback events were associated with natal tributary overshoot behavior, particularly by John Day River steelhead at McNary Dam but also by Tucannon River fish (Little Goose and Lower Granite dams), Walla Walla River fish (Ice Harbor and Lower Monumental dams), and fish from Bonneville reservoir tributaries (The Dalles and John Day dams).

Winter and early spring radiotelemetry monitoring was used at The Dalles, John Day, and McNary dams to help infer fallback routes. Many steelhead were detected in dam forebays for days to weeks before falling back. We were most confident assigning routes to fallback events that were through ice and trash sluiceways at The Dalles (8.3-21.1% of events) and McNary (4.8-12.0%) dams and through the adult fish ladders (4.2-9.5%). Several events were likely via the navigation locks (2.1-5.7%, all dams) which were monitored in 2014 only. The percentage of fallback events that appeared to occur via spillways and powerhouses was highly variable. Estimates through spillways ranged from ~5-71% (all dams, both years) and were ~9-21% via powerhouses (all dams, 2014 only); there was more uncertainty regarding use of powerhouse routes in 2013 when the navigation locks were unmonitored. In 2014-2015, a temporary spillway weir (TSW) was operated experimentally at McNary Dam to test whether surface flow would facilitate steelhead fallback. Results were inconclusive from the small number of radio-tagged steelhead that were exposed to the experiment, in part because the operational experiment could not be fully implemented.

Survival and distribution – Steelhead that at least partially overwintered in the FCRPS survived to tributaries at high rates (91-92%) in the two study years. These survival rates were far higher than for the steelhead that did not overwinter in the FCRPS (56-58% survival), though rates are not directly comparable because overwintering was conditional on surviving the summer and fall fisheries. Several factors likely contributed to the higher survival for the overwintering group, including that they had survived the summer and fall fisheries and that many overwintered in an FCRPS reservoir close to their natal tributary confluence.

The final pre-spawn detection locations (i.e., the most upstream locations) for all radio-tagged steelhead included ~26% at Columbia River main stem sites, ~10% at lower Snake River dams or reservoirs, ~14-16% in Columbia River tributaries other than the Snake River, and ~49-50% in Snake River tributaries (we note again that late-run Snake River stocks were oversampled and a portion of the run was not sampled due to high temperatures). The most frequent final location in both 2013 and 2014 was the Clearwater River (29-30% of total samples). The Salmon River had 8-9%, the Snake River upstream from the Lower Granite reservoir had 7-11%, and the John Day and Deschutes rivers had 4-5% each. The final pre-spawn locations for the FCRPS overwintering groups were much different from the total samples: ~81% were in Snake River tributaries (primarily Clearwater River), ~10-11% were in Columbia River tributaries, and just ~2-6% and 3-6% were in the main stem Columbia and main stem Snake rivers, respectively.

Kelts – Of the steelhead that entered tributaries and were not reported as harvested in tributary fisheries or recaptured at hatcheries, 17% (2013-2014) and 25% (2014-2015) had springtime behaviors that indicated that they initiated downstream kelt migrations and entered the FCRPS. Most (77-87%) of the identified kelts were from Snake River tributaries. A total of 511 kelt dam fallback events were detected or inferred from downstream monitoring, with 38% of the events at lower Columbia River dams and 62% at Snake River dams. The earliest fallback events by post-spawn kelts were in late March or early April at most dams and events were most frequent from mid-April to mid-May.

Migration mortality for kelts appeared to be quite high, especially for populations with long migration distances. Survival of Snake River kelts was 35-44% from Lower Granite Dam to Ice Harbor Dam and was 12-26% from Lower Granite Dam to Bonneville Dam. Among the Snake River kelt groups, survival to Bonneville Dam was 17% (fin-clipped), 22% (unclipped), 26% (male), 19% (female), 10% (Clearwater River), 33% (Salmon River), and 30% (other Snake River tributaries). There were 18 kelts from the John Day River and their survival to Bonneville Dam was 83%; kelt sample sizes were ≤3 for other Columbia River tributaries.

5.3 LETTER REPORTS

Temperatures and tagging protocol for AFF in 2002 **Peery**	**25 Jan 2002**
Preliminary summary of juvenile bypass system fallbacks: 2000-2001 **Peery, Jepson**	**25 Jul 2002**
Lower Granite Dam transition pool weir test 2001 **Naughton, Peery**	**15 Nov 2002**
2001 Hanford reach fall Chinook salmon estimate **Peery**	**12 Dec 2002**
Fish ladder passage times **Peery**	**23 Jan 2003**
No title **Peery**	**12 Feb 2003**
Behavior in the forebay of Bonneville Dam - 2002 **Peery, Stuehrenberg**	**28 Mar 2003**
Spawning status of radio-tagged adult Chinook salmon **Peery**	**28 Mar 2003**

Preliminary summary of effects of Dworshak water on passage of adult salmon and steelhead: 2002
September releases 18 Jun 2003
Peery

Lower Granite Dam transition pool weir test 2001 and 2002 14 Jul 2003
Naughton, Peery

Chinook salmon fallback at John Day Dam – 2000 & 2002 27 Oct 2003
Peery

2001 & 2002 Fallback information at The Dalles, John Day dams 15 Dec 2003
Peery, Boggs

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Bonneville, The Dalles, John Day, and Ice Harbor dams 22 Mar 2004
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Clabough, Peery

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Johnson, Peery

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Dam during 2003 5 Sep 2005
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Keefer

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Keefer

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Keefer, Peery

Preliminary summary of adult steelhead escapement upstream from Lower Granite Dam
Keefer, Peery 19 Jan 2006

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Summary of 2004 straying rates for known-origin Chinook salmon and steelhead in the Columbia/Snake hydrosystem 24 Jan 2006
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Jepson, Peery 22 Jun 2006

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Summary of steelhead fallback during November at The Dalles Dam 16 Jan 2007
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Keefer, Peery 31 May 2007

Behavior of radio-tagged adult spring Chinook at The Dalles Dam - 2007 4 Jun 2007
Jepson

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Univ. of Idaho 13 Jun 2007

Estimates of pinniped predation at Bonneville Dam on specific Chinook salmon stocks
Keefer, Peery 24 Sep 2007

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Keefer, Caudill 6 Oct 2008

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Preliminary evaluation of radio-telemetry data for June-tagged Chinook salmon at Bonneville Dam - 2009 22 Sep 2009
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Jepson, Clabough, Caudill

Evaluation of passage and fallback events by radio-tagged Chinook salmon at Ice Harbor and Lower Monumental Dams as they relate to fish count discrepancies -2009 11 Feb 2010
Jepson, Keefer, Caudill

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Keefer, Caudill 10 Mar 2010

Temperature regimes during upstream migration and the use of thermal refugia by adult salmon and steelhead in the Columbia River basin 6 May 2010
Keefer, Caudill, Peery

Preliminary evaluation of radio-telemetry data for Chinook salmon at McNary Dam – 2010
Jepson, Caudill, Keefer, Burke 12 Jan 2011

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Keefer

Temperature regimes during upstream migration and use of thermal refugia by adult salmon and steelhead in the Columbia River basin 5 Jul 2011
Keefer, Caudill

Behavior of radio-tagged adult steelhead before, during, and after the spill test at The Dalles Dam in September 2014 24 Sep 2015
Jepson, Keefer, Caudill

5.4 SUBJECT MATTER INDEX

This keyword index was developed during a review of each publication produced during the adult salmon and steelhead radiotelemetry study. We identified keywords from the content, and then populated the index, which is organized by FCRPS project and includes a section for system-wide information. The **blue text** indicates technical reports, in a YEAR-Report # format. The **black text** indicates letter reports, in a YEAR-Date format. The **red text** indicates peer-reviewed papers, in a YEAR-Journal Abbreviation format. Journal abbreviations are: CJFAS = Canadian Journal of Fisheries Management; EA = Ecological Applications; EBF = Environmental Biology of Fishes; JFB = Journal of Fish biology; NAJFM = North American Journal of Fisheries Management; PLOS1 = Public Library of Science; RRA = River Research and Applications; TAFS = Transactions of the American Fisheries Society

5.4.1 Bonneville Dam and pool

Depth, swimming	
Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB
Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Escapement	
Estimation	2006-NAJFM(1), 2007-CJFAS
Fallback	
Count correction / adjustment	2000-1, 2000-5, 2002-2, 2004-4, 2004-TAFS, 2005-6, 2006-NAJFM(1), 2006-NAJFM(2)
Distribution after fallback	2000-1, 2000-5, 2002-2, 2004-3, 2004-4, 2004-10, 2005-6
Environmental effects	
Dissolved gas	2000-1, 2000-5, 2001-3, 2004-4
Flow	2000-1, 2000-5, 2001-3, 2004-4, 2005-6,
No spill	2000-1, 2004-4, 2003-15Dec, 2004-22Mar
Spill	2000-1, 2000-5, 2001-3, 2003-NAJFM, 2003-15Dec, 2004-4, 2004-22Mar, 2005-6, 2006-NAJFM(2)

Spill test	2001-3, 2005-6
Temperature	2000-1, 2001-3, 2004-4, 2003-NAJFM
Turbidity	2000-1, 2000-5, 2003-NAJFM, 2004-4,
Escapement effects	2000-1, 2000-5, 2002-2, 2003-NAJFM, 2004-4, 2004-22Mar, 2005-CJFAS, 2006-NAJFM(1), 2006-NAJFM(2)
Fishway-specific estimates	
Bradford Island fishway	1999-1, 2000-1, 2000-5, 2001-3, 2003-NAJFM, 2004-4, 2004-10, 2005-6, 2005-7
Washington-shore fishway	2000-1, 2001-3, 2004-4, 2004-10, 2005-6, 2005-7
Forebay release site	2004-7
Injury effects	2002-2
Kelt steelhead	2015-15
Migration delay	2002-2
Percentage / Rate	1999-1, 2000-1, 2000-5, 2001-3, 2002-2, 2003-NAJFM, 2003-5, 2003-15Dec, 2004-4, 2004-TAFS, 2004-10, 2004-22Mar, 2005-7, 2006-NAJFM(1), 2006-NAJFM(2), 2006-5, 2006-26Jul, 2006-15Aug, 2007-18Oct, 2009-22Sep, 2010-1, 2011-1
Reascension after fallback	2000-5, 2002-2, 2003-NAJFM, 2004-3, 2004-4, 2004-10, 2005-6, 2006-NAJFM(1), 2006-NAJFM(2), 2006-15Aug, 2007-18Oct, 2009-29Jun, 2009-22Sep, 2010-1, 2011-1
Route of fallback	
Fishway	2000-1,
Forebay	1999-1, 2003-NAJFM
Ice and trash sluiceway	2000-1, 2004-4, 2004-7, 2005-6
Juvenile bypass system	2002-25Jul, 2004-3, 2004-4
Navigation lock	2000-1, 2004-4, 2004-7, 2005-6,
Powerhouse / Turbine	2000-1, 2004-4, 2005-Jan, 2006-26Jul
Spillway	2000-1, 2004-4, 2004-7, 2005-6
Spill experiment (2000-2003)	2006-5
Straying	2004-4
Survival (See Escapement)	
Timing	
Seasonal effects	2000-1, 2001-3
Time to fallback	2000-1, 2001-3, 2004-4
Tributary overshoot	2000-1, 2003-15Dec, 2004-3, 2005-6

Fishway use

Approaches	2003-5, 2004-10, 2005-7, 2006-5, 2006-15Aug, 2007-4D, 2008-5, 2009-22Sep, 2010-1, 2011-1, 2015-6

Adult trap, effects	2007-12Oct
Cascades Island modifications	2009-29Jun, 2009-22Sep, 2010-1, 2011-1, 2014-10, 2015-6
Counting window	2004-2
Diel behavior	2004-2, 2008-5, 2013-EBF
Efficiency / Effectiveness	
Dam passage	2000-5, 2002-2, 2003-5, 2005-7, 2008-5, 2010-1, 2011-1, 2014-10, 2015-6
Fishway entrance	2003-5, 2005-7, 2006-6Jun, 2008-5, 2009-29Jun, 2009-22Sep, 2010-1, 2011-1, 2011-5Jul, 2014-10, 2015-6
Fishway passage	2003-5, 2005-7, 2008-5, 2014-10, 2015-6
Entries	2005-7, 2003-5, 2006-5, 2006-15Aug, 2007-4D, 2008-5, 2010-1, 2011-1, 2014-10, 2015-6
Exit to tailrace	2003-5, 2005-7, 2006-6Jun, 2006-15Aug, 2007-4D, 2008-5, 2009-29Jun, 2009-22Sep, 2010-1, 2011-1, 2011-5Jul, 2014-10, 2015-6
Fate, non-passers	2008-5
Fishway switching	2003-5, 2005-7, 2008-5
Navigation lock	2003-5, 2005-7
North downstream entrance	2014-10, 2015-6
Orifice gates, floating	2003-5, 2005-7, 2006-6Jun, 2008-5, 2011-5Jul
Picket lead, Bradford Island video	2012-5Sep
Transition pool behavior	2000-5, 2002-2, 2003-5, 2004-2, 2005-7, 2008-5
Turnaround in fishway	2004-2, 2008-5
Upstream migrant tunnel (UMT)	2010-10Mar
Vertical-slot weirs	2004-2

Forebay behavior

Routes	2003-28Mar, 2004-7

Migration route

Shoreline orientation	2004-7, 2004-8
Tailrace	2002-2, 2004-8

Passage times / rates

Counting window	2004-2
Dam	2000-5, 2002-2, 2003-5, 2004-TAFS, 2004-7, 2004-10, 2005-3, 2005-7, 2006-5, 2006-15Aug, 2007-CJFAS, 2007-4D, 2008-5, 2009-29Jun, 2010-1, 2011-1
Fishway	2003-5, 2005-7, 2008-5, 2009-29Jun, 2009-22Sep, 2010-1, 2011-1, 2014-10, 2015-6
Ladder	2003-5, 2005-7, 2007-12Oct, 2008-5

Adult trap, effects	2007-12Oct
Reservoir reaches	1999-1, 2000-5, 2002-2, 2004-TAFS, 2004-7, 2004-10, 2004-22Dec, 2005-CJFAS, 2005-3, 2006-22Jun
Tailrace	2003-5, 2005-7, 2006-15Aug, 2007-4D, 2008-5, 2009-29Jun, 2009-22Sep, 2010-1, 2011-1, 2014-10, 2015-6
Transition pool	2003-5, 2005-7, 2008-5, 2009-29Jun, 2009-22Sep, 2010-1, 2011-1, 2014-10, 2015-6
Exit effects	2000-5, 2002-2, 2003-5, 2008-5
Upstream migrant tunnel (UMT)	2010-10Mar
Vertical-slot weirs	2004-2

Sea Lions / Pinnipeds	
Escapement, effect on	2007-24Sep
Passage time, effect on	2007-18Oct
Predation	
Post-fallback	2007-18Oct
Sea lion exclusion device	2007-4D

Spill experiment (2000-2003)	2006-5

Temperature exposure	
Fishway	2008-3
Reservoir	2008-3
Tailrace	2008-3

5.4.2 The Dalles Dam and pool

Depth, swimming	
Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB

Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB

Escapement	
Estimation	2007-CJFAS
Fallback	
Count correction / adjustment	2000-2, 2000-5, 2002-2, 2004-TAFS, 2005-6, 2006-NAJFM(2)
Distribution after fallback	2000-2, 2000-5, 2002-2, 2004-10, 2005-6, 2007-16Jan
Environmental effects	
Dissolved gas	2000-2, 2000-5
Flow	2000-2, 2000-5, 2005-6,
No spill	2000-2, 2003-15Dec, 2004-22Mar
Spill	2000-2, 2000-5, 2003-15Dec, 2004-22Mar, 2005-6, 2006-NAJFM(2)
Temperature	2000-2
Turbidity	2000-2, 2000-5
Escapement	2000-2, 2000-5, 2002-2, 2004-22Mar, 2006-NAJFM(2)
Fishway-specific estimates	2000-2, 2000-5, 2004-10
Kelt steelhead	2015-15
Migration delay	2002-2
Percentage / Rate	2000-2, 2000-5, 2002-2, 2003-15Dec, 2004-TAFS, 2004-10, 2004-22Mar, 2005-6, 2006-NAJFM(2), 2007-16Jan
Reascension after fallback	2000-5, 2002-2, 2005-6, 2004-10, 2006-NAJFM(2)
Route of fallback	
Spillway	2000-2,
Survival (See Escapement)	
Timing	
Seasonal effects	2000-2, 2003-15Dec, 2007-16Jan
Time to fallback	2000-2
Tributary overshoot	2000-2, 2002-2, 2003-15Dec, 2005-6
Fishway use	
Approaches	2007-2, 2015-24Sep
Diel behavior	2013-EBF
East fishway	2007-2, 2007-4Jun, 2015-24Sep, 2014-11, 2015-7
Efficiency	
Dam passage	2002-2, 2007-2, 2007-4Jun
Fishway entrance	2007-2, 2015-7, 2015-24Sep
Fishway passage	2007-2,

  Entries 2007-2, 2015-24Sep, 2014-11, 2015-7
  Fishway switching 2007-2, 2014-11, 2015-7
  North fishway 2006-22Jun, 2007-2, 2007-4Jun, 2015-24Sep, 2014-11, 2015-7
  Spill effects 2007-2, 2007-4Jun, 2015-24Sep, 2014-11, 2015-7
  Transition pool 2007-2

Passage times / rates
  Abundance, effects 2015-24Sep
  Count station 2003-23Jan
  Dam 2000-5, 2002-2, 2003-1, 2004-TAFS, 2004-10, 2005-3, 2007-2, 2007-4Jun, 2015-24Sep, 2014-11, 2015-7
  Environmental effects 2007-2, 2014-11, 2015-7
  Fishway 2007-2, 2007-4Jun, 2007-13Jun, 2015-24Sep, 2014-11, 2015-7
  Ladder 2003-4, 2003-23Jan, 2005-29Aug, 2007-2
  Reservoir 2000-5, 2002-2, 2004-TAFS, 2004-10, 2005-CJFAS, 2005-3
  Tailrace 2007-2, 2007-4Jun, 2014-11, 2015-7
  Transition pool 2007-2

Shad
  Effects of fishery 2003-4, 2007-13Jun

Spill
  Experiment (2014) 2015-24Sep

Spill wall
  Post-construction evaluation 2014-11, 2015-7

Temperature exposure
  Fishway 2008-3
  Reservoir 2008-3
  Tailrace 2008-3

5.4.3 John Day Dam and pool

Depth, swimming	
Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB
Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Escapement	
Estimation	2007-CJFAS
Fallback	
Count correction / adjustment	2000-3, 2000-5, 2002-2, 2004-TAFS, 2005-6, 2006-NAJFM(2)
Distribution after fallback	2000-3, 2000-5, 2002-2, 2004-3, 2004-10, 2005-6
Environmental effects	
Dissolved gas	2000-3, 2000-5
Flow	2000-3, 2000-5, 2005-6
No spill	2000-3, 2003-27Oct, 2004-22Mar
Spill	2000-3, 2000-5, 2003-27Oct, 2004-22Mar, 2005-6, 2006-NAJFM(2)
Temperature	2000-3
Turbidity	2000-3, 2000-5
Escapement	2000-3, 2000-5, 2002-2, 2004-22Mar, 2005-6, 2006-NAJFM(2)
Fishway-specific estimates	2000-3, 2000-5, 2004-10
Kelt steelhead	2015-15
Migration delay	2002-2
Percentage / Rate	2000-3, 2000-5, 2002-2, 2003-27Oct, 2004-TAFS, 2004-10, 2004-22Mar, 2005-6, 2006-NAJFM(2)
Population-specific estimates	
Reascension after fallback	2000-3, 2000-5, 2002-2, 2004-3, 2004-10, 2005-6, 2006-NAJFM(2)
Route of fallback	
Juvenile bypass system	2002-25Jul, 2004-3
Spillway	2000-3
Survival (See Escapement)	
Timing	

    - Seasonal effects 2000-3
    - Time to fallback 2000-3
- Tributary overshoot 2000-3, 2004-3, 2005-6

Fishway use

- Approach 1996-5, 1996-6, 2005-Sep, 2008-4, 2014-11, 2015-7
- Diel behavior 2013-EBF
- Efficiency
    - Dam passage 2002-2, 2008-4, 2014-11, 2015-7
    - Fishway entrance 2005-Sep, 2008-4, 2014-11, 2015-7
    - Fishway passage 2008-4, 2014-11, 2015-7
- Entries 1999-5, 1996-6, 2005-Sep, 2008-4, 2014-11, 2015-7
- Exit to tailrace 2003-1, 2005-Sep, 2008-4, 2014-11, 2015-7
    - Temperature effect 2003-1
- Ladder, jumping 1999-5
- Orifice gates 2005-Sep
- Transition pool 2003-1, 2008-4
- Turnaround in fishway 2003-1, 2008-4

Passage times / rates

- Count station 2003-23Jan
- Dam 1996-6, 2000-5, 2002-2, 2004-TAFS, 2004-10, 2005-3, 2005-9Nov, 2005-16Nov, 2008-4
    - Flow 2005-9Nov, 2008-4
    - Spill 2005-9Nov, 2005-16Nov, 2008-4
    - Temperature 2003-1, 2005-9Nov, 2008-4
- Entry 2003-1, 2008-4, 2014-11, 2015-7
- Fishway 1999-5, 1996-6, 2003-1, 2014-11, 2015-7
- Ladder 1999-4, 2003-1, 2003-23Jan, 2004-TAFS, 2005-29Aug, 2008-4, 2014-11, 2015-7
- Reservoir 2000-5, 2002-2, 2004-10, 2005-CJFAS, 2005-3
- Tailrace 1999-5, 1996-6, 2003-1, 2008-4, 2014-11, 2015-7
- Transition pool 2008-4, 2014-11, 2015-7

Shad fishery

- Effects on salmon passage 1999-4

Spill / No spill	
Effect on fishway use	1999-5, 2008-4
Fall spill to attract steelhead	1999-5
Turbine operation	
Effect on fishway use	1999-6
Temperature exposure	
Fishway	2008-3
Reservoir	2008-3
Tailrace	2008-3

5.4.4 McNary Dam and pool

Depth, swimming	
Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB
Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Escapement	
Estimation	2006-NAJFM(1), 2006-NAJFM(2), 2007-CJFAS
Fallback	
Count correction / adjustment	2000-5, 2002-2, 2004-TAFS, 2005-6, 2006-NAJFM(1), 2006-NAJFM(2)
Dissolved gas	
Distribution after fallback	2000-5, 2002-2, 2004-3, 2004-10
Environmental effects	
Dissolved gas	2000-5,
Flow	2000-5, 2005-6
Spill	2000-5, 2005-6, 2006-NAJFM(2)
Turbidity	2000-5,

Escapement	2000-5, 2002-2, 2005-6, 2006-NAJFM(1), 2006-NAJFM(2)
Fishway-specific estimates	2000-5, 2004-10
Kelt steelhead	2015-15
Migration delay	2002-2
Percentage / Rate	2000-5, 2002-2, 2004-TAFS, 2004-10, 2005-6, 2006-NAJFM(1), 2006-NAJFM(2)
Reascension after fallback	2000-5, 2002-2, 2004-3, 2004-10, 2005-6
Route of fallback	
Juvenile bypass system	2002-25Jul, 2004-3
Survival (See Escapement)	
Temporary spillway weir test	2015-15
Tributary overshoot	2002-2, 2004-3, 2005-6
Overwintering steelhead	2015-15

Fishway use

Abundance, effects on passage	2004-11D
Adjustable overflow weirs	2004-11D
Approaches	2003-5, 2005-7, 2009-24Nov
Count window	2004-11D
Diel behavior	2004-11D, 2013-EBF
Efficiency	
Dam passage	2000-5, 2003-5, 2005-7
Fishway entrance	2003-5, 2005-7, 2009-24Nov
Fishway passage	2003-5, 2005-7
Entries	2003-5
Exit to tailrace	2003-5, 2005-7, 2006-3
Fishway switching	2003-5, 2005-7, 2006-3
Ladder	2003-5, 2004-11D, 2005-7, 2006-3
Overnighting	2006-3
Tilting weirs	2004-11D, 2011-12Jan
Transition pool behavior	2000-5, 2003-5, 2005-7
Velocity reduction, night	2009-24Nov

Passage times / rates

Count window	2004-11D
Dam	2000-5, 2002-2, 2003-5, 2004-TAFS, 2004-10, 2005-3, 2005-7, 2006-3
Fishway	2003-5, 2005-7

Ladder	2003-5, 2004-11D, 2005-7, 2005-29Aug, 2011-12Jan
Reservoir	2000-5, 2002-2, 2003-2, 2004-TAFS, 2004-10, 2005-CJFAS, 2005-3
Tailrace	2003-5, 2005-7, 2006-3
Transition pool	2003-5, 2005-7
Exit effect	2000-5, 2003-5, 2005-7

Temperature exposure

Fishway	2006-3, 2008-3
Reservoir	2008-3
Tailrace	2008-3

5.4.5 Ice Harbor Dam and pool

Depth, swimming

Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB

Dissolved gas supersaturation

Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB

Escapement

Estimation	2006-NAJFM(1), 2007-CJFAS

Fallback

Count correction / adjustment	2000-5, 2002-2, 2004-TAFS, 2005-6, 2006-NAJFM(1), 2010-11Feb
Distribution after fallback	2000-5, 2002-2, 2004-3, 2005-6
Environmental effects	
Dissolved gas	2000-5,
Flow	2000-5, 2005-6
No spill	2004-22Mar
Spill	2000-5, 2004-22Mar, 2005-6
Turbidity	2000-5,
Escapement	2000-5, 2002-2, 2004-22Mar, 2005-6

Fishway-specific estimates	2000-5
Kelt steelhead	2015-15
Migration delay	2002-2
Percentage / Rate	2000-5, 2002-2, 2004-TAFS, 2004-22Mar, 2005-6, 2006-NAJFM(1)
Reascension after fallback	2000-5, 2002-2, 2004-3, 2005-6
Route of fallback	
Juvenile bypass system	2002-25Jul, 2004-3
Survival (See Escapement)	
Tributary overshoot	2002-2, 2004-3, 2005-6

Fishway passage

Approaches	2003-5
Count correction	2010-11Feb
Count window	2004-11D
Diel behavior	2004-11D
Efficiency	
Dam passage	2000-5, 2003-5, 2014-3,
Fishway entrance	2003-5
Fishway passage	2003-5
Exit to tailrace	2003-5, 2006-3, 2014-3
Fishway switching	2003-5, 2006-3, 2014-3
Ladder	2003-5, 2006-3
Overnighting	2006-3
Transition pool behavior	2000-5, 2003-5
Vertical slot weirs	2004-11D

Passage times / rates

Abundance, effects on passage	2004-11D
Count window	2004-11D
Dam	2000-5, 2002-2, 2003-2, 2003-5, 2004-TAFS, 2005-3, 2006-3, 2013-PLOS1
Fishway	2003-5, 2013-PLOS1, 2014-3
Ladder	2003-5, 2013-PLOS1, 2014-3
Reservoir	2002-2, 2004-TAFS, 2014-3
Tailrace	2003-5, 2005-3, 2006-3
Transition pool	2003-5,
Exit effect	2000-5, 2002-2, 2003-5

Temperature	
Dworshak water release	2003-18Jun
Fish body temperature	2013-PLOS1
Fishway exit behavior	2013-PLOS1

Trap, adult	
Effects on passage	2014-3

Temperature exposure	
Fishway	2003-2, 2008-3
Forebay	2003-2
Reservoir	2008-3
Tailrace	2008-3

5.4.6 Lower Monumental Dam and pool

Depth, swimming	
Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB

Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB

Drilling, spill basin	
Effects on passage	2004-6

Escapement	
Estimation	2007-CJFAS

Fallback	
Count correction / adjustment	2004-TAFS, 2005-6
Dissolved gas	

Distribution after fallback	2005-6
Environmental effects	
Flow	2005-6
Spill	2005-6
Escapement	2005-6
Kelt steelhead	2015-15
Percentage / Rate	2004-TAFS, 2005-6, 2014-3
Reascension after fallback	2005-6
Survival (See Escapement)	
Tributary overshoot	2005-6

Fishway passage

Abundance, effects of	2006-1
Approaches	2004-6, 2006-10D, 2014-3
Count correction	2010-11Feb
Count window	2006-1
Diel effects	2006-1, 2006-10D
Efficiency	2006-10D
Dam passage	2014-3
Fishway entrance	2006-10D
Fishway passage	
Entries	2004-6, 2006-10D, 2014-3
Exits to tailrace	2006-3
Fishway switching	2006-3
Overnighting	2006-3
Transition pool	2006-1

Passage times / rates

Count window	2006-1
Dam	2004-TAFS, 2004-6, 2005-3, 2006-10D, 2013-PLOS1, 2014-3
Fishway	2006-1, 2013-PLOS1, 2006-10D
Ladder	2006-1, 2013-PLOS1, 2006-10D
Reservoir	2004-TAFS, 2005-3, 2007-31May
Tailrace	2004-6, 2006-10D, 2014-3

River environment	
Flow	2006-10D
Spill	
Effects on passage time	2006-10D
Spill deflectors	2006-10D
Temperature	
Effects on passage time	2006-3, 2006-10D
Fish body temperature	2006-3, 2008-3, 2013-PLOS1
Fishway exit behavior	2006-3, 2013-PLOS1
Temperature exposure	
Fishway	2006-3, 2008-3
Reservoir	2008-3
Tailrace	2008-3

5.4.7 Little Goose Dam and pool

Depth, swimming	
Reservoir	2004-8, 2005-TAFS, 2010-JFB
Tailrace	2004-8, 2005-TAFS, 2010-JFB
Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Escapement	
Estimation	2007-CJFAS
Fallback	
Count correction / adjustment	2004-TAFS, 2005-6
Distribution after fallback	2005-6
Environmental effects	

Flow	2005-6
Spill	2005-6
Escapement	2005-6
Kelt steelhead	2015-15
Percentage / Rate	2004-TAFS, 2005-6, 2014-3
Reascension after fallback	2005-6
Survival (See Escapement)	
Tributary overshoot	2005-6, 2008-6Oct

Fishway passage

Approaches	2014-3
Diel behavior	2014-3
Efficiency	
Dam passage	2014-3
Fishway entrance	2014-3
Fishway passage	2014-3
Entries	2014-3
Exit to tailrace	2006-3, 2014-3
Overnighting	2006-3
Transition pool behavior	2000-5

Passage time

Dam	2004-TAFS, 2005-3, 2006-3, 2007-31May, 2013-PLOS1, 2014-3
Fishway	2007-31May, 2013-PLOS1
Ladder	2004-TAFS
Reservoir	2004-TAFS
Tailrace	2005-3, 2006-3, 2014-3

Spill

Effects on passage time	2007-31May

Temperature

Dworshak water release	2013-PLOS1
Effects on fishway passage	2006-3, 2014-3
Fish body temperature	2006-3, 2013-PLOS1
Fishway exit behavior	2006-3, 2013-PLOS1

Turbine operation	
Effects on fish passage	2014-3
Temperature exposure	
Fishway	2006-3, 2008-3
Reservoir	2008-3
Tailrace	2008-3

5.4.8 Lower Granite Dam and pool

Depth, swimming	
Reservoir	2004-8
Tailrace	2004-8, 2005-TAFS, 2006-6
Transition pool	2006-6
Dissolved gas supersaturation	
Reservoir exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Tailrace exposure	2004-8, 2005-TAFS, 2007-RRA(1), 2008-1, 2008-2, 2010-JFB
Escapement	
Estimation	2006-NAJFM(1), 2007-CJFAS
Fallback	
Count correction / adjustment	2000-5, 2002-2, 2004-TAFS, 2005-6, 2006-NAJFM(1)
Distribution after fallback	2005-6
Environmental effects	
Dissolved gas	2000-5
Flow	2000-5, 2005-6,
Spill	2000-5, 2005-6,
Turbidity	2000-5
Escapement	2002-2, 2005-6,
Kelt steelhead	2004-Dec, 2015-15
Migration delay	2002-2

Percentage / Rate	2000-5, 2002-2, 2004-TAFS, 2005-6, 2006-NAJFM(1), 2014-3
Reascension after fallback	2000-5, 2002-2, 2005-6,
Route of fallback	
Removable spillway weir (RSW)	2004-Dec
Survival (See Escapement)	
Tributary overshoot	2002-2, 2005-6, 2008-6Oct
Fishway use	
Approaches	2003-5, 2005-7, 2014-3
Efficiency	
Dam passage	2000-5, 2003-5, 2014-3,
Fishway entrance	2003-5, 2005-7, 2005-7, 2014-3
Fishway passage	2003-5, 2005-7, 2007-RRA(2), 2014-3
Entries	2003-5, 2005-7, 2014-3
Exit to tailrace	2003-5, 2005-7, 2006-3, 2006-6, 2007-1
Overnighting	2006-3, 2007-1
Transition pool / Junction pool	2002-15Nov, 2003-5, 2003-14Jul, 2005-7, 2006-6, 2007-1, 2007-RRA(2)
Migration route	
Shoreline orientation	2004-8
Tailrace	2004-8
Passage time	
Dam	2000-5, 2002-2, 2003-2, 2003-5, 2004-TAFS, 2005-3, 2005-7, 2006-6, 2007-RRA(2), 2007-1, 2013-PLOS1, 2014-3
Fishway	2003-5, 2005-7, 2006-6, 2007-1, 2013-PLOS1
Ladder	2003-5, 2005-7, 2006-6, 2007-1, 2013-PLOS1
Reservoir	2002-2, 2004-TAFS, 2005-3
Tailrace	2003-5, 2005-7, 2006-6, 2007-1, 2014-3
Transition pool	2002-15Nov, 2003-5, 2003-14Jul, 2005-7, 2006-6, 2007-RRA(2), 2007-1
Exit effect	2000-5, 2002-2, 2003-5, 2005-7, 2006-6, 2007-1
Temperature exposure	
Dworshak water release	2003-18Jun, 2013-PLOS1
Fish body temperature	2003-18Jun, 2006-3, 2013-PLOS1
Fishway exit behavior	2006-3, 2013-PLOS1

Fishway temperature	2003-2, 2006-3, 2014-3
Forebay temperature	2003-2, 2014-3
Tailrace	2008-3

5.4.9 Priest Rapids Dam and pool

Fallback

Fishway-specific estimates	2004-10
Percentage/Rate	1996-1, 1998-5, 2002-2, 2004-10
Reascension	1996-1, 1998-5, 2004-10

Fishway use

Approaches	1996-1, 1998-5
Coded-wire tag trap	1998-5, 1998-5
Counting station	1998-5
Entries	1996-1, 1998-5
Fishway fence	1998-5
Junction pool	1996-1, 1998-5
Orifice gates, open / closed	1996-1, 1998-5
Transition pool	1998-5, 1998-5

Passage times / rates

Dam	2002-2, 2004-10
Fishway	1996-1, 1998-5
Junction pool	1996-1, 1998-5
Ladder	1996-1, 1998-5
Reservoir	2004-10
Tailrace	1996-1, 1998-5

5.4.10 Wanapum Dam and pool

Fallback

Fishway-specific estimates	2004-10
Percentage/Rate	1998-5, 2004-10
Reascension	1998-5, 2004-10

Fishway use

Approaches	1998-5
Entries	1998-5
Slotted entrances	1998-5
Junction pool	1998-5
Orifice gates, open / closed	1998-5
Transition pool	1998-5

Passage times / rates

Dam	2004-10
Fishway	1998-5
Junction pool	1998-5
Ladder	1998-5
Reservoir	2004-10
Tailrace	1998-5

5.4.11 System-wide and multiple-dam reaches

Barging (see Transport)

Conversion (see Escapement)

Data storage transmitters

Fall Chinook	2004-8, 2007-RRA, 2007-JFB, 2008-2, 2008-3, 2010-6May
Stock-specific estimates	2008-3
Sp-Su Chinook	2004-8, 2007-RRA, 2007-JFB, 2008-2, 2008-3, 2010-6May

Stock-specific estimates	2008-3
Steelhead	2004-8, 2007-RRA, 2007-JFB, 2008-2, 2008-3, 2010-6May
Stock-specific estimates	2008-3
Diel behavior (see Migration timing)	
Distribution	
Fall Chinook	2006-24Jan, 2006-8
Jack Chinook	2014-3, 2014-12, 2015-8
Sockeye	2004-10, 2014-12, 2015-8
Sp-Su Chinook	2000-5, 2003-12Feb, 2006-18Jan, 2006-24Jan, 2014-3, 2014-12, 2015-8
Steelhead	2002-2, 2006-19Jan, 2006-24Jan, 2014-12, 2015-8, CJFAS-*ip*
En route mortality (see Escapement)	
Energetics	
Migration costs	2005-8D, 2009-4
Reproductive costs	2005-8D, 2009-4
Proximate analysis	2005-8D, 2009-4
Escapement to tributaries	
Energy use	2005-8D
Environmental effects	2002-2, 2003-6D, 2005-5Oct, 2005-CJFAS (2), 2005-2, 2007-CJFAS, 2009-CJFAS, 2014-3, 2014-12, 2015-8
Fall Chinook salmon	2003-6D, 2005-2, 2006-24Jan, 2006-8, 2007-CJFAS, 2012-FR, 2010-NAJFM
Fish traits	2007-CJFAS, 2014-12, 2015-8
Genetic stock identification	2014-12, 2015-8
Hanford Reach	2002-12Dec, 2006-8
Injury effects	2006-NAJFM(2), 2011-CJFAS, 2014-12, 2015-8, CJFAS-*ip*
Jack Chinook	2014-3, 2014-12, 2015-8
Overwintering (see overwintering)	
Population-specific estimates	2014-12, 2015-8
Sea lion effects	2005-5Oct, 2007-24Sep, 2011-CJFAS, 2012-TAFS, 2014-12, 2015-8
Sp-Su Chinook	2005-5Oct, 2005-CJFAS, 2005-2, 2006-13Jan, 2006-18Jan, 2006-24Jan, 2007-CJFAS, 2008-EA, 2005-8D, 2012-TAFS, 2014-3, 2014-12, 2015-8
Sockeye	2005-CJFAS, 2006-NAJFM, 2014-12, 2015-8

Steelhead	2002-2, 2005-5Oct, 2005-CJFAS, 2005-2, 2006-13Jan, 2006-19Jan, 2006-24Jan, 2007-CJFAS, 2008-EA, 2009-CJFAS, 2014-12, 2015-8, 2015-15, CJFAS-*ip*
Tributary turnoff	2002-2, 2005-2, 2014-12, 2015-8

Fallback

Escapement, effects on	2002-2, 2004-10, 2005-2, 2005-6, 2005-5Oct, 2005-CJFAS, 2006-13Jan, 2006-NAJFM, 2008-EA, 2015-8
Injury	2002-2, 2004-10, 2006-NAJFM(2)
Jack Chinook	2014-12, 2015-8
Kelt steelhead	2015-15, CJFAS-*ip*
Multiple dams	2006-JFB
Overshoot of tributaries	2004-TAFS, 2005-6
Reascension	2002-2, 2004-10, 2005-6
Spill, effects of	2002-2, 2005-5Oct, CJFAS-*ip*
Surface flow routes	2015-15, CJFAS-*ip*
Transport effects	2006-7, 2008-EA
Winter	2008-NAJFM, 2015-15

Harvest / Fate

Fall Chinook	2005-CJFAS, 2005-2, 2006-8, 2006-24Jan, 2011-15Dec, 2010-NAJFM
Sp-Su Chinook	2000-5, 2003-12Feb, 2005-2, 2005-5Oct, 2005-CJFAS, 2006-13Jan, 2006-24Jan, 2011-15Dec, 2008-EA, 2014-12, 2015-8
Sockeye	2004-10, 2005-CJFAS, 2014-12, 2015-8
Steelhead	2002-2, 2005-CJFAS, 2005-2, 2006-19Jan, 2006-24Jan, 2008-EA, 2011-15Dec, 2014-12, 2015-8, CJFAS-*ip*

Homing / Straying

Orientation	2006-2, 2006-CJFAS, 2006-JFB, 2008-EA, 2008-JFB
Permanent straying	
Fall Chinook	2004-18Oct, 2005-2, 2005-5, 2005-5Oct
Sockeye	2015-8
Sp-Su Chinook	2004-18Oct, 2005-2, 2005-5, 2005-5Oct, 2006-2, 2006-7, 2006-24Jan, 2008-EA, 2014-12, 2015-8
Steelhead	2004-18Oct, 2005-2, 2005-5, 2005-5Oct, 2006-7, 2006-24Jan, 2008-18Apr, 2008-EA, 2009-CJFAS, 2014-12, 2015-8
Transport, effects of	2005-5, 2006-7, 2008-18Apr, 2008-EA

Temporary straying	
Fall Chinook	2003-6D, 2005-5Oct, 2006-TAFS(2), 2010-6May, 2011-15Dec
Sockeye	2010-6May
Sp-Su Chinook	2000-5, 2005-5Oct, 2006-2, 2008-JFB, 2010-6May, 2011-15Dec
Steelhead	2002-2, 2005-5Oct, 2006-TAFS(1), 2008-18Apr, 2009-CJFAS, 2010-6May, 2011-15Dec
Kelts	
Downstream migration survival	2015-15
Fallback (see Fallback)	
Methods development	
Bonneville adult fish facility	2002-25Jan
Escapement estimation	2012-FR
Genetic stock identification	2014-12, 2015-15, CJFAS-*ip*
Parentage-based tagging	2014-12, 2015-15, CJFAS-*ip*
Proximate analysis	2005-8D
Tagging protocols	
Effects of temperature restriction	2002-25Jan
Transmitter regurgitation	2004-NAJFM
Migration mortality (see Escapement)	
Migration route	
Environmental effects	2006-CJFAS
Ladder selection	2006-CJFAS
Migration timing	
Diel behavior	2004-10, 2013-EBF
Environmental effects	2002-2, 2003-6D, 2004-NAJFM, 2006-TAFS(2), 2008-TAFS
Fall Chinook	2003-6D, 2006-TAFS(2), 2006-8, 2012-FR, 2010-NAJFM
Run composition	2004-NAJFM, 2004-10, 2006-8, 2009-CJFAS, 2008-TAFS, 2010-NAJFM
Sp-Su Chinook	1998-5, 2000-5, 2004-NAJFM, 2008-TAFS, 2012-TAFS
Little White Salmon Hatchery	2004-22Dec
South Fork Salmon River	2005-8D, 2009-4
Upper Salmon River	2008-2Apr

Sockeye	1998-5, 2004-10
Steelhead	2002-2, 2006-TAFS(1), CJFAS-*ip*
Overwintering steelhead	
Environmental effects	2008-NAJFM, 2015-15
Fallback	2002-2, 2008-NAJFM, 2015-15
Locations	2002-2, 2008-NAJFM, 2015-15
Percentages/Rates	2002-2, 2008-NAJFM, 2015-15
Population-specific estimates	2008-NAJFM, 2015-15
Reservoir use	2002-2, 2008-NAJFM, 2015-15
Passage time	
Environmental / Seasonal effects	2003-6D, 2004-TAFS, 2004-JFB, 2005-3, 2005-CJFAS, 2005-8D, 2006-TAFS(1), 2006-TAFS(2), 2007-CJFAS, 2009-CJFAS, 2009-4
Fallback effects	2000-5, 2002-2, 2004-TAFS, 2004-10, 2005-3
Hanford Reach	1998-5
Injury effects	2002-2, 2004-10
Multi-dam reaches	2000-5, 2002-2, 2003-2, 2003-18Jun, 2004-TAFS, 2004-10, 2005-3, 2005-CJFAS, 2005-8D, CJFAS-*ip*
Tributary reaches	2004-JFB, 2005-3, 2005-8D, 2008-2Apr, 2009-4
Prespawn mortality	
Sp-Su Chinook	2003-28Mar, 2005-8D, 2005-5Oct, 2009-4
Reach conversion (see Escapement)	
Sea Lions / Pinnipeds	
Density dependence	2011-CJFAS, 2012-TAFS
Escapement effects (see Escapement)	
Injuries rates	2011-CJFAS
Migration timing effects	2011-CJFAS, 2012-TAFS
Passage time, effect on	2007-18Oct
Population-specific effects	2007-24Sep, 2012-TAFS
Straying (see Homing/Straying)	

Survival (see Escapement)

Thermal refuge use (see Homing / Straying)

Transport
- Escapement, effects on 2005-5Oct, 2006-7, 2008-EA
- Fallback, effects on 2005-5Oct, 2006-JFB, 2006-7, 2008-EA
- Straying (see Homing / Straying)

Tributaries
- Entry timing
  - Sp-Su Chinook 2000-5, 2009-4
  - Steelhead 2002-2
- Escapement above L. Granite
  - Sp-Su Chinook 2006-18Jan, 2005-8D, 2009-4
  - Steelhead 2006-19Jan, CJFAS-*ip*
- Migration rate
  - Sp-Su Chinook 2000-5, 2004-JFB, 2009-4
- South Fork Salmon River 2005-8D, 2009-4
- Temporary use (see Homing/Straying)

Tributary overshoot
- Population-specific estimates 2006-2, 2008-JFB
- Little White Salmon
  - Sp-Su Chinook 2004-22Dec
- Umatilla River
  - Sp-Su Chinook 2004-12Apr
  - Steelhead 2004-12Apr
- Spring Creek Hatchery
  - Fall Chinook 2004-22Dec
- Tucannon River
  - Sp-Su Chinook 2008-6Oct
  - Steelhead 2008-6Oct

Wandering (see Homing / Straying)

6.0 ADULT PASSAGE METRICS

This section presents a summary of monitoring effectiveness and a standardized set of annual adult salmon and steelhead passage metrics across FCRPS dams and dam-to-dam reaches to facilitate comparisons across years, species, life history types, and locations. The metrics were calculated using data from the coded 'general migration' files described in Section 3.1.6. The metrics (Figure 31) were selected from among the most commonly reported adult passage summaries in the papers and technical reports, though we note few have been systematically reported across species, life history types, and FCRPS projects because metrics were tailored to study objectives each year.

Rigorous statistical analyses that address how passage metrics relate to the dozens of major and minor structural and operational changes at FCRPS dams (see Tables 20-27) would require dozens of analyses at multiple scales which also accounted for concomitant environmental effects. Such an effort and was well beyond the scope of this project. Rather, we highlight example time series for selected passage metrics in relation to major structural (i.e., sea lion exclusion devices at Bonneville, The Dalles spill wall, the John Day ladder rebuild) and operational (i.e., Bonneville powerhouse priority) changes. Additional site- and modification- or operation-specific statistical evaluations of historical data in the assembled databases will facilitate future effectiveness monitoring (i.e., pre- and post-evaluations should be facilitated by the synthesized databases.

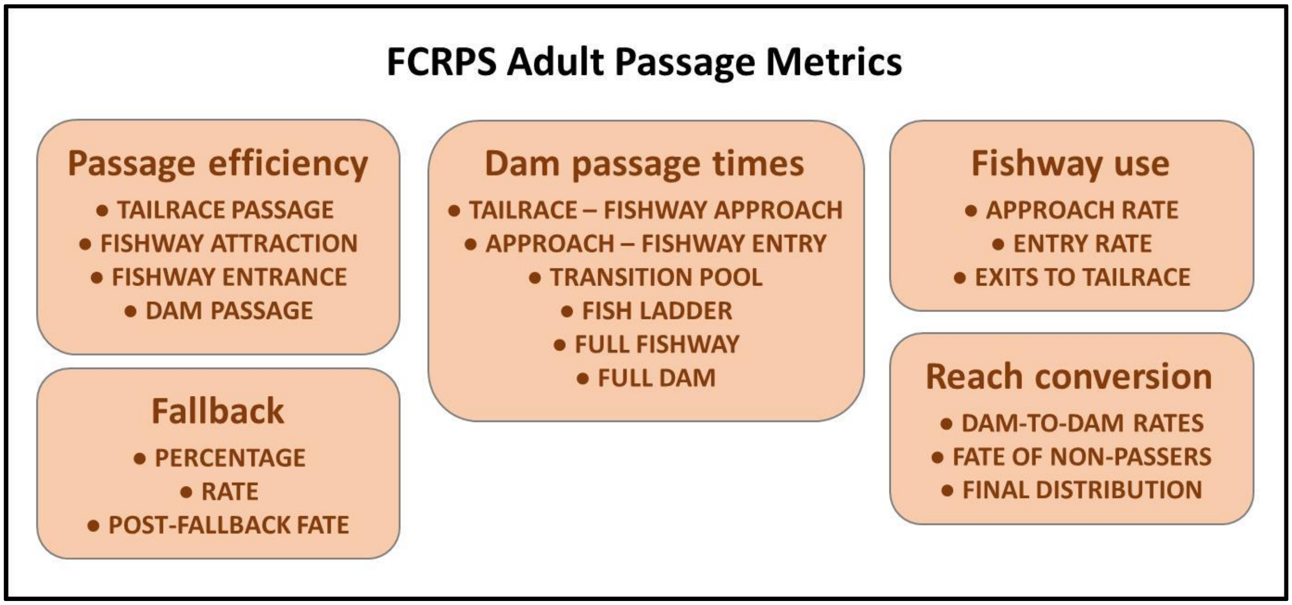


Figure 31. Schematic of the adult salmon and steelhead passage metrics reported in this section.

6.1 RADIO ANTENNA DETECTION EFFICIENCY

Estimates of detection efficiency were calculated for a variety of radiotelemetry sites over the course of the study. Detection efficiencies at the underwater coaxial cable antennas used to monitor adult fishways at the FCRPS dams tended to be high (e.g., >90%) because distances between fishway antennas and tagged fish were mostly <15 m. Furthermore, antenna redundancy inside dam fishways typically increased dam-wide detection efficiency (i.e., across antennas) to near 100%. Most missed fish detections were associated with radio transmitter loss or failure or receiver power outages. Underwater antennas were also occasionally lost after being tangled in debris.

6.1.1 AERIAL ANTENNA DETECTION EFFICIENCY: TAILRACES

Detection efficiency of the aerial antennas used to monitor tailraces, dam forebays, reservoirs, and tributary sites were far more variable than estimates for the underwater antennas. Tailrace and reservoir sites, in particular, had relatively low detection efficiency because they were used to monitor fish over long distances (e.g., some main stem Columbia and Snake River antennas were used to monitor a > 1 km-wide channel), and because radio signals rapidly attenuate as transmitter depth in the water column increases. Fish migration depths were often >10 m in tailraces and reservoirs, leading to higher rates of missed detections, whereas fish depth was restricted in fishways. The most-consistently monitored sites using aerial antennas were the FCRPS dam tailraces. Detection efficiency estimates at these sites varied widely among dams (Figure 32) as a function of channel depth, width, and bathymetry. There were also among-species and among-life history type differences in detection, presumably reflecting behavioral differences (e.g., some species are more surface-oriented or shore-oriented than others), and differences in signal strength among transmitter models.

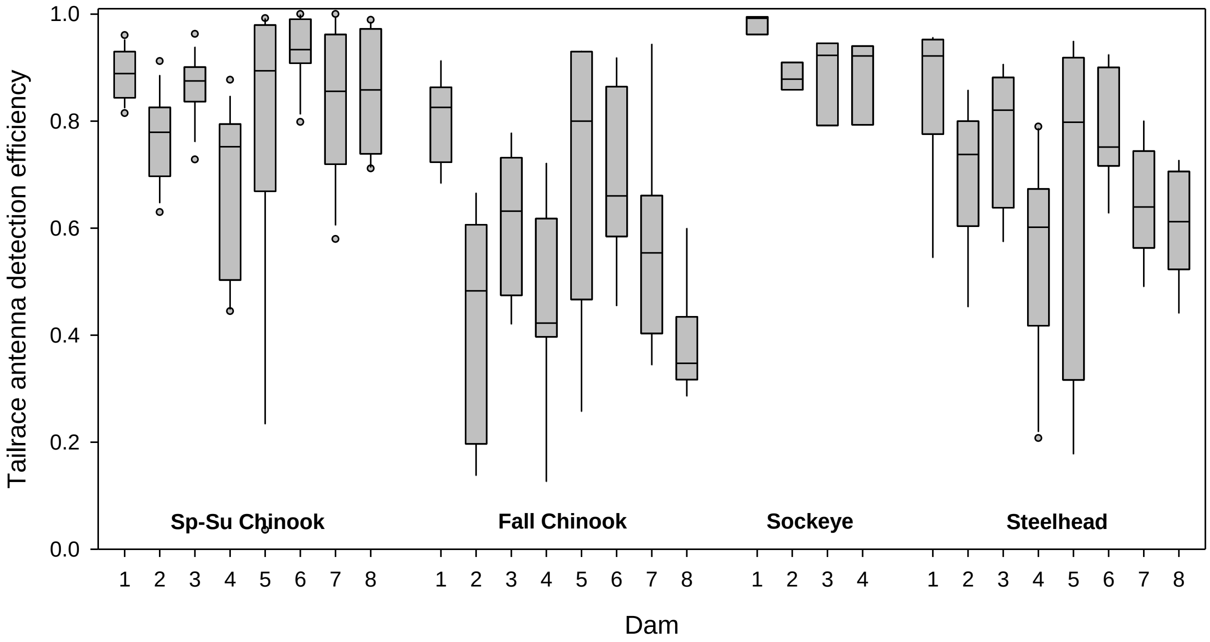


Figure 32. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of the annual detection efficiency estimates for the aerial antennas used to monitor radio-tagged adult salmon and steelhead as they entered and exited tailraces at FCRPS dams. Efficiency was calculated as the proportion of individuals detected at a dam that were first detected at tailrace antenna(s). Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.2 FISH PASSAGE EFFICIENCY ESTIMATES

Fish passage efficiency metrics are synonymous with a variety of terms (e.g., passage effectiveness, dam conversion rate, etc.), but essentially measure the proportion or ratio of fish that move from one site to another. Efficiency metrics can be important indicators of which passage environments, fishway features, or specific fishway segments present passage problems for upstream migrants and they are useful for comparing behaviors across locations and species. Notably, motivation for upstream movement is often an implicit underlying assumption (i.e., that 100% of adults would reach the upstream site in the absence of any obstacles), but behaviors like tributary overshoot behaviors violate this assumption. The most-often reported passage efficiency metrics at the FCRPS dams measured how fish move from tailraces, to fishway openings, into fishways, through fishway transition areas, and past the dams via ladders. The series of metrics presented below aggregate all similar sites at each individual FCRPS dam (e.g., the metrics are ‘dam-wide’ rather than site-specific for each category). Site-specific metrics were considered beyond the scope of this report.

6.2.1 TAILRACE PASSAGE EFFICIENCY

With a few exceptions, ≥95% of adult salmon and steelhead that entered a dam tailrace was eventually detected at one or more fishway antennas at that dam (Figure 33). Efficiency estimates were higher, on average, at the Snake River dams than at the lower Columbia River dams. Estimates that were <95% tended to be associated with fisheries harvest in or near tailraces as well as natal site overshoot behavior (i.e., fish temporarily entered tailraces upstream from their natal tributary or hatchery).

6.2.2 FISHWAY ATTRACTION EFFICIENCY

Attraction efficiency is the proportion of adults detected approaching a fishway among those detected in the tailrace. Fishway attraction efficiency estimates (Figure 34) closely paralleled the estimates for tailrace passage efficiency. This was unsurprising given that most antennas deployed at the base of the FCRPS dams were located at fishway openings; exceptions were antennas at navigation locks, ice and trash sluiceway outfalls, etc.. Attraction to fishway openings was generally ≥95% among adult salmon and steelhead that entered a dam tailrace.

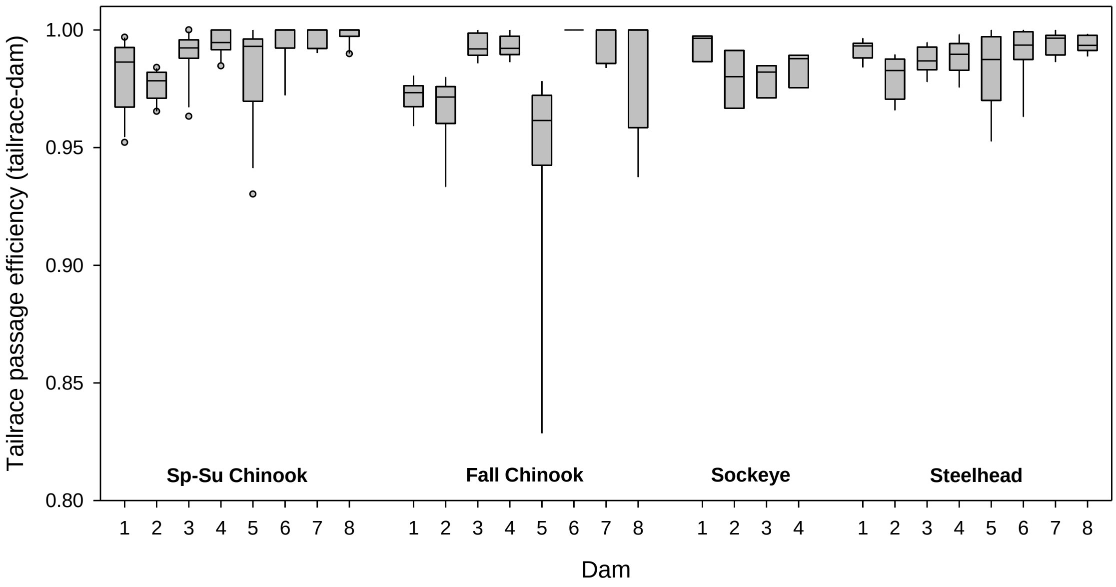


Figure 33. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of the annual tailrace passage efficiency estimates for adult salmon and steelhead, by species and run, 1996-2014. Efficiency was calculated as the proportion of individuals that were detected in a dam tailrace and eventually detected at any antenna at the dam itself (note: fish that passed tailrace sites undetected were included in denominators). Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

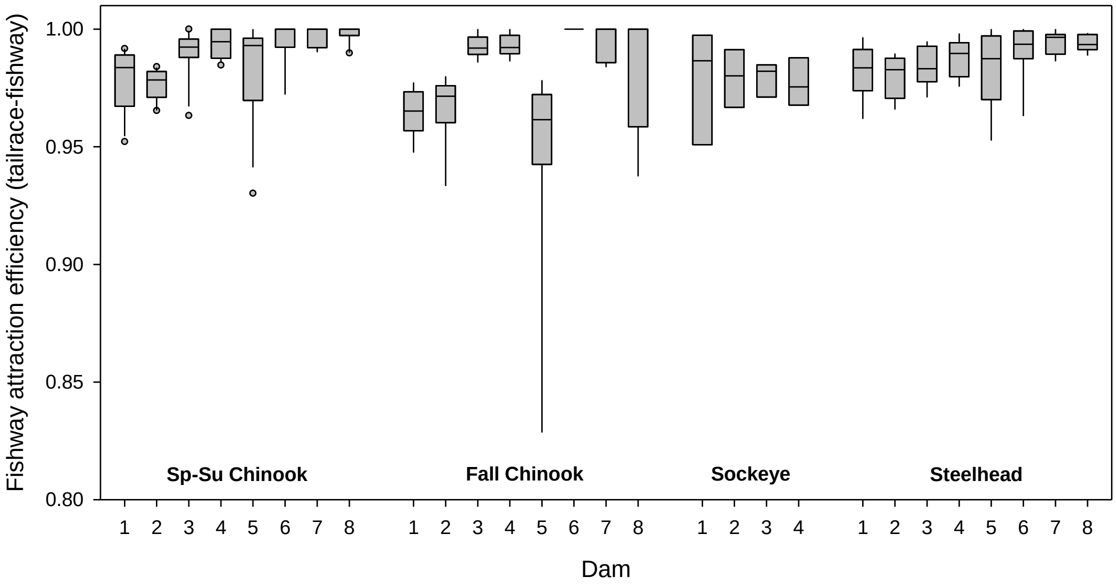


Figure 34. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of the annual fishway attraction efficiency estimates for adult salmon and steelhead, by species and run, 1996-2014. Efficiency was calculated as the proportion of individuals that were detected in a dam tailrace and eventually detected approaching or entering an adult fishway at the dam (note: fish that passed tailrace sites undetected were included in denominators). Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.2.3 FISHWAY ENTRANCE EFFICIENCY

Almost all adult fish detected approaching an adult fishway opening eventually entered a fishway at that dam (Figure 35). Most annual fishway entrance efficiency estimates were ≥95%. The few exceptions, including spring–summer Chinook salmon at The Dales and Ice Harbor dams and fall Chinook salmon at Ice Harbor and Little Goose dams, were associated with harvest and/or tributary or hatchery overshoot. For example, a number of the fall Chinook salmon that did not enter an Ice Harbor fishway eventually returned to the Columbia River Hanford reach.

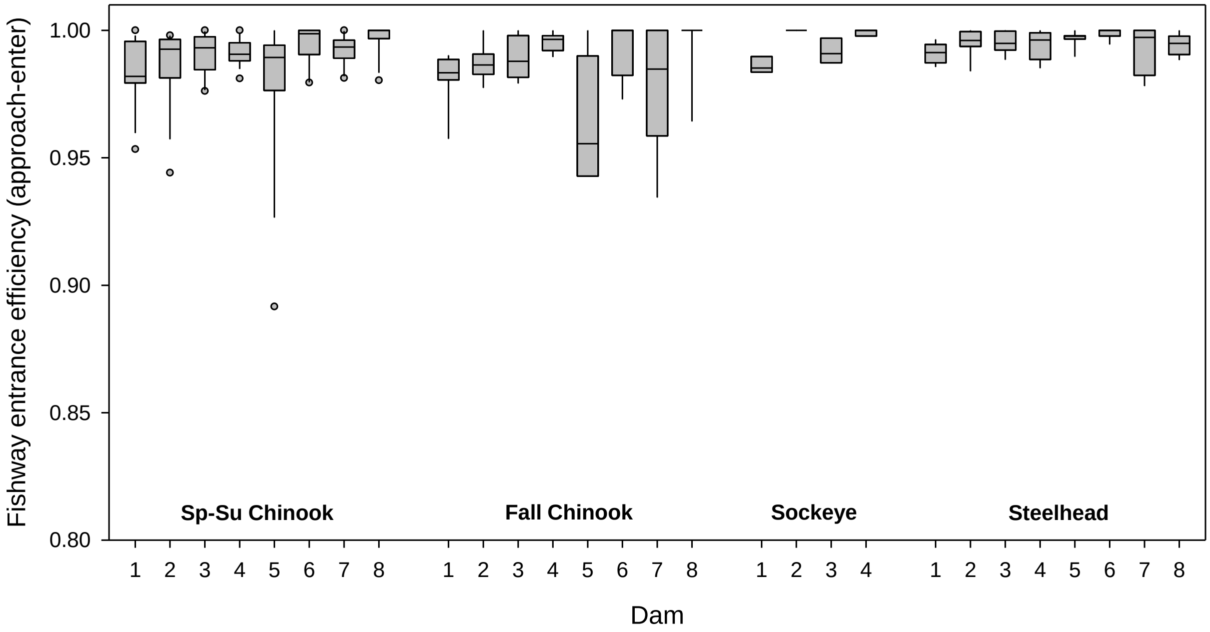
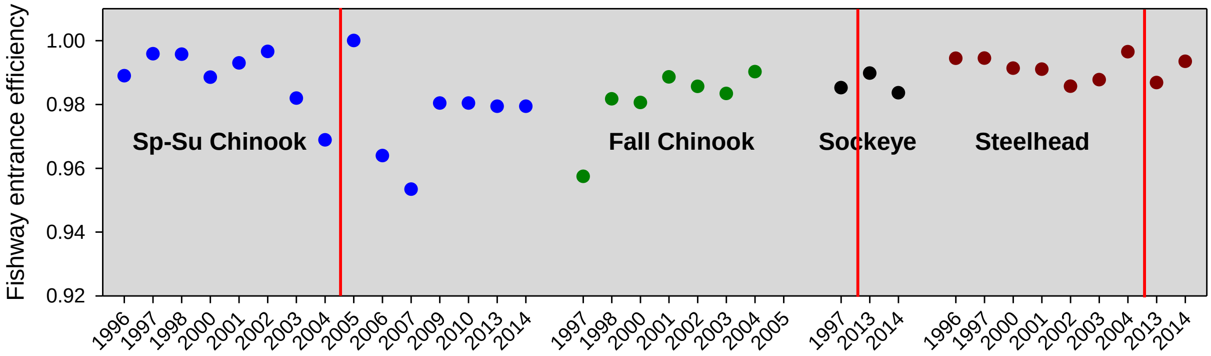


Figure 35. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of the annual fishway entrance efficiency estimates for adult salmon and steelhead, by species and run, 1996-2014. Efficiency was calculated as the proportion of individuals detected approaching a fishway opening that eventually entered a fishway. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.



Time Series Example 1. Annual fishway entrance efficiency estimates at Bonneville Dam in relation to the installation of Sea Lion Exclusion Devices (SLEDs), which were first tested in 2005 (red lines) and were deployed seasonally thereafter.

6.2.4 FISHWAY PASSAGE EFFICIENCY

Fishway passage efficiency estimates were the proportion of fish that entered a fishway and eventually passed the dam (Figure 36). The metric captured a range of behaviors, including one or more fish exits from a fishway back to the tailrace. Estimates for spring–summer Chinook salmon and steelhead were generally ≥96%, except at John Day Dam where about half the annual estimates were lower for these runs. Estimates for fall Chinook salmon were the most variable among runs, with many annual values <95%; the lowest fall Chinook salmon estimates were at John Day, Little Goose, and Ice Harbor dams (Figure 36).

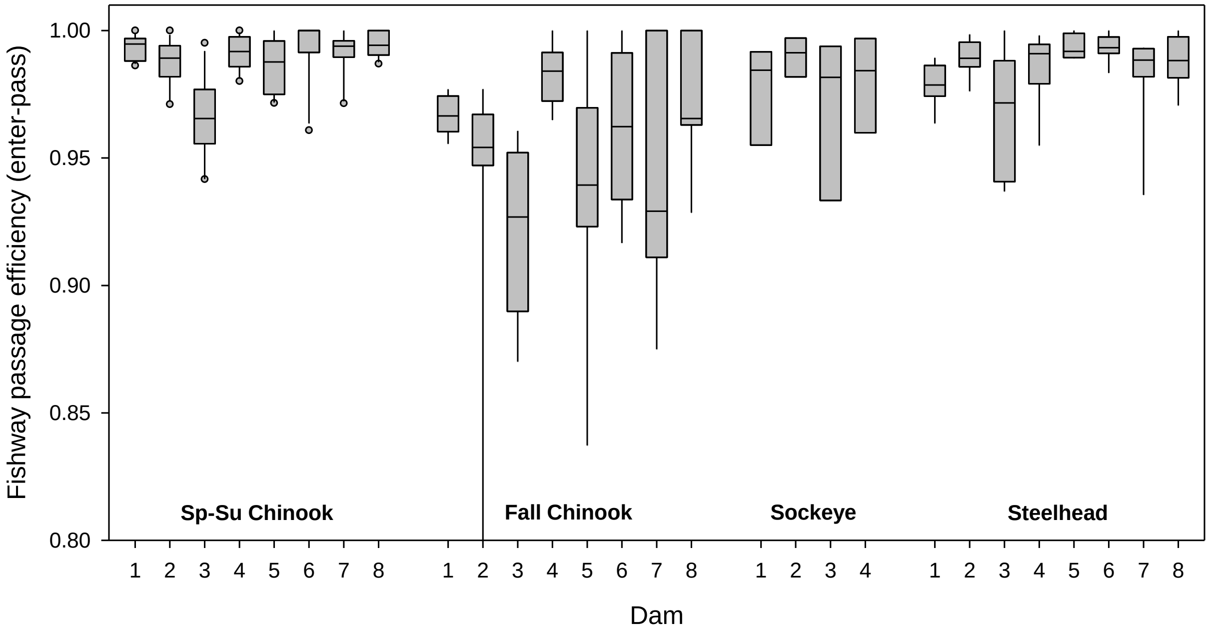
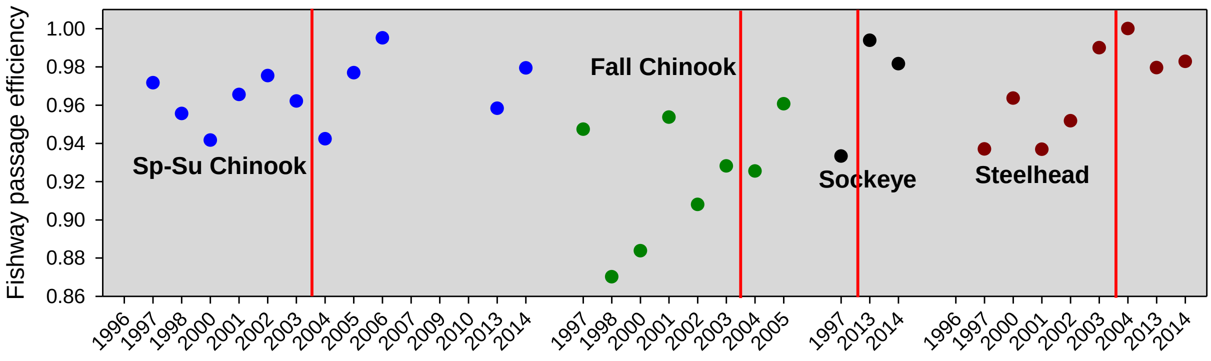


Figure 36. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of the annual fishway passage efficiency estimates for adult salmon and steelhead, by species and run, 1996-2014. Efficiency was calculated as the proportion of individuals and detected entering a fishway opening that eventually passed the dam. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.



Time Series Example 2. Annual dam-wide fishway passage efficiency estimates at John Day Dam in relation to the 2003 completion of the south ladder flow control section (red lines).

6.2.5 DAM PASSAGE EFFICIENCY

Dam passage efficiency was the proportion of fish that entered a tailrace and eventually passed a dam (i.e., total individual FCRPS project passage). Passage efficiency estimates for steelhead and sockeye salmon were the least variable year-to-year and were generally ≥92% (Figure 37, Table 28). Most estimates for spring–summer Chinook salmon were also ≥92%, but values were lower in a few years, especially at the lower Columbia River dams. Fall Chinook salmon estimates were the lowest, on median, and the most variable both across FCRPS projects and among years (Figure 37, Table 28). The aforementioned main stem harvest and natal site overshoot behaviors contributed to the low estimates for fall Chinook salmon relative to the other runs.

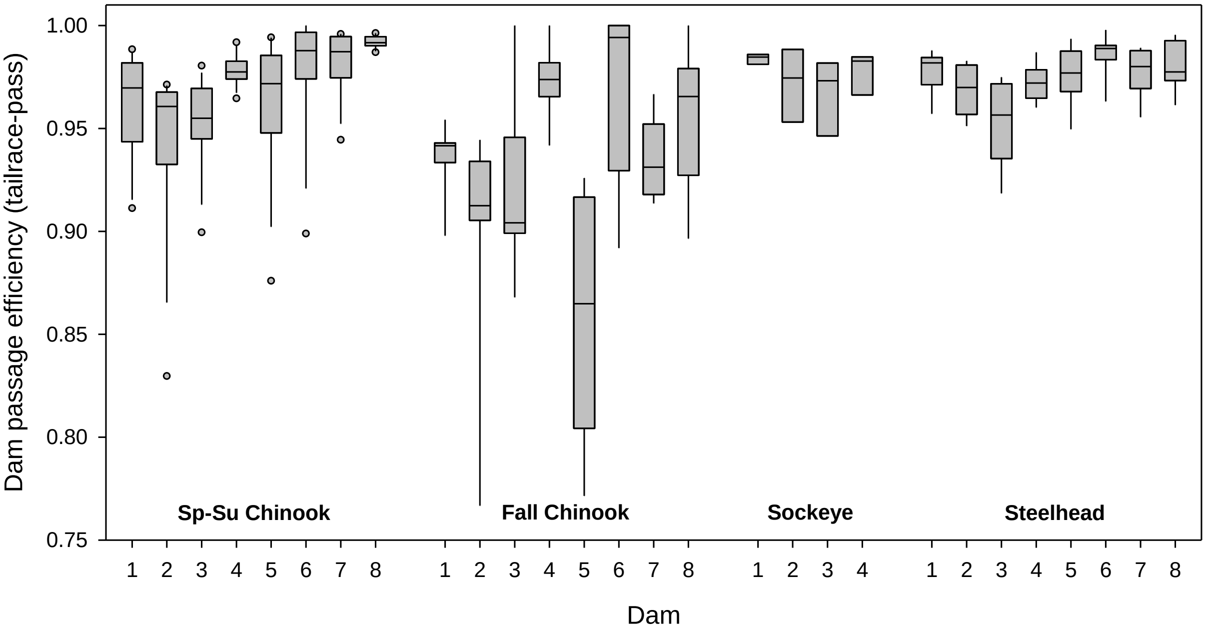


Figure 37. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of the annual dam passage efficiency estimates for adult salmon and steelhead, by species and run, 1996-2014. Efficiency was calculated as the proportion of individuals detected in a dam tailrace or at any fishway antenna that eventually passed the dam. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

Table 28. **Annual dam passage efficiency estimates** by run, year, and dam. Efficiency was calculated as the proportion of individuals detected in a dam tailrace or at any fishway antenna that eventually passed the dam. Number of fish in the denominator in parentheses.

		Dam							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Sp-Su Chinook	1996	0.970 (832)	0.830 (546)	0.900 (408)	0.974 (308)	0.876 (129)	-		0.991 (106)
	1997	0.981 (968)	0.901 (790)	0.957 (656)	0.980 (598)	0.952 (331)	0.978 (316)	0.971 (308)	0.990 (297)
	1998	0.981 (942)	0.934 (814)	0.948 (668)	0.965 (593)	0.936 (267)	0.984 (247)	0.996 (243)	0.992 (240)
	2000	0.983 (966)	0.929 (903)	0.946 (717)	0.980 (636)	0.988 (248)	0.992 (244)	0.996 (238)	0.996 (235)
	2001	0.988 (865)	0.967 (1066)	0.975 (995)	0.983 (925)	0.962 (577)	0.996 (554)	0.986 (552)	0.996 (542)
	2002	0.985 (893)	0.960 (965)	0.973 (861)	0.981 (783)	0.979 (384)	1.000 (375)	0.995 (372)	0.995 (368)
	2003	0.955 (1143)	0.957 (885)	0.952 (751)	0.973 (668)	0.994 (325)	0.997 (319)	0.987 (317)	0.990 (312)
	2004	0.940 (530)	0.970 (439)	0.955 (400)	0.977 (355)	0.994 (173)	0.994 (172)	0.988 (171)	0.994 (169)
	2005	-	0.971 (139)	0.969 (131)	0.992 (122)	0.929 (42)	-	-	-
	2006	0.920 (348)	-	0.945 (218)	0.974 (196)	0.973 (111)	0.972 (108)	0.944 (108)	0.990 (102)
	2007	0.911 (293)	0.963 (409)	0.922 (372)	0.969 (324)	0.971 (170)	-	-	-
	2009	0.945 (580)	0.962 (524)	0.955 (423)	0.976 (377)	0.958 (192)	0.899 (188)	0.973 (187)	-
	2010	0.952 (580)	0.957 (462)	0.980 (409)	0.989 (371)	-	0.973 (221)	0.979 (141)	-
	2013	0.969 (589)	0.962 (524)	0.944 (465)	0.988 (413)	0.976 (166)	0.981 (160)	0.987 (156)	0.987 (154)
	2014	0.974 (588)	0.969 (408)	0.969 (446)	0.977 (399)	0.985 (196)	1.000 (1.92)	0.995 (188)	0.995 (185)
	Mean	**0.961**	**0.945**	**0.953**	**0.979**	**0.962**	**0.981**	**0.983**	**0.992**
Fall Chinook	1997	0.898 (49)	0.767 (30)	1.000 (19)	1.000 (15)	-	-	-	-
	1998	0.937 (973	0.911 (685)	0.868 (553)	0.977 (435)	0.771 (35)	1.000 (26)	0.947 (19)	0.938 (16)
	2000	0.933 (706)	0.918 (804)	0.899 (634)	0.964 (473)	0.917 (36)	1.000 (33)	0.939 (33)	0.897 (29)
	2001	0.954 (546)	0.906 (787)	0.948 (612)	0.970 (497)	0.894 (104)	0.988 (86)	0.914 (81)	0.972 (72)
	2002	0.943 (717)	0.914 (815)	0.899 (635)	0.984 (487)	0.839 (87)	0.942 (69)	0.919 (62)	0.966 (58)
	2003	0.942 (617)	0.939 (479)	0.899 (388)	0.973 (300)	0.804 (46)	0.892 (37)	0.976 (30)	0.966 (29)
	2004	0.943 (526)	0.944 (450)	0.909 (384)	0.942 (292)	0.926 (27)	1.000 (26)	0.923 (26)	1.000 (23)
	2005	-	0.905 (464)	0.940 (364)	0.974 (272)	0.865 (37)	-	-	-
	Mean	**0.936**	**0.901**	**0.920**	**0.973**	**0.860**	**0.970**	**0.935**	**0.956**

Table 28 Continued. **Annual dam passage efficiency estimates** by run, year, and dam. Efficiency was calculated as the proportion of individuals detected in a dam tailrace or at any fishway antenna that eventually passed the dam. Number of fish in the denominator in parentheses. No estimates calculated for sockeye salmon at Snake River dams due to small *n*.

		Fallback location							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Sockeye	1997	0.986 (570)	0.953 (512)	0.981 (372)	0.953 (512)	-	-	-	-
	2013	0.985 (392)	0.975 (353)	0.982 (330)	0.985 (328)	-	-	-	-
	2014	0.981 (372)	0.988 (346)	0.973 (336)	0.966 (326)	-	-	-	-
	Mean	**0.984**	**0.972**	**0.979**	**0.968**	-	-	-	-
Steelhead	1996	0.977 (736)	0.983 (584)	0.919 (491)	0.968 (401)	0.969 (318)	-	-	0.970 (266)
	1997	0.966 (945)	0.964 (696)	0.920 (589)	0.979 (485)	0.976 (382)	0.986 (365)	0.955 (337)	0.984 (307)
	2000	0.985 (825)	0.957 (903)	0.959 (756)	0.960 (653)	0.977 (478)	0.982 (456)	0.979 (435)	0.961 (414)
	2001	0.984 (791)	0.973 (987)	0.951 (910)	0.978 (806)	0.984 (495)	0.998 (470)	0.989 (444)	0.995 (444)
	2002	0.976 (934)	0.981 (1060)	0.953 (964)	0.962 (864)	0.950 (655)	0.991 (643)	0.981 (619)	0.977 (600)
	2003	0.988 (577)	0.957 (464)	0.957 (414)	0.971 (340)	0.986 (277)	0.989 (271)	0.985 (266)	0.977 (260)
	2004	0.983 (286)	0.951 (205)	0.972 (178)	0.987 (154)	0.990 (97)	0.989 (94)	0.989 (92)	0.978 (89)
	2013	0.957 (770)	0.981 (670)	0.975 (697)	0.974 (533)	0.967 (958)	0.963 (434)	0.966 (413)	0.990 (396)
	2014	0.982 (773)	0.970 (665)	0.971 (595)	0.972 (573)	0.994 (465)	0.989 (449)	0.980 (441)	0.995 (429)
	Mean	**0.978**	**0.968**	**0.953**	**0.972**	**0.977**	**0.986**	**0.978**	**0.981**

6.3 TAILRACE, FISHWAY, AND DAM PASSAGE TIMES

Fish passage times have been used as indicators of FCRPS dam passage performance for adult salmon and steelhead at spatial scales ranging from individual fishway segments to multi-dam reaches. Dam-wide metrics have been reported for a variety of segments, typically delineated by movements from one environment to another (e.g., from the tailrace into a fishway) or from one fishway segment to another (e.g., from a transition pool into the overflow-weir section of a fish ladder). The series of metrics presented in this section aggregate all similar sites at each individual FCRPS dam (i.e., the metrics are 'dam-wide' rather than site-specific).

Time of day was a consistently important predictor of upstream fish passage times, especially when the study segment included turbulent or otherwise challenging hydraulic conditions or when fish had to pass multiple segments (e.g., from the tailrace past a dam). Adult salmon and steelhead passage times in almost all segments also tended to be right-skewed, with a portion of the fish taking much longer than the average time. Median values therefore tended to be more representative of the population-level central value than mean values. The series of figures in this section includes box plots of annual median values and box plots for all individual passage times to capture both the multi-year central tendency in the distributions and the among-individual variability.

6.3.1 FIRST TAILRACE TO FIRST FISHWAY APPROACH

Annual median fish passage times through a dam tailrace to their first detection at an antenna outside a fishway opening mostly ranged from 1-3 h (Figure 38). The most variable times for this segment were for spring–summer Chinook salmon at Bonneville Dam, likely reflecting a combination of seasonal effects (e.g., high spring discharge) and effects of tagging and release (i.e., fish released downstream in the afternoon or evening were more likely to spend a night in the tailrace before passing a fishway). All species and life history types also had relatively long median passage times through The Dalles tailrace (Figure 38), likely reflecting the longer distance from The Dalles tailrace antennas to the dam (~3.2 km) relative to distances at other FCRPS dams (*mean* = ~1.3 km) and/or parallel orientation of the powerhouse to the shore.

Distributions of individual fish passage times were right-skewed for all runs at all dams (Figure 39). Individual times were most variable at Bonneville and The Dalles dams, consistent with the annual median values. Between ~5% and ~25% of each run took 10 h or longer to pass the tailrace at each FCRPS dam.

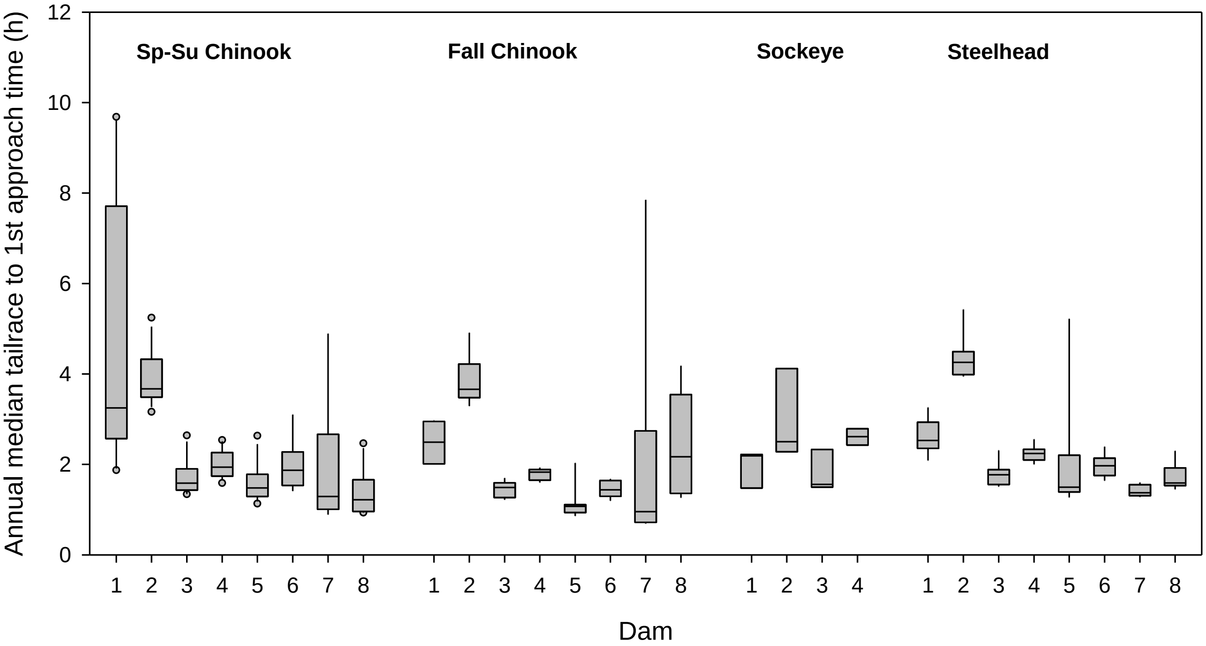


Figure 38. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all annual median passage times from first tailrace detection to first detected approach at a fishway opening, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

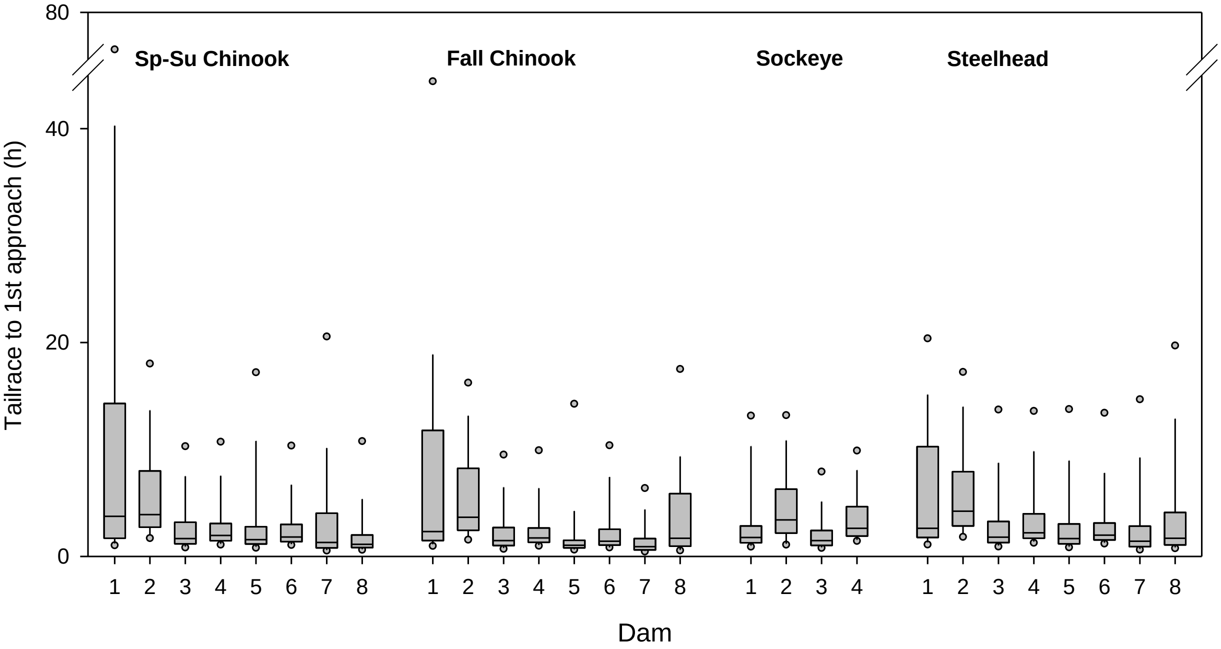
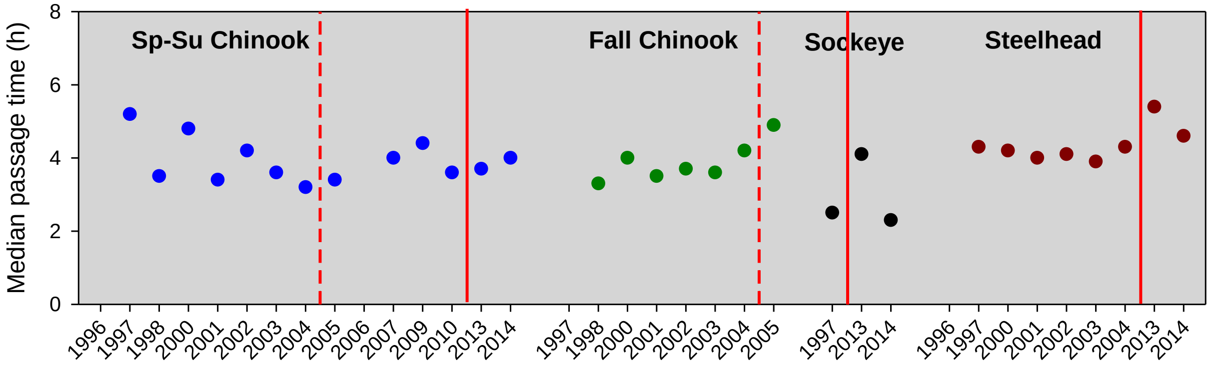


Figure 39. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of individual fish passage times from first tailrace detection to first detected approach at a fishway opening, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.



Time Series Example 3. Annual median passage times from first tailrace detection to first detected fishway approach estimates at The Dalles Dam in relation to the installation of spill wall sections in Bays 6-7 in 2004 (red dashed lines) and in Bays 8-9 in 2010 (red solid lines).

6.3.2 FIRST FISHWAY APPROACH TO FIRST FISHWAY ENTRY

Annual median fish passage times from first detection outside a fishway opening to first entry into a fishway were generally <1 h for fall Chinook salmon, sockeye salmon, and steelhead (Figure 40). Annual medians were somewhat longer and more variable for spring–summer Chinook salmon, but were still mostly from 1-4 h. Longer passage times for the spring–summer group presumably reflected seasonal effects (e.g., high discharge) associated with slower fishway discovery and entry. Distributions of individual fish passage times were right-skewed for all runs at all dams (Figure 41). About a quarter of the spring–summer Chinook salmon took ~6 h or longer to enter a fishway at each FCRPS dam.

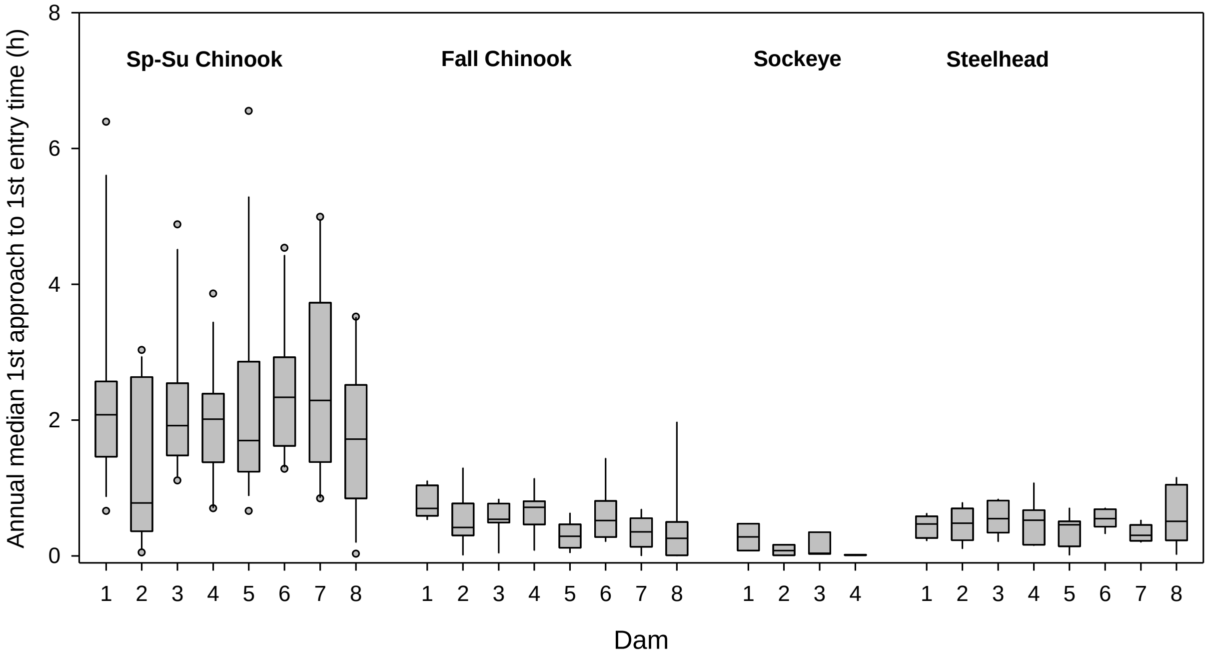


Figure 40. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all annual median passage times from first fishway approach at a fishway opening to first enter a fishway, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

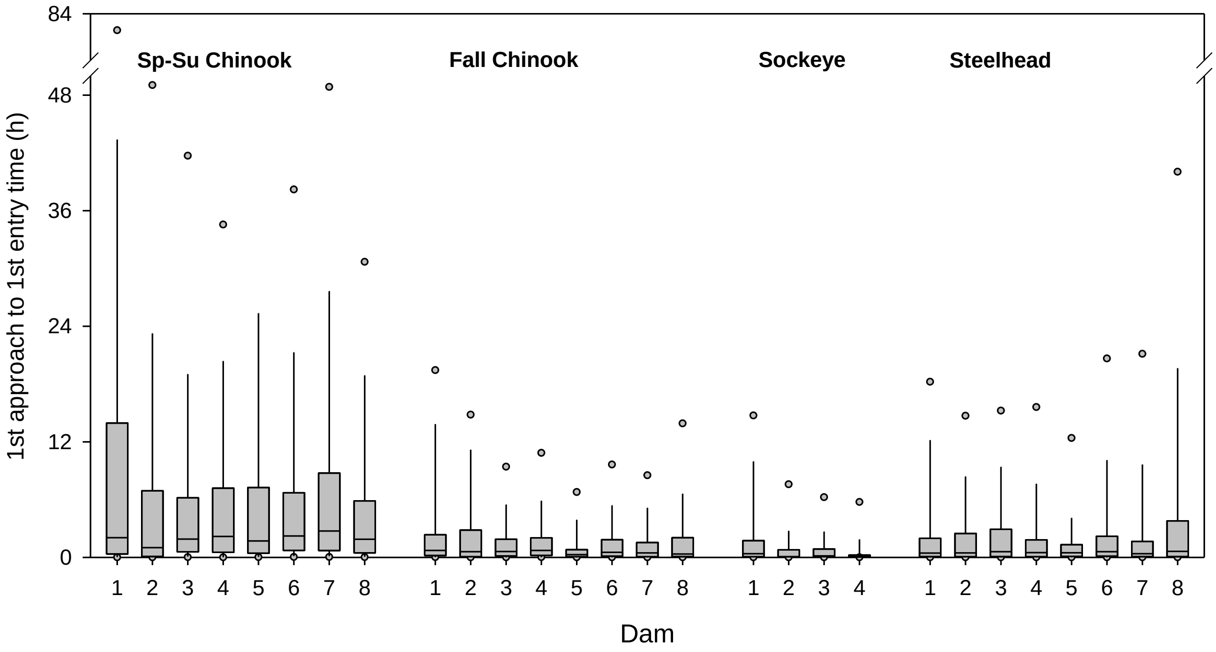


Figure 41. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all individual fish passage times from first fishway approach at a fishway opening to first enter a fishway, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.3.3 FIRST TRANSITION POOL ENTRY TO LAST LADDER ENTRY

After entering a fishway, most radio-tagged fish moved very quickly into a transition area, also referred to as a transition pool. These pools mark the transition from collection channels to the weired, overflow-and-orifice portions of the fishway. The number of weirs fully submerged in the transition pools fluctuated with tailrace water elevation; seasonal elevation changes of several meters occurred at Bonneville Dam, but were smaller at upstream dams. At times there were also water temperature gradients associated with transition areas, especially in summer and early fall and gradients were strongest at Lower Granite Dam. Gradients occurred when relatively warm water from dam forebays moved down the gravity-fed fish ladders and then encountered cooler water that was pumped from the dam tailrace through diffusers in the fishway floor. Many high-volume fishway diffusers providing discharge for attraction at the entrance at FCRPS dams are located in the transition areas.

The combination of hydraulic and temperature conditions plus structural features in the transition areas has been associated with a wide variety of adult fish behaviors and consequently highly variable passage times. Fish behaviors ranged from direct movement through transition areas into fish ladders to downstream movement out of the transition area back into a dam tailrace. In many cases fish entered the transition area in one fishway, exited to the tailrace, and then entered a second fishway and transition area before passing a dam.

Annual median transition pool passage times were ≤5 h for most runs at most dams (Figure 42). The highest medians were at John Day Dam for spring–summer and fall Chinook salmon and steelhead. At least some of the slow passage at John Day Dam was associated with the aforementioned temperature gradients. Fall Chinook salmon also had relatively long annual median times at Lower Monumental, Little Goose, and Lower Granite dams, where temperature gradient effects have also been identified. Passage time distributions for individual fish were right-skewed for all runs at all dams (Figure 43). From ~10% to ~25% of the fish in each run×dam combination had passage times >24 h. Exit from a transition pool back to the tailrace was strongly associated with the fish that had the longest passage times.

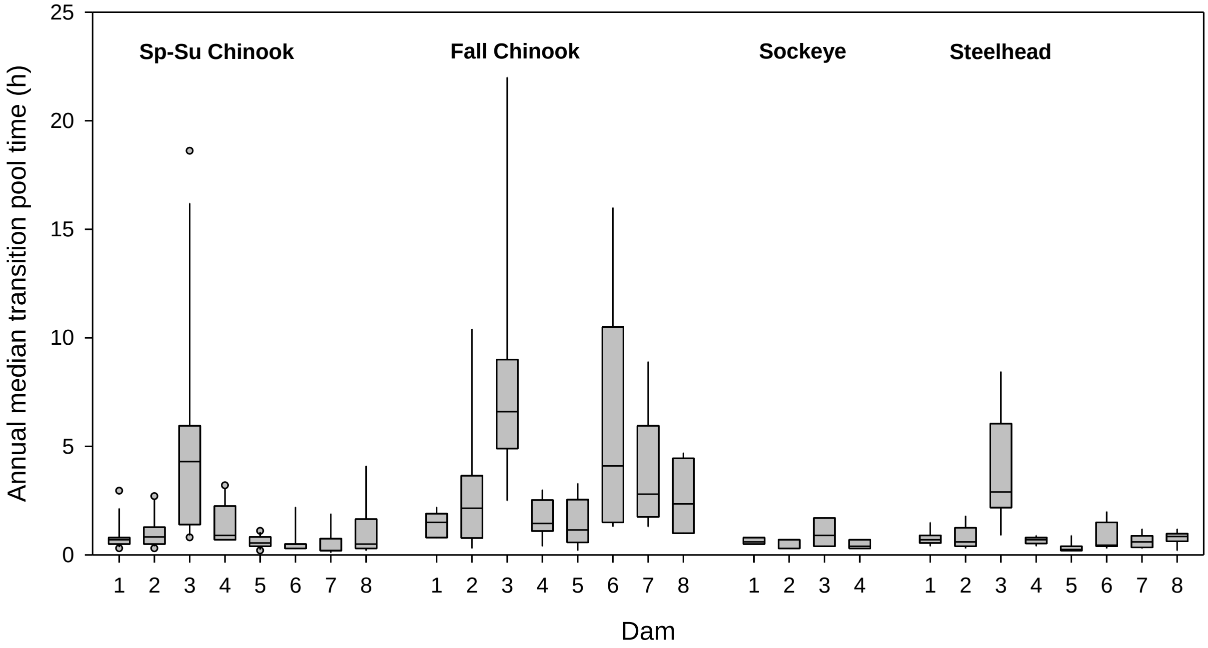


Figure 42. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all annual median passage times from first transition pool entry to exit a transition pool into a ladder, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

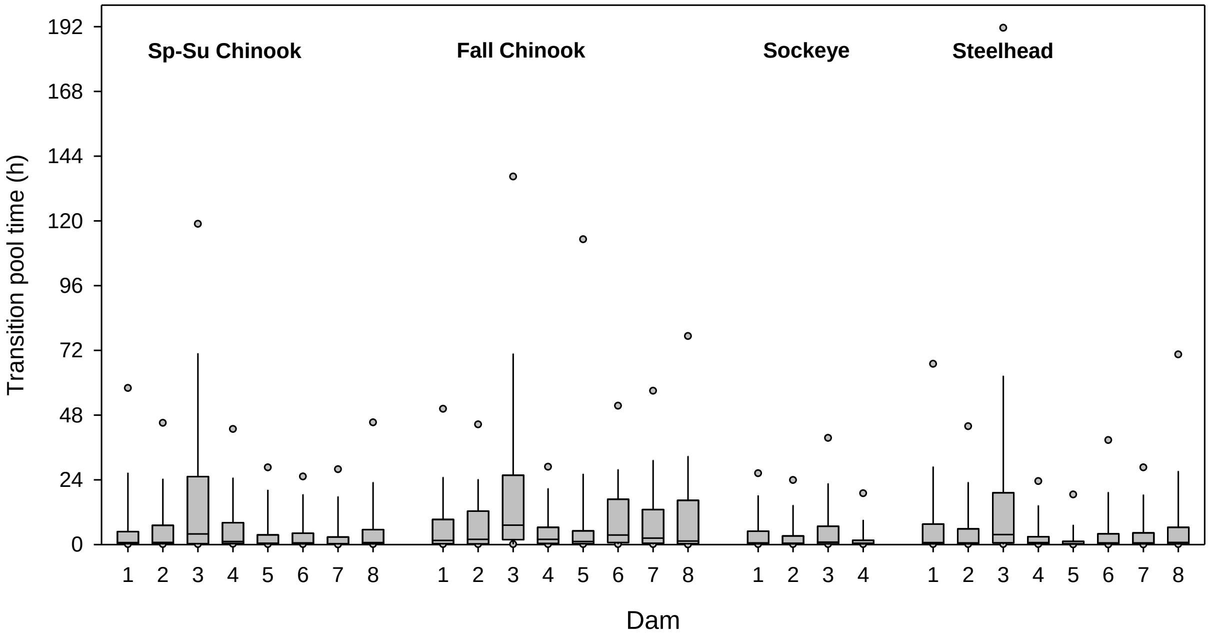


Figure 43. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all individual fish passage times from first transition pool entry to exit a transition pool into a ladder, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.3.4 LAST LADDER ENTRY TO PASS DAM

Ladder passage times were calculated from the upstream exit of the transition pool to exit of the fishway. Median fish passage times through the overflow-and-orifice sections of the fish ladders were remarkably similar among runs and dams (Figure 44). The exception was at Lower Granite Dam, where operation of the adult trap and (to a lesser degree) larger temperature gradients contributed to longer passage times for some fish from all runs. Annual median times were generally 2-3 h at dams other than Lower Granite Dam and very few fish took >10 h to pass a ladder at any dam (Figure 45). This metric was so consistent in part because it was calculated from the time a fish *last* exited a transition pool into a ladder and passed a dam; times would have been longer and more variable had the start time been the first detection in a ladder.

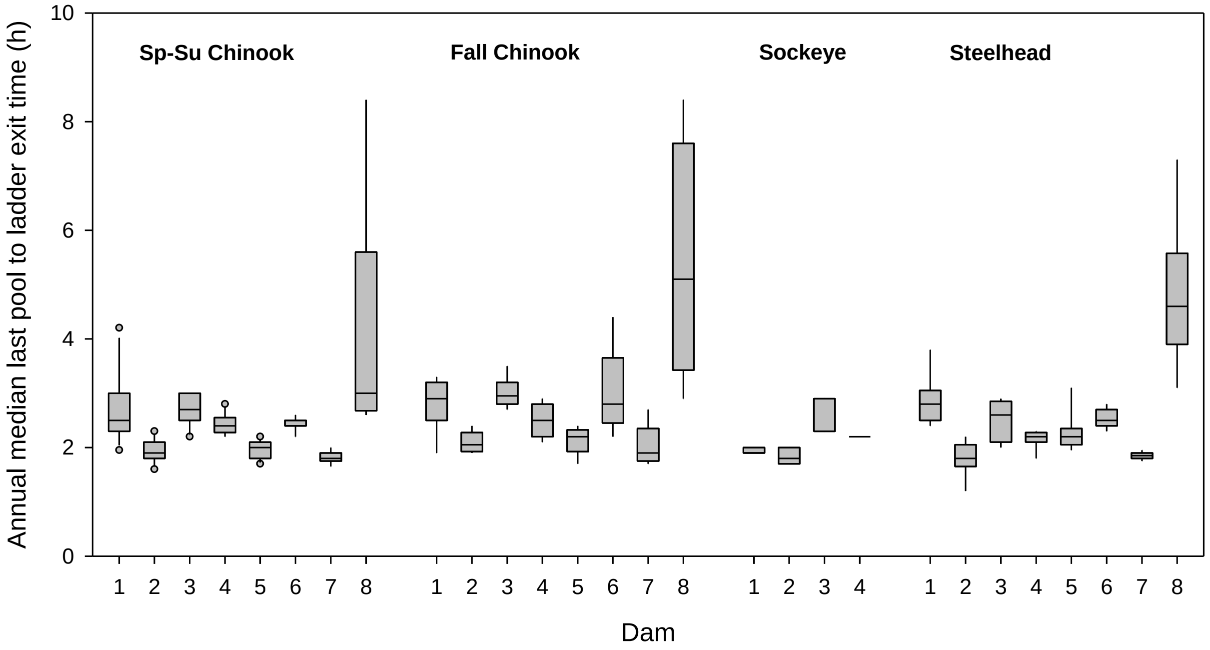


Figure 44. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all annual median passage times from last transition pool detection to exit a ladder into the dam forebay, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

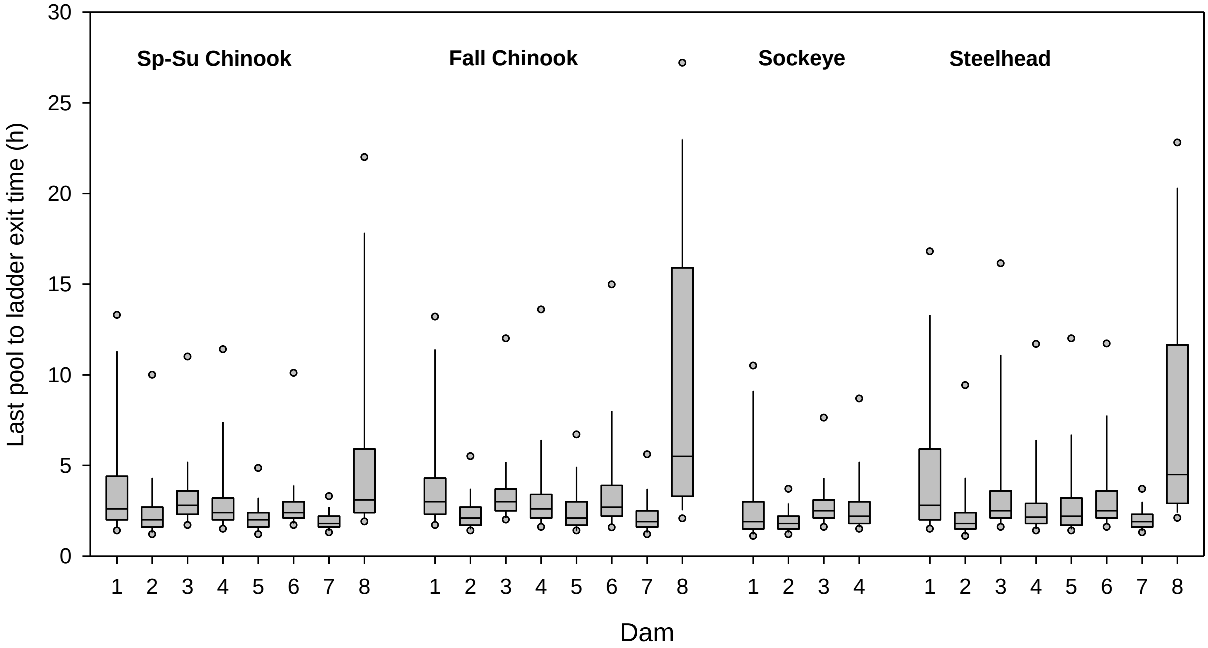
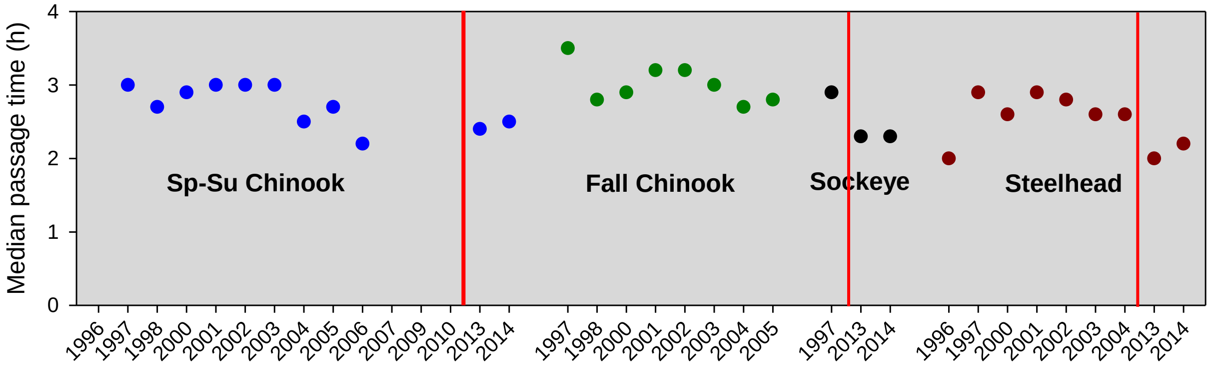


Figure 45. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all individual fish passage times from last transition pool detection to exit a ladder into the dam forebay, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.



Time Series Example 4. Annual median passage times from last ladder entry to pass John Day Dam in relation to the completion of the in 2010 north ladder flow control section rebuild (red lines).

6.3.5 FIRST FISHWAY ENTRY TO PASS DAM

This metric combines three distinct passage segments: (1) the typically rapid passage from fishway entry to a transition pool; (2) the highly variable transition pool passage time; and (3) ladder ascension time. Annual median passage times from first fishway entry to pass most FCRPS dams ranged from ~3 h to ~10 h (Figure 46). Considerably longer annual medians (~6-20 h) were common for spring–summer Chinook salmon and steelhead at John Day Dam and for all runs at Lower Granite Dam. Slower passage, on median, at John Day Dam was associated with relatively high fishway exit rates into the tailrace, whereas operation of the Lower Granite adult trap was likely the driver of slow passage there.

The individual fish data for this metric produced strongly right-skewed distributions (Figure 47). In large part, the fish with long passage times were those that exited a fishway or transition area into the tailrace one or more times, as described in Section 5.3.3.

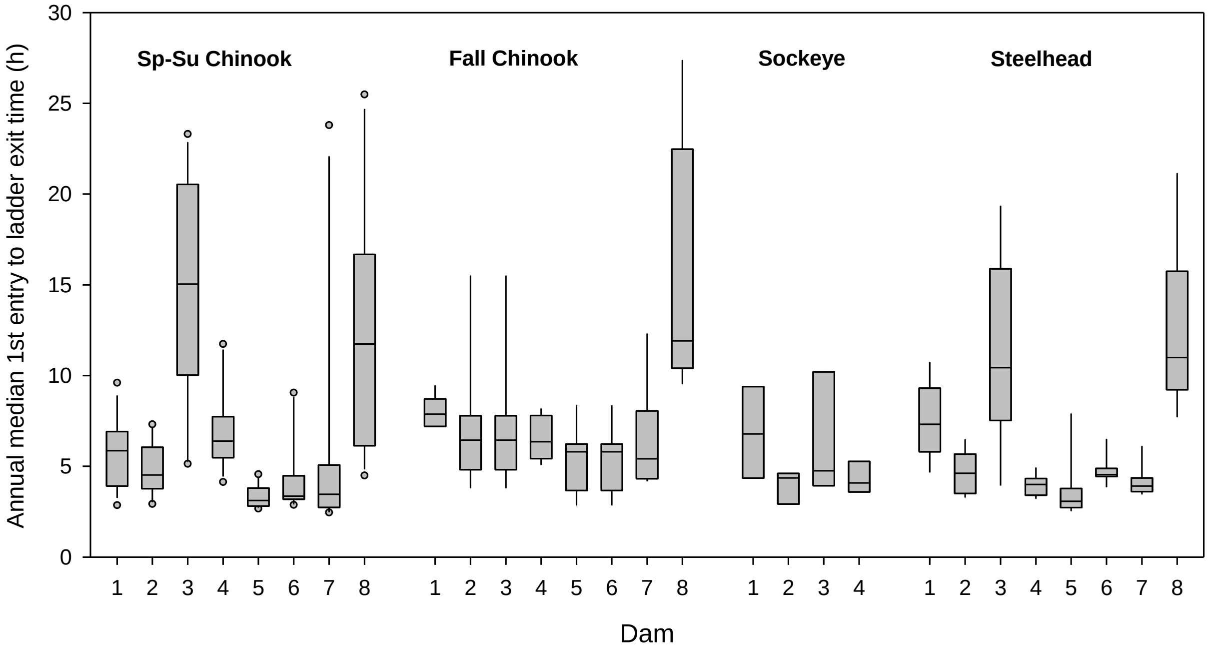


Figure 46. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all annual median passage times from first fishway entry to exit a ladder into the dam forebay, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

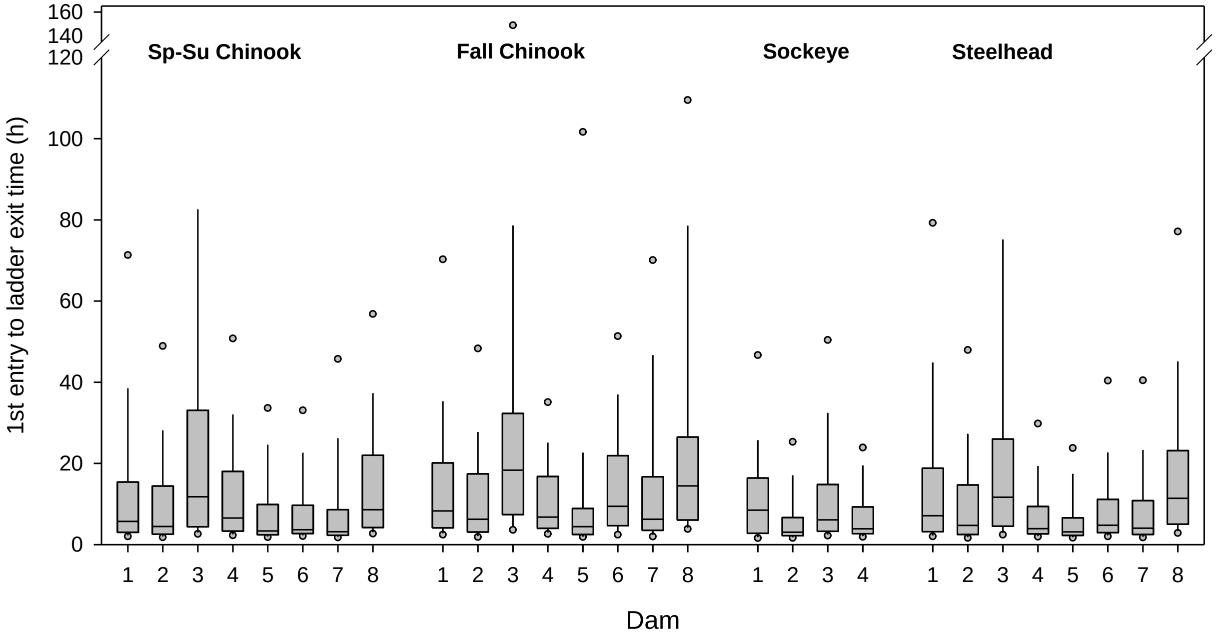


Figure 47. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all individual fish passage times from first fishway entry to exit a ladder into the dam forebay, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.3.6 FIRST TAILRACE TO PASS DAM

This metric encapsulates all of the time that fish spent at a FCRPS project up from first detection in a tailrace to the first fishway exit and passage into the dam forebay (i.e., any time spent after passing a dam and the falling back downstream was excluded). Annual median times indicated differences among species and dams (Figure 48, Table 29). Spring–summer Chinook salmon passed in median times ranging from ~12 h to ~36 h, with relatively longer passage at Bonneville and John Day dams and relatively fast passage at Lower Monumental and Little Goose dams. Annual medians for fall Chinook salmon and steelhead were generally a bit faster than those for spring–summer Chinook salmon at all projects, likely because the former encountered lower river discharge and spill and warmer water temperatures. Annual medians for sockeye salmon were in a narrow range of ~8 to ~16 h per dam across the four lower Columbia River dams (Figure 48).

The distributions of individual fish passage times (Figure 49) showed broadly similar patterns across species and dams. Grand median values ranged from ~10 h to ~ 24 h and at most projects, approximately a quarter of the fish took >24 h to pass. Variability in full-dam or full-project passage times reflected seasonal and annual environmental effects as well as behavioral differences among groups of fish. Longer individual passage times were associated with spending a night (or more) in a dam tailrace, downstream movement from a tailrace into a reservoir before passage, and one or more exits from a fishway back into a tailrace.

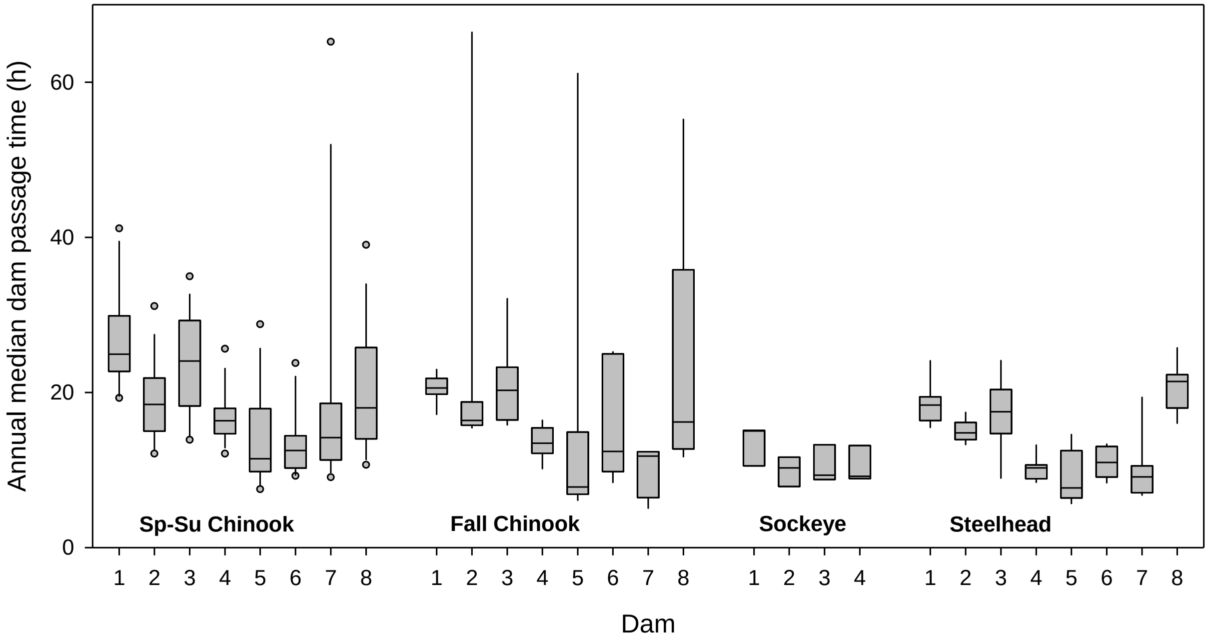


Figure 48. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all annual median passage times from first detection in a tailrace to exit a ladder into the dam forebay, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

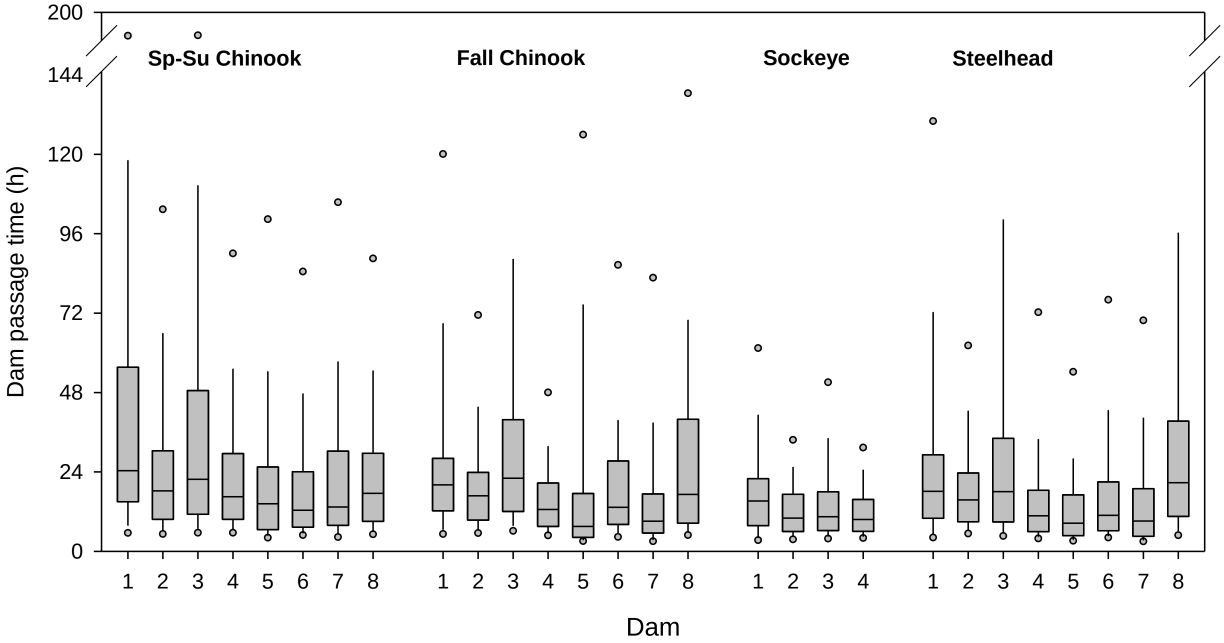
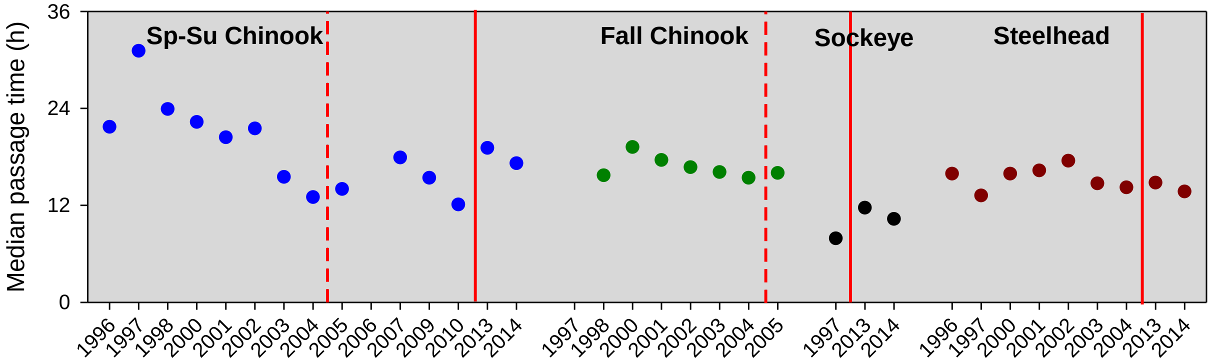
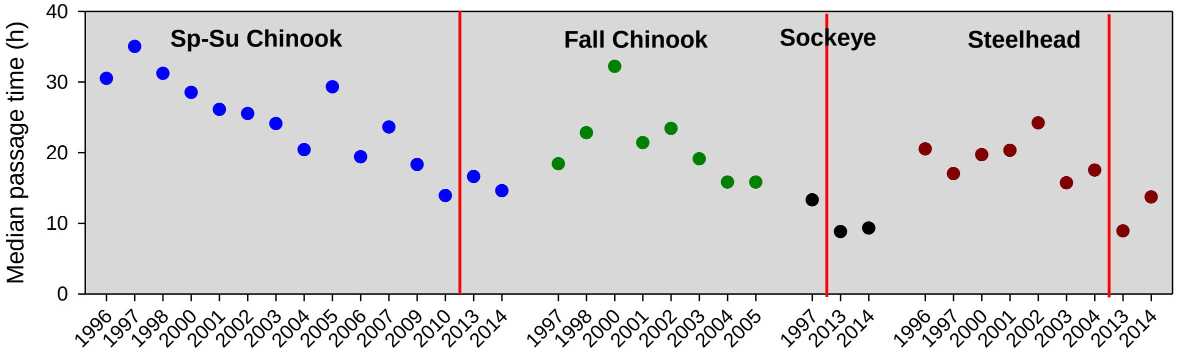


Figure 49. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of all individual fish passage times from first detection in a tailrace to exit a ladder into the dam forebay, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.



Time Series Example 5. Annual median passage times from first tailrace detection to pass The Dalles Dam in relation to the installation of spill wall sections in Bays 6-7 in 2004 (red dashed lines) and in Bays 8-9 in 2010 (red solid lines).



Time Series Example 6. Annual median passage times from first tailrace detection to pass John Day Dam in relation to the completion of the in 2010 north ladder flow control section rebuild (red lines).

Table 29. Median dam passage times (hours) by run, year, and dam. Number of fish in the sample in parentheses. Mean values exclude annual estimates with $n < 10$ fish in the denominator.

Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Spring-Summer Chinook	1996	22.7 (629)	21.7 (349)	30.5 (302)	25.6 (227)	17.4 (75)	- (0)	- (0)	39.0 (64)
	1997	24.6 (905)	31.1 (556)	35.0 (531)	16.1 (327)	19.4 (276)	23.8 (289)	21.2 (264)	25.1 (281)
	1998	19.6 (846)	23.9 (530)	31.2 (505)	21.5 (358)	28.8 (235)	18.2 (194)	15.9 (161)	26.5 (163)
	2000	26.6 (895)	22.3 (555)	28.5 (492)	18.0 (465)	14.6 (241)	12.8 (216)	12.8 (208)	18.0 (179)
	2001	23.8 (703)	20.4 (832)	26.1 (692)	16.9 (599)	10.7 (485)	13.3 (354)	14.4 (406)	10.6 (413)
	2002	41.1 (749)	21.5 (704)	25.5 (711)	20.8 (612)	10.7 (369)	10.9 (372)	13.9 (307)	20.9 (303)
	2003	30.5 (954)	15.5 (614)	24.0 (640)	16.4 (449)	11.4 (215)	12.7 (297)	10.9 (220)	26.5 (218)
	2004	29.9 (438)	13.0 (342)	20.4 (331)	14.1 (251)	8.4 (166)	9.2 (170)	9.1 (132)	21.3 (163)
	2005	24.9 (78)	14.0 (115)	29.3 (117)	14.7 (56)	9.9 (6)	- (0)	- (0)	- (0)
	2006	29.1 (242)	- (0)	19.4 (179)	12.1 (74)	7.5 (4)	11.2 (96)	19.5 (94)	15.3 (95)
	2007	38.4 (223)	17.8 (224)	23.6 (304)	17.2 (142)	14.3 (72)	- (0)	- (0)	- (0)
	2009	23.0 (487)	15.4 (418)	18.2 (389)	15.8 (291)	11.5 (164)	9.5 (163)	15.9 (178)	13.8 (104)
	2010	25.5 (460)	12.1 (285)	13.9 (320)	13.3 (158)	- (0)	14.8 (195)	11.7 (80)	12.2 (72)
	2013	19.3 (456)	19.0 (352)	16.6 (397)	17.1 (223)	22.7 (67)	12.3 (143)	11.1 (149)	14.2 (146)
	2014	21.4 (451)	17.2 (392)	14.6 (382)	15.9 (286)	9.4 (128)	10.0 (191)	65.2 (19)	14.8 (178)
	Mean	**26.7**	**18.9**	**23.8**	**17.0**	**14.9**	**13.2**	**18.5**	**19.9**
Fall Chinook	1997	23.0 (19)	66.5 (4)	18.4 (13)	14.0 (1)	61.2 (1)	8.3 (1)	12.2 (1)	- (0)
	1998	20.6 (781)	15.7 (216)	22.8 (299)	10.1 (283)	6.7 (25)	9.8 (17)	8.4 (17)	14.8 (7)
	2000	21.8 (543)	19.2 (300)	32.2 (260)	16.5 (178)	8.2 (27)	25.0 (14)	12.4 (18)	55.3 (6)
	2001	17.1 (474)	17.6 (468)	21.4 (284)	13.9 (273)	7.5 (86)	12.4 (52)	11.8 (43)	17.6 (22)
	2002	21.0 (567)	16.7 (411)	23.4 (415)	12.8 (286)	8.6 (63)	11.1 (42)	12.4 (18)	13.1 (13)
	2003	20.3 (427)	16.1 (276)	19.1 (214)	12.0 (117)	6.0 (13)	25.3 (28)	6.4 (17)	29.3 (10)
	2004	19.8 (329)	15.4 (234)	15.8 (222)	13.0 (106)	7.3 (16)	13.0 (22)	5.0 (11)	11.6 (3)
	2005	- (0)	16.0 (51)	15.8 (144)	15.9 (23)	17.0 (9)	- (0)	- (0)	- (0)
	Mean	**20.5**	**16.7**	**21.1**	**13.4**	**8.8**	**16.1**	**9.4**	**20.0**

Table 29 Continued. Median dam passage times (hours) by run, year, and dam. Number of fish in the sample in parentheses. Mean values exclude annual estimates with *n* < 10 fish in the denominator.

		Fallback location							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Sockeye	1997	15.0 (556)	7.9 (417)	13.2 (345)	13.1 (168)	-	-	-	-
	2013	15.1 (373)	11.6 (300)	8.8 (297)	8.9 (254)	-	-	-	-
	2014	10.5 (344)	10.3 (310)	9.3 (306)	9.2 (283)	-	-	-	-
	Mean	**13.6**	**9.9**	**10.4**	**10.4**	**-**	**-**	**-**	**-**
Steelhead	1996	17.0 (679)	15.9 (362)	20.5 (402)	10.4 (208)	14.6 (234)	- (0)	- (0)	25.8 (158)
	1997	17.4 (794)	13.2 (300)	17.0 (479)	8.4 (305)	13.4 (351)	10.2 (269)	10.6 (196)	22.1 (211)
	2000	19.7 (748)	15.9 (656)	19.6 (516)	10.3 (375)	7.7 (418)	10.8 (315)	9.0 (272)	22.5 (236)
	2001	18.4 (737)	16.3 (819)	20.3 (509)	10.4 (424)	6.9 (406)	8.3 (293)	9.3 (239)	18.1 (208)
	2002	24.2 (829)	17.5 (759)	24.2 (685)	13.3 (523)	6.4 (558)	11.2 (541)	10.4 (357)	21.8 (212)
	2003	19.1 (484)	14.7 (362)	15.7 (333)	10.1 (123)	5.6 (117)	12.4 (242)	6.7 (123)	21.4 (137)
	2004	18.4 (246)	14.1 (153)	17.5 (147)	9.4 (89)	6.4 (72)	8.7 (86)	6.8 (60)	17.9 (63)
	2013	15.4 (399)	14.8 (404)	8.9 (381)	8.4 (103)	11.5 (77)	13.2 (302)	19.4 (1)	19.3 (237)
	2014	15.7 (523)	13.7 (378)	13.7 (329)	10.9 (166)	8.4 (82)	13.4 (316)	7.9 (318)	16.0 (253)
	Mean	**18.4**	**15.1**	**17.5**	**10.2**	**9.0**	**11.0**	**8.7**	**20.5**

6.4 FALLBACK AT FCRPS DAMS

Fallback at FCRPS dams by upstream-migrating fish has been linked to a variety of behavioral, environmental, and operational factors and the behavior varies widely among species, among years, and among FCRPS projects. Fallback is a management concern because it inflates fish counts when fish reascend dams and has been repeatedly associated with lower adult survival to spawning areas, presumably due to a mix of direct (i.e., turbine mortality) and indirect (e.g., fish injury, migration delay) effects. Some fallback events are by fish that migrate past their natal site ('overshoot') and must move back downstream to complete homing. Other fallback events have been associated with FCRPS operations – especially spill – and with river environment (there is typically more fallback when river discharge is high). Other fallback events may be simply associated with other fish movements. The historical metrics have included fallback percent (a measure of how many unique fish fall back after passing a dam) and fallback rate (a broader measure that incorporates multiple fallback events by individual fish).

6.4.1 FALLBACK PERCENTAGES AND RATES

The distributions of annual fallback percentages (Figure 50, Table 30) and fallback rates (Figure 51, Table 31) were very similar, with rates generally higher than percentages by a few points for each run×dam combination due to multiple fallback events per dam by some fish. In general, fallback patterns for spring–summer Chinook salmon showed relatively higher annual percentages and rates at Bonneville and The Dalles dams, and progressively lower annual estimates at upstream dams. Mean annual percentages ranged from 3.5% at Little Goose Dam to 7.7% at Bonneville Dam (Table 30).

Fallback by fall Chinook salmon was much more variable among dams, with annual estimates ranging from ~3-10% at Bonneville and The Dalles, from ~1-4% at John Day and McNary dams, and from ~1 to >20% at the lower Snake River dams. Mean percentages for fall Chinook salmon ranged from 2.1% at McNary Dam to 13.9% at Little Goose Dam (Table 30). Sockeye salmon fallback was highest at Bonneville Dam. Fallback patterns for steelhead showed that percentages and rates were more similar across FCRPS dams than for the other runs, and were generally between ~2% and ~10%. Mean steelhead percentages ranged from 3.9% at Lower Monumental Dam to 7.7% at McNary Dam. (Note that no post-spawn fallback by steelhead kelts were included in the estimates in Figures 50-51 or Tables 30-31.)

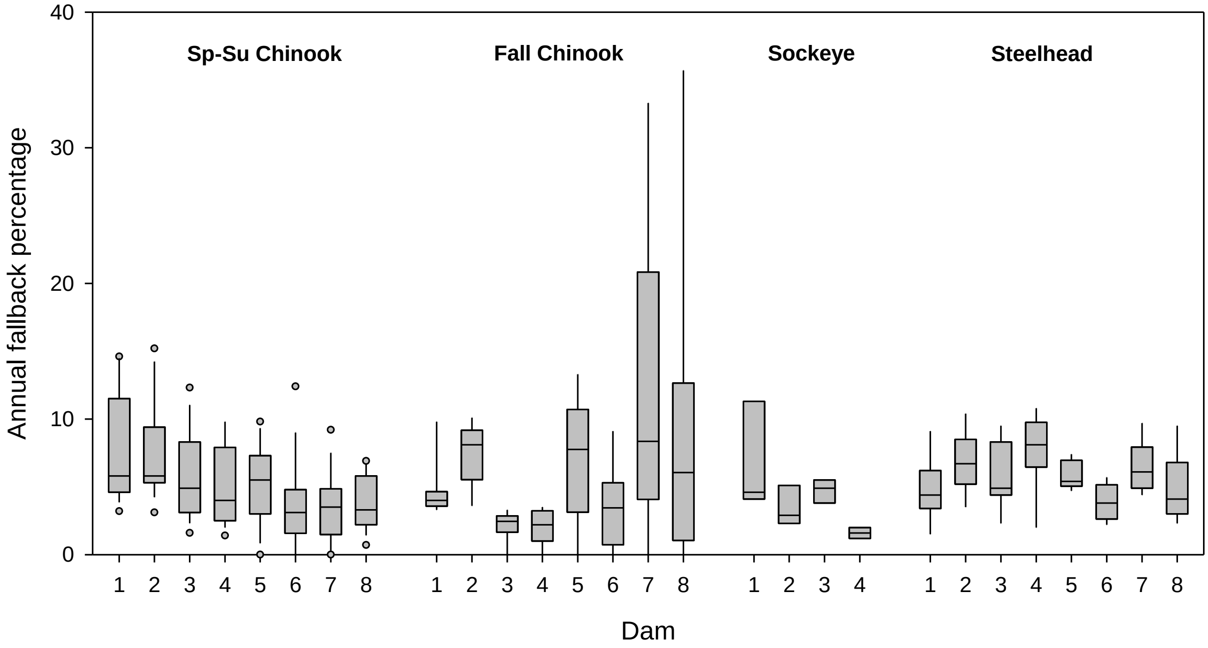


Figure 50. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual fallback percentage, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite. Estimates for Bonneville Dam do not include fish released in the dam forebay.

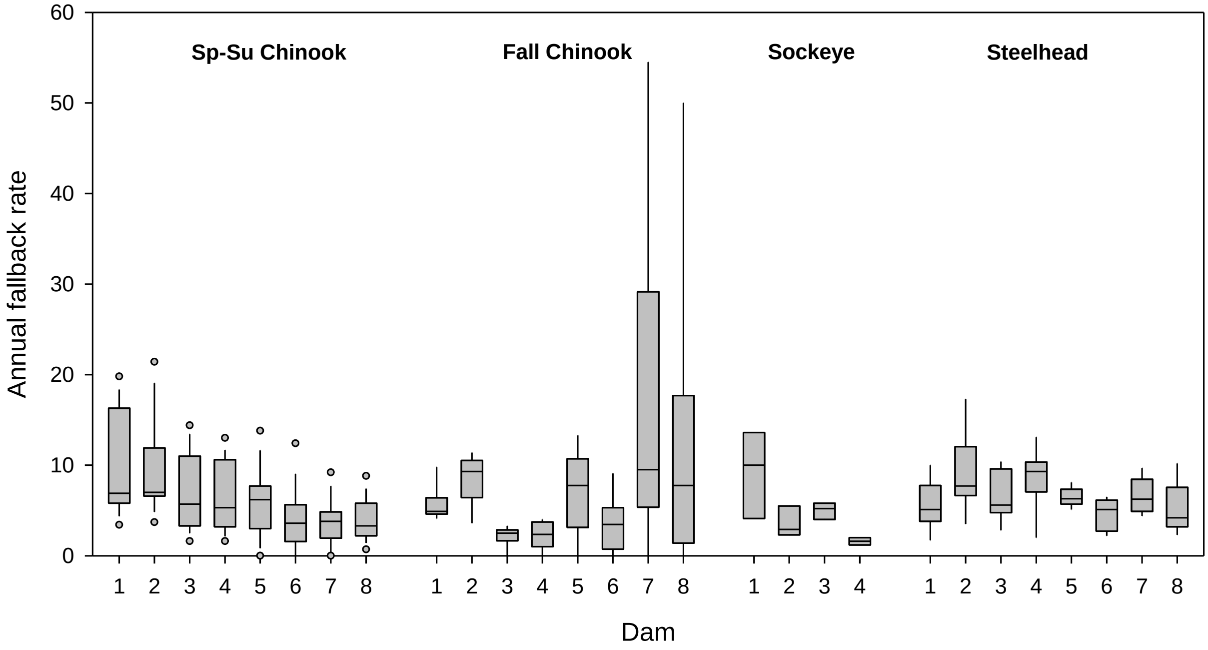


Figure 51. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual fallback rate, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite. Estimates for Bonneville Dam do not include fish released in the dam forebay.

Table 30. **Annual fallback percentage** by run, year, and dam. Number of fish in the denominator in parentheses. Mean values exclude annual estimates with *n* < 10 fish in the denominator. Estimates for Bonneville Dam do not include fish released in the dam forebay.

		Fallback location							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Spring-Summer Chinook	1996	14.4 (820)	15.2 (454)	12.3 (374)	9.8 (305)	8.3 (121)	- (0)	- (0)	1.9 (105)
	1997	14.6 (964)	13.6 (771)	10.0 (649)	7.9 (594)	9.0 (324)	5.1 (314)	9.2 (305)	6.1 (295)
	1998	11.5 (931)	10.9 (797)	10.2 (660)	9.0 (589)	7.3 (260)	4.1 (243)	5.8 (242)	4.2 (240)
	2000	13.0 (963)	9.4 (872)	6.0 (714)	4.4 (635)	9.8 (246)	4.5 (244)	3.8 (238)	3.0 (235)
	2001	4.3 (866)	5.5 (1048)	2.9 (990)	1.4 (923)	1.4 (566)	0.9 (554)	1.5 (551)	0.7 (542)
	2002	6.1 (884)	5.6 (948)	4.9 (858)	4.6 (777)	4.5 (382)	2.7 (375)	2.7 (372)	3.3 (367)
	2003	4.6 (1119)	6.6 (868)	4.3 (747)	2.4 (664)	5.5 (325)	2.8 (318)	3.2 (317)	2.6 (312)
	2004	3.2 (525)	5.3 (432)	2.8 (400)	3.1 (355)	5.2 (172)	0.0 (171)	0.6 (171)	2.4 (169)
	2005	4.3 (141)	5.1 (136)	3.1 (130)	2.5 (122)	0.0 (40)	0.0 (42)	0.0 (42)	2.2 (46)
	2006	11.3 (355)	5.0 (238)	6.7 (210)	9.8 (193)	6.3 (111)	12.4 (105)	4.7 (107)	6.9 (102)
	2007	5.8 (469)	5.8 (397)	3.5 (343)	6.3 (320)	7.1 (169)	3.4 (146)	1.4 (145)	2.0 (150)
	2009	5.7 (562)	6.2 (466)	6.4 (404)	3.5 (375)	5.4 (186)	1.8 (169)	2.2 (182)	4.5 (111)
	2010	4.8 (561)	5.4 (446)	8.3 (400)	3.8 (371)	2.7 (222)	2.3 (215)	4.3 (138)	4.1 (98)
	2013	6.0 (583)	8.1 (509)	3.5 (457)	2.4 (411)	3.0 (166)	5.6 (160)	3.9 (155)	5.8 (154)
	2014	5.1 (583)	3.1 (481)	1.6 (441)	4.0 (399)	5.6 (195)	4.7 (192)	5.3 (188)	6.5 (185)
	Mean	**7.7**	**7.4**	**5.8**	**5.0**	**5.4**	**3.6**	**3.5**	**3.7**
Fall Chinook	1997	9.8 (51)	3.6 (28)	0.0 (19)	0.0 (15)	0.0 (1)	0.0 (1)	0.0 (1)	0.0 (1)
	1998	3.5 (943)	10.1 (666)	3.3 (547)	2.3 (435)	6.9 (29)	3.8 (26)	22.2 (18)	13.3 (15)
	2000	4.0 (683)	7.9 (782)	2.4 (630)	1.9 (471)	2.9 (35)	9.1 (33)	33.3 (33)	35.7 (28)
	2001	4.7 (532)	6.5 (764)	2.5 (606)	3.4 (496)	11.0 (100)	5.8 (86)	10.0 (80)	4.2 (72)
	2002	4.0 (700)	8.3 (792)	1.6 (627)	3.5 (484)	9.8 (82)	2.9 (69)	4.9 (61)	5.2 (58)
	2003	3.8 (606)	9.2 (468)	1.8 (384)	2.7 (297)	13.3 (45)	0.0 (37)	6.7 (30)	6.9 (29)
	2004	3.3 (547)	9.1 (441)	2.9 (382)	2.1 (288)	3.8 (26)	3.8 (26)	3.8 (26)	0.0 (23)
	2005	4.5 (598)	5.2 (444)	2.7 (364)	0.7 (270)	8.6 (35)	3.1 (32)	16.7 (30)	10.7 (28)
	Mean	**4.7**	**7.5**	**2.2**	**2.1**	**8.0**	**4.1**	**13.9**	**10.9**

Table 30 Continued. **Annual fallback percentage** by run, year, and dam. Number of fish in the denominator in parentheses. Mean values exclude annual estimates with *n* < 10 fish in the denominator. Estimates for Bonneville Dam do not include fish released in the dam forebay.

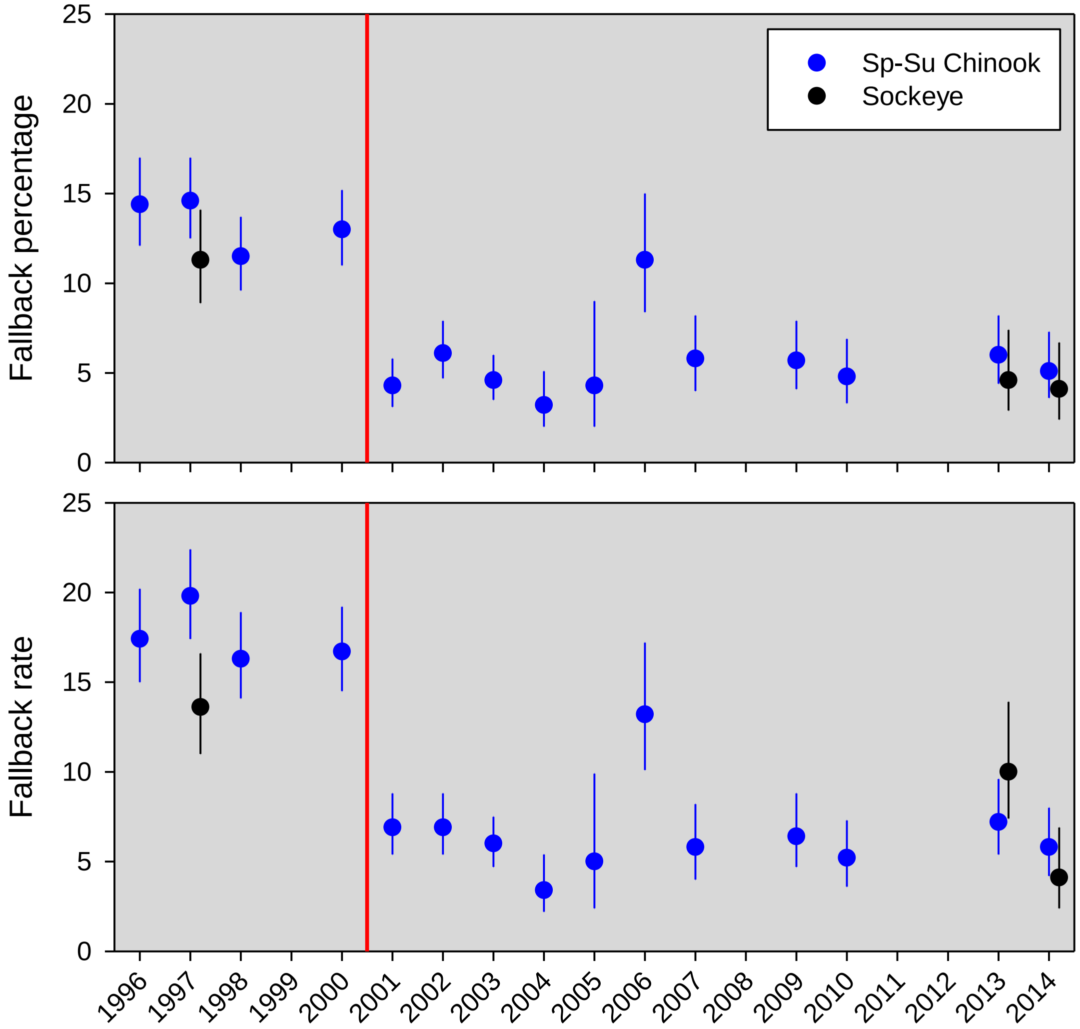
		Fallback location							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Sockeye	1997	11.3 (568)	5.1 (495)	3.8 (471)	2.0 (460)	0.0 (1)	- (0)	- (0)	- (0)
	2013	4.6 (391)	2.9 (346)	4.9 (325)	1.2 (324)	33.3 (3)	0.0 (2)	0.0 (1)	100.0 (1)
	2014	4.1 (367)	2.3 (343)	5.5 (330)	1.6 (318)	33.3 (3)	0.0 (3)	33.3 (3)	33.3 (3)
	Mean	**6.7**	**3.4**	**4.7**	**1.6**	**-**	**-**	**-**	**-**
Steelhead	1996	4.7 (731)	6.4 (574)	9.5 (473)	8.0 (399)	7.4 (309)	- (0)	- (0)	9.5 (264)
	1997	9.1 (930)	6.7 (687)	7.8 (576)	10.8 (480)	5.0 (378)	4.4 (363)	8.4 (333)	6.2 (305)
	2000	6.8 (820)	6.2 (884)	4.4 (749)	10.3 (642)	4.7 (472)	2.2 (450)	5.8 (432)	4.1 (410)
	2001	4.4 (788)	7.3 (975)	6.4 (904)	9.2 (797)	6.7 (492)	5.7 (470)	9.7 (443)	7.4 (443)
	2002	3.7 (924)	7.9 (1049)	4.6 (959)	5.5 (849)	5.3 (624)	4.7 (641)	5.8 (617)	4.2 (599)
	2003	5.6 (572)	10.4 (450)	8.8 (407)	7.4 (337)	5.1 (276)	2.6 (269)	6.4 (265)	2.7 (258)
	2004	3.1 (289)	3.5 (198)	2.3 (176)	2.0 (153)	7.2 (97)	3.2 (93)	6.5 (92)	2.3 (88)
	2013	3.9 (760)	9.1 (661)	4.9 (588)	8.1 (520)	5.8 (445)	5.3 (418)	4.4 (412)	3.3 (394)
	2014	1.5 (783)	4.2 (647)	4.4 (585)	8.2 (536)	5.4 (464)	2.7 (449)	4.6 (435)	4.0 (428)
	Mean	**4.8**	**6.9**	**5.9**	**7.7**	**5.8**	**3.9**	**6.5**	**4.9**

Table 31. **Annual fallback rate** by run, year, and dam. Number of fish in the denominator in parentheses. Mean values exclude annual estimates with *n* < 10 fish in the denominator. Estimates for Bonneville Dam do not include fish released in the dam forebay.

		Fallback location							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Spring-Summer Chinook	1996	17.4 (820)	21.4 (454)	14.4 (374)	10.8 (305)	9.1 (121)	- (0)	- (0)	1.9 (105)
	1997	19.8 (964)	17.5 (771)	12.8 (649)	10.6 (594)	10.2 (324)	5.7 (314)	9.2 (305)	6.1 (295)
	1998	16.3 (931)	13.6 (797)	11.1 (660)	10.7 (589)	7.3 (260)	4.1 (243)	6.2 (242)	4.6 (240)
	2000	16.7 (963)	11.9 (872)	6.4 (714)	5.5 (635)	13.8 (246)	4.5 (244)	3.8 (238)	3.0 (235)
	2001	6.9 (866)	7.0 (1048)	3.2 (990)	1.6 (923)	1.4 (566)	0.9 (554)	1.5 (551)	0.7 (542)
	2002	6.9 (884)	7.2 (948)	5.7 (858)	5.8 (777)	5.5 (382)	2.7 (375)	2.7 (372)	3.3 (367)
	2003	6.0 (1119)	8.1 (868)	4.7 (747)	3.2 (664)	6.8 (325)	3.1 (318)	3.8 (317)	2.6 (312)
	2004	3.4 (525)	5.6 (432)	3.3 (400)	3.7 (355)	5.8 (172)	0.0 (171)	0.6 (171)	2.4 (169)
	2005	5.0 (141)	6.6 (136)	3.1 (130)	2.5 (122)	0.0 (40)	0.0 (42)	0.0 (42)	2.2 (46)
	2006	13.2 (355)	6.7 (238)	7.6 (210)	13.0 (193)	7.2 (111)	12.4 (105)	4.7 (107)	8.8 (102)
	2007	5.8 (469)	6.5 (397)	5.0 (343)	8.4 (320)	7.7 (169)	4.1 (146)	2.1 (145)	2.0 (150)
	2009	6.4 (562)	6.7 (466)	7.2 (404)	4.0 (375)	5.9 (186)	1.8 (169)	2.2 (182)	4.5 (111)
	2010	5.2 (561)	6.7 (446)	11.0 (400)	4.3 (371)	2.7 (222)	2.3 (215)	4.3 (138)	4.1 (98)
	2013	7.2 (583)	9.2 (509)	3.7 (457)	2.9 (411)	3.0 (166)	5.6 (160)	3.9 (155)	5.8 (154)
	2014	5.8 (583)	3.7 (481)	1.6 (441)	5.3 (399)	6.2 (195)	5.7 (192)	5.3 (188)	6.5 (185)
	Mean	**9.5**	**9.2**	**6.7**	**6.2**	**6.2**	**3.8**	**3.6**	**3.9**
Fall Chinook	1997	9.8 (51)	3.6 (28)	0.0 (19)	0.0 (15)	0.0 (1)	0.0 (1)	0.0 (1)	0.0 (1)
	1998	4.1 (943)	11.4 (666)	3.3 (547)	2.3 (435)	6.9 (29)	3.8 (26)	33.3 (18)	20.0 (15)
	2000	5.1 (683)	9.0 (782)	2.4 (630)	1.9 (471)	2.9 (35)	9.1 (33)	54.5 (33)	50.0 (28)
	2001	6.8 (532)	8.0 (764)	2.6 (606)	3.8 (496)	11.0 (100)	5.8 (86)	11.3 (80)	5.6 (72)
	2002	4.7 (700)	9.6 (792)	1.6 (627)	3.5 (484)	9.8 (82)	2.9 (69)	4.9 (61)	8.6 (58)
	2003	4.6 (606)	10.7 (468)	1.8 (384)	4.0 (297)	13.3 (45)	0.0 (37)	6.7 (30)	6.9 (29)
	2004	4.6 (547)	10.0 (441)	2.9 (382)	2.4 (288)	3.8 (26)	3.8 (26)	7.7 (26)	0.0 (23)
	2005	5.2 (598)	5.9 (444)	2.7 (364)	0.7 (270)	8.6 (35)	3.1 (32)	16.7 (30)	10.7 (28)
	Mean	**5.6**	**8.5**	**2.2**	**2.3**	**8.0**	**4.1**	**19.3**	**14.5**

Table 31 Continued. **Annual fallback rate** by run, year, and dam. Number of fish in the denominator in parentheses. Mean values exclude annual estimates with *n* < 10 fish in the denominator. Estimates for Bonneville Dam only include fish released downstream from the dam.

		Fallback location							
Run	Year	BO	TD	JD	MN	IH	LM	GO	GR
Sockeye	1997	13.6 (568)	5.5 (495)	4.0 (471)	2.0 (460)	0.0 (1)	- (0)	- (0)	- (0)
	2013	10.0 (391)	2.9 (346)	5.2 (325)	1.2 (324)	33.3 (3)	0.0 (2)	0.0 (1)	100.0 (1)
	2014	4.1 (367)	2.3 (343)	5.8 (330)	1.6 (318)	33.3 (3)	0.0 (3)	66.7 (3)	66.7 (3)
	Mean	**9.2**	**3.6**	**5.0**	**1.6**	**-**	**-**	**-**	**-**
Steelhead	1996	5.1 (731)	7.7 (574)	10.4 (473)	9.3 (399)	8.1 (309)	- (0)	- (0)	10.2 (264)
	1997	10.0 (930)	7.7 (687)	8.9 (576)	13.1 (480)	5.6 (378)	5.2 (363)	9.0 (333)	7.2 (305)
	2000	7.3 (820)	7.1 (884)	4.7 (749)	10.9 (642)	5.1 (472)	2.2 (450)	5.8 (432)	4.1 (410)
	2001	4.7 (788)	9.8 (975)	6.7 (904)	9.8 (797)	7.5 (492)	6.0 (470)	9.7 (443)	7.9 (443)
	2002	4.5 (924)	11.4 (1049)	5.0 (959)	6.4 (849)	6.3 (624)	5.0 (641)	6.0 (617)	4.3 (599)
	2003	8.2 (572)	17.3 (450)	10.3 (407)	7.7 (337)	5.8 (276)	2.6 (269)	6.8 (265)	3.1 (258)
	2004	3.1 (289)	3.5 (198)	2.8 (176)	2.0 (153)	7.2 (97)	6.5 (93)	6.5 (92)	2.3 (88)
	2013	5.3 (760)	12.7 (661)	5.6 (588)	9.4 (520)	7.0 (445)	6.2 (418)	4.4 (412)	3.3 (394)
	2014	1.7 (783)	6.2 (647)	4.8 (585)	8.8 (536)	6.0 (464)	3.1 (449)	4.6 (435)	4.2 (428)
	Mean	**5.5**	**9.3**	**6.6**	**8.6**	**6.5**	**4.6**	**6.6**	**5.2**



Time Series Example 7. Annual fallback percentages (top) and rates (bottom) with 95% confidence intervals for spring–summer Chinook salmon and sockeye salmon at Bonneville Dam in relation to the 2001 operational shift in Powerhouse Priority from Powerhouse 1 to Powerhouse 2 (red lines). Estimates do not include fish released in the Bonneville forebay.

6.4.2 FINAL DISTRIBUTION OF FALLBACK FISH

Adult fallback at FCRPS dams has been linked to reduced migration success. This section provides basic summaries of the types of migration outcomes for radio-tagged fish that fell back at dams and the final distribution of fish upstream and downstream from the fallback location. Estimates of fallback associated with possible natal site overshoot are reported, but it is important to recognize that overshoot assignments are inherently uncertain in the absence of natal origin information. The section also includes comparisons of migration outcomes for fish that did and did not fall back at each FCRPS dam. To facilitate comparisons among dams and among runs, migrations outcomes were considered successful for all fish last detected in tributaries or hatcheries; this approach was a simplified version of how adult escapement has been studied and includes some potential biases associated with monitoring effort (e.g., limited monitoring in Columbia River tributaries upstream from Priest Rapids Dam and year-to-year differences in monitoring effort at individual dams or tributaries).

In total, 60-66% of spring–summer Chinook salmon that fell back at lower Columbia River dams and 70-78% of those that fell back at lower Snake River dams were last detected at a tributary or hatchery (Table 32). A small percentage (0-7%) were reported harvested in main stem fisheries, and 22-33% had unknown, or unaccounted-for fates. The spring–summer Chinook salmon that returned to tributaries and hatcheries after fallback were widely distributed throughout the Columbia and Snake River basins (Table 33). Estimates of natal site overshoot by spring–summer Chinook salmon was highest (~33% of unique fish that fell back) at McNary Dam, with a majority of those fish entering the Umatilla River. Overshoot was also possible for ~20% of the spring–summer Chinook salmon that fell back at Little Goose Dam with about half of those fish last detected in the Tucannon River (Table 33).

Table 32. Number of unique spring–summer Chinook salmon that fell back at each lower Columbia and lower Snake River dam, 1996-2014, and the distributions of their last detections (%) by downstream, upstream, and total fate categories. Fish from all Bonneville release sites, including forebay sites, were included.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	936	685	447	329	185	105	113	106
Downstream								
Tributary or hatchery (%)	1	17	15	33	15	14	20	8
Main stem harvest (%)	0	4	4	3	0	0	0	0
Unknown fate (%)	15	16	18	16	15	27	17	20
Upstream								
Tributary or hatchery (%)	59	46	47	33	62	55	56	70
Main stem harvest (%)	7	2	2	2	1	0	0	0
Unknown fate (%)	18	14	13	13	8	4	7	2
Total								
Tributary or hatchery (%)	*60*	*63*	*62*	*66*	*77*	*70*	*76*	*78*
Main stem harvest (%)	*7*	*6*	*6*	*5*	*1*	*0*	*0*	*0*
Unknown fate (%)	*33*	*30*	*32*	*29*	*23*	*30*	*24*	*22*

Table 33. Distributions of spring-summer Chinook salmon that fell back at dams and were last detected in tributaries or hatcheries. Blue and green shaded cells = possible natal site overshoot. Fish from all Bonneville release sites, including forebay sites, were included.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	936	685	447	329	185	105	113	106
Tributary / Hatchery (*n*)	562	433	279	217	142	73	86	83
Tributary / Hatchery (%)	60.0%	63.2%	62.4%	66.0%	76.8%	69.5%	76.1%	78.3%
Potential overshoot (%)	1.5%	15.5%	15.4%	32.5%	15.1%	14.3%	20.4%	8.5%
Tributary / Hatchery (*n*)								
Below Bonneville (all sites)	14	5	3	1				
Herman Creek		1						
Wind River	69	14	3	1	1	1		
Little White Salmon River	24	14	3					
White Salmon River	4	6						
Hood River	5	13	2					
Klickitat River	19	62	20	7	1	1	1	1
Fifteenmile Creek	1	1						
Deschutes River	62	40	38	13	2	1	1	
John Day River	22	10	13	14	2	2	1	
Rock Creek	2							
Umatilla River	6	2	5	71	14	9	7	3
Walla Walla River			1	1	1			
Yakima River	25	4	17	8	6			
Ringold Hatchery	3	2	2	3				
Wenatchee River	27	15	13	10	1	1		
Entiat River	1							
Wells Hatchery	2	3	3	1				
Methow River	4		2	1				
Okanogan River	4	1	2					
Lyons Ferry Hatchery					1		1	
Tucannon River	4	5	3	3	9	3	12	5
LGR Dam (Hatchery transport)	6	7	6	2			2	
Clearwater River	98	98	57	48	36	26	29	18
Snake R. > Clearwater River	17	12	8	4	10	6	5	13
Asotin Creek								
Grande Ronde River	8	9	2	4	9	3	3	4
Salmon River	117	93	72	23	41	19	21	37
Imnaha River	14	9	2	2	8		3	1
Hells Canyon Hatchery	4	7	2			1		1

In total, 42-67% of fall Chinook salmon that fell back at lower Columbia River dams and 54-81% of those that fell back at lower Snake River dams were last detected at a tributary or hatchery (Table 34). A portion (9-11%) of those that fell back at lower Columbia River dams were reported harvested in main stem fisheries. The percentage unaccounted for ranged from 25-46% of those that fell back at lower Columbia River dams and from 19-46% of those that fell back in the Snake River.

The fall Chinook salmon that returned to tributaries and hatcheries after fallback were last detected at a variety of sites, but were most frequently at Bonneville Hatchery, in tributaries to the Bonneville pool, in the Deschutes River, and in the Hanford reach (Table 35). Estimates of potential natal site overshoot was higher for fall Chinook salmon than for spring–summer Chinook salmon, with >40% of fallback events potentially by overshoot fall Chinook salmon at The Dalles, John Day, McNary, Ice Harbor, and Little Goose dams. The tributaries most commonly associated with apparent overshoot fish included the Little White Salmon, White Salmon, Klickitat, Deschutes, and Umatilla rivers and the Lyons Ferry Hatchery.

Table 34. Number of unique fall Chinook salmon that fell back at each lower Columbia and lower Snake River dam, 1996-2014, and the distributions of their last detection locations (%) by fate categories downstream and upstream from the fallback location. Fish from all Bonneville release sites, including forebay sites, were included.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	319	352	86	69	32	13	34	23
Downstream								
Tributary or hatchery (%)	15	44	41	42	63	38	50	35
Main stem harvest (%)	3	6	8	9	0	0	0	0
Unknown fate (%)	35	23	37	22	13	46	18	43
Upstream								
Tributary or hatchery (%)	27	16	8	25	19	15	21	22
Main stem harvest (%)	8	3	2	0	0	0	0	0
Unknown fate (%)	11	7	3	3	6	0	12	0
Total								
Tributary or hatchery (%)	*42*	*61*	*49*	*67*	*81*	*54*	*71*	*57*
Main stem harvest (%)	*11*	*9*	*10*	*9*	*0*	*0*	*0*	*0*
Unknown fate (%)	*46*	*30*	*41*	*25*	*19*	*46*	*29*	*43*

Table 35. Distributions of fall Chinook salmon that fell back at dams and were last detected in tributaries or hatcheries. Blue and green shaded cells = possible natal site overshoot. Fish from all Bonneville release sites, including forebay sites, were included.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	319	352	86	69	32	13	34	23
Tributary / Hatchery (*n*)	135	214	42	46	26	7	24	13
Tributary / Hatchery (%)	42.3%	60.8%	48.8%	66.7%	81.3%	53.8%	70.6%	56.5%
Potential overshoot (%)	15.7%	44.3%	40.7%	42.0%	62.5%	38.5%	50.0%	26.1%
Tributary / Hatchery (*n*)								
Below Bonneville (all sites)	50	7	1					
Herman Creek	3	1						
Eagle Creek	1							
Wind River	3	2						
Little White Salmon River[1]	8	34	2					
Spring Creek Hatchery	4	3						
White Salmon River	7	30	5	1				
Hood River	2	6	1					
Klickitat River	8	73	9	3	1			
Deschutes River	8	19	17	7				
Umatilla River	2	1		18	6	1		
Walla Walla River	1				1			
Yakima River	1	1			6	1	1	
Ringold Hatchery								
Priest Rapids Hatchery	4	4			1	1	1	
Hanford	25	26	5	13	5	2	1	
Lyons Ferry Hatchery	2	1		1	2		14	6
Tucannon River								
LGR Dam (then Hatchery)				1	1		2	2
Clearwater River	3	4	1	2		1	1	3
Snake River > Clearwater R.	2	2	1		1		4	2
Grande Ronde River					1	1		
Hells Canyon Hatchery	1				1			

[1] includes hatchery

In total, 49-62% of sockeye salmon that fell back at lower Columbia River dams were last recorded in tributaries (Table 36), primarily the Wenatchee and Okanogan rivers (Table 37). Main stem harvest was reported for 7-14% of the sockeye salmon that fell back at Bonneville and The Dalles dams. The rest of the fish that fell back at the lower Columbia River dams (32-44%) had unknown for fate.

Table 36. Number of unique sockeye salmon that fell back at each lower Columbia and lower Snake River dam, 1996-2014, and the distributions of their last detection locations (%) by fate categories downstream and upstream from the fallback location.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	97	43	52	18	2	0	1	2
Downstream								
Tributary or hatchery (%)	0	0	0	0	0	0	0	0
Main stem harvest (%)	0	2	0	0	0	0	0	0
Unknown fate (%)	5	21	4	6	0	0	0	0
Upstream								
Tributary or hatchery (%)	54	49	62	56	0	0	0	50
Main stem harvest (%)	14	5	0	0	0	0	0	0
Unknown fate (%)	27	23	35	39	100	0	100	50
Total								
Tributary or hatchery (%)	*54*	*49*	*62*	*56*	*0*	*0*	*0*	*50*
Main stem harvest (%)	*14*	*7*	*0*	*0*	*0*	*0*	*0*	*0*
Unknown fate (%)	*32*	*44*	*38*	*44*	*100*	*0*	*100*	*50*

Table 37. Distributions of sockeye salmon that fell back at dams and were last detected in tributaries or hatcheries. Blue and green shaded cells = possible natal site overshoot.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	97	43	52	18	2	0	1	2
Tributary / Hatchery (*n*)	52	21	32	10	0	0	0	1
Tributary / Hatchery (%)	53.6%	48.8%	61.5%	55.6%	0.0%	0.0%	0.0%	50.0%
Potential overshoot (%)	-	-	-	-	-	-	-	-
Tributary / Hatchery (*n*)								
Wenatchee River	15	10	16	4				
Entiat River	1							
Chelan River								
Methow River	1		1					
Okanogan River	35	11	15	6				
Salmon River								1

In total, 42-59% of steelhead that fell back at lower Columbia River dams and 48-62% of those that fell back at lower Snake River dams were last detected at a tributary or hatchery (Table 38). A portion (9-15%) of those that fell back at lower Columbia River dams and at lower Snake River dams (4-7%) were reported harvested in main stem fisheries. The percentage unaccounted for ranged from 30-43% of those that fell back at lower Columbia River dams and 32-45% of those that fell back in the Snake River.

The steelhead that returned to tributaries and hatcheries after fallback were last detected throughout the basin (Table 39). Estimates of natal site overshoot (1-33%) by steelhead were relatively low compared to spring–summer and fall Chinook salmon. The highest overshoot estimate was at McNary Dam and was associated with many fish last detected in the John Day River.

Table 38. Number of unique steelhead that fell back at each lower Columbia and lower Snake River dam, 1996-2014, and the distributions of their last detection locations (%) by fate categories downstream and upstream from the fallback location. Fish from all Bonneville release sites, including forebay sites, were included.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	416	433	320	384	202	127	193	158
Downstream								
Tributary or hatchery (%)	1	5	12	33	14	7	11	8
Main stem harvest (%)	0	4	4	5	1	3	4	5
Unknown fate (%)	19	19	15	17	29	31	25	28
Upstream								
Tributary or hatchery (%)	41	46	47	28	42	41	50	54
Main stem harvest (%)	15	7	6	4	3	4	3	1
Unknown fate (%)	24	19	16	13	10	14	7	3
Total								
Tributary or hatchery (%)	*42*	*52*	*59*	*61*	*56*	*48*	*61*	*62*
Main stem harvest (%)	*15*	*11*	*10*	*9*	*4*	*7*	*7*	*6*
Unknown fate (%)	*43*	*38*	*31*	*30*	*40*	*45*	*32*	*32*

Table 39. Distributions of steelhead that fell back at dams and were last detected in tributaries or hatcheries. Blue and green shaded cells = possible natal site overshoot. Fish from all Bonneville release sites, including forebay sites, were included.

	Fallback location							
	BO	TD	JD	MN	IH	LM	GO	GR
Unique fallback fish (*n*)	416	433	320	384	202	127	193	158
Tributary / Hatchery (*n*)	176	223	189	234	113	61	118	98
Tributary / Hatchery (%)	42.3%	51.5%	59.1%	60.9%	55.9%	48.0%	61.1%	62.0%
Potential overshoot (%)	1.0%	5.3%	12.2%	32.8%	14.4%	7.1%	10.9%	7.6%
Tributary / Hatchery (*n*)								
Below Bonneville (all sites)	4	1						
Herman Creek	1							
Wind River	2	1						
Little White Salmon River	8	2	1					
White Salmon River	4	1	1	1				
Hood River	5	5	1					
Klickitat River	12	12	5	2				
Fifteenmile Creek		1						
Deschutes River	21	34	31	11	1			
John Day River	17	30	38	92	12	4	3	1
Rock Creek		1		1				
Umatilla River	3	1	6	19	3	1		
Walla Walla River	3		2	6	12	4	1	1
Yakima River	2	4	4	4	1			
Wenatchee River	1	1						
Methow River		2	1	1				
Lyons Ferry Hatchery	1	1			1		4	1
Tucannon River	2	1		1	5	2	13	9
Clearwater River	28	62	40	32	30	12	39	31
Snake River > Clearwater River	19	30	27	28	16	10	17	24
Asotin Creek								
Grande Ronde River	6	6	10	6	8	4	6	7
Salmon River	35	26	20	30	21	20	32	24
Imnaha River	1	1	1		2	3	2	
Hells Canyon Hatchery	1		1		1	1	1	

6.4.3 ESCAPEMENT OF FALLBACK VERSUS NON-FALLBACK FISH

Adult fallback at FCRPS dams is consistently associated with reduced escapement to tributaries and hatcheries, even after accounting for potential tributary overshoot. This section provides comparisons of escapement estimates for adults that did or did not fall back at individual FCRPS dams. We defined escapement conservatively, where only fish that were last detected in tributaries, at hatcheries / traps, or in the Hanford Reach (fall Chinook salmon) were considered successful. The method was conservative because potential main stem spawners and those that entered unmonitored tributaries or entered tributaries without detection were classified as unsuccessful. Fish originating from sites upstream from Priest Rapids Dam, for example, were more likely to enter tributaries undetected due to reduced monitoring effort relative to lower Columbia and Snake River tributaries.

Across years, escapement estimates for spring–summer Chinook salmon that fell back at the four lower Columbia River dams were 0.034-0.063 lower than estimates for salmon that did not fall back at these sites (Table 40). Fallback at the lower Snake River dams had a higher escapement cost: escapement estimates were 0.110-0.191 lower for fallback fish than estimates for fish that did not fall back.

Table 40. Estimated escapement (Esc) to tributaries and hatcheries for spring–summer Chinook salmon that did or did not fall back at each FCRPS dam, with all years combined. Total *n* = number of fish that passed dam; Esc *n* = number last detected in tributaries or hatcheries; Esc *prop* = Esc *n*/Total *n*; *Difference* = the difference in escapement between fish that did not fallback and those that did fall back.

	Did not fall back at dam			Fell back at dam			
Dam	Total *n*	Esc *n*	Esc *prop*	Total *n*	Esc *n*	Esc *prop*	***Difference***
Bonneville[1]	9,049	5,801	0.641	830	504	0.607	***0.034***
The Dalles	8,083	5,407	0.669	685	434	0.634	***0.035***
John Day	7,219	4,943	0.685	447	278	0.622	***0.063***
McNary	6,684	4,689	0.702	329	217	0.660	***0.042***
Ice Harbor	3,327	2,919	0.877	185	142	0.768	***0.110***
Lower Monumental	3,231	2,865	0.887	105	73	0.695	***0.191***
Little Goose	3,131	2,835	0.905	113	85	0.752	***0.153***
Lower Granite	3,090	2,883	0.933	107	84	0.785	***0.148***

[1] Only includes fish released downstream from Bonneville Dam

Across years, differences in escapement estimates for fall Chinook salmon that did or did not fall back were highly variable, though fallback fish always escaped at lower rates (Table 41). Differences were smallest at The Dalles (0.009) and Ice Harbor (0.013) dams and were highest at Lower Granite (0.353) and Lower Monumental (0.310) dams. Differences ranged from 0.136-0.190 at the four other dams. Note that sample sizes were much smaller at the four Snake River dams than at the four lower Columbia River dams (Table 41).

Across years, differences in escapement estimates for sockeye salmon that did or did not fall back were consistently high (Table 42). Differences were 0.110 at Bonneville Dam, 0.229 at The Dalles Dam, 0.131 at John Day Dam, and 0.206 at McNary Dam. Escapement differences for steelhead that did or did not fall back were highly variable, though fallback fish always escaped at lower rates (Table 43). Differences were smallest at John Day (0.059) and McNary

(0.070) dams and were highest at Lower Monumental (0.347) and Lower Granite (0.274) dams. Differences ranged from 0.124-0.239 at the four other dams.

Table 41. Estimated escapement (Esc) to tributaries and hatcheries for fall Chinook salmon that did or did not fall back at each FCRPS dam, with all years combined. Total *n* = number of fish that passed dam; Esc *n* = number last detected in tributaries or hatcheries, including the Hanford Reach; Esc *prop* = Esc *n*/Total *n*; *Difference* = the difference in escapement between fish that did not fallback and those that did fall back.

	Did not fall back at dam			Fell back at dam			
Dam	Total *n*	Esc *n*	Esc *prop*	Total *n*	Esc *n*	Esc *prop*	***Difference***
Bonneville[1]	3,733	2,226	0.596	158	69	0.437	***0.160***
The Dalles	3,797	2,342	0.617	352	214	0.608	***0.009***
John Day	3,181	2,158	0.678	86	42	0.488	***0.190***
McNary	2,628	2,111	0.803	69	46	0.667	***0.137***
Ice Harbor	293	242	0.826	32	26	0.813	***0.013***
Lower Monumental	290	246	0.848	13	7	0.538	***0.310***
Little Goose	234	197	0.842	34	24	0.706	***0.136***
Lower Granite	183	168	0.918	23	13	0.565	***0.353***

[1] Only includes fish released downstream from Bonneville Dam

Table 42. Estimated escapement (Esc) to tributaries and hatcheries for sockeye salmon that did or did not fall back at each FCRPS dam, with all years combined. Total *n* = number of fish that passed dam; Esc *n* = number last detected in tributaries or hatcheries; Esc *prop* = Esc *n*/Total *n*; *Difference* = the difference in escapement between fish that did not fallback and those that did fall back.

	Did not fall back at dam			Fell back at dam			
Dam	Total *n*	Esc *n*	Esc *prop*	Total *n*	Esc *n*	Esc *prop*	***Difference***
Bonneville[1]	1,225	791	0.646	97	52	0.536	***0.110***
The Dalles	1,146	822	0.717	43	21	0.488	***0.229***
John Day	1,086	811	0.747	52	32	0.615	***0.131***
McNary	1,092	832	0.762	18	10	0.556	***0.206***

[1] Only includes fish released downstream from Bonneville Dam

Table 43. Estimated escapement (Esc) to tributaries and hatcheries for steelhead that did or did not fall back at each FCRPS dam, with all years combined. Total *n* = number of fish that passed dam; Esc *n* = number last detected in tributaries or hatcheries; Esc *prop* = Esc *n*/Total *n*; *Difference* = the difference in escapement between fish that did not fallback and those that did fall back. Fallback by kelts excluded.

	Did not fall back at dam			Fell back at dam			
Dam	Total *n*	Esc *n*	Esc *prop*	Total *n*	Esc *n*	Esc *prop*	***Difference***
Bonneville[1]	6,204	3,709	0.598	323	128	0.396	***0.202***
The Dalles	5,748	3,689	0.642	431	223	0.517	***0.124***
John Day	5,104	3,326	0.652	319	189	0.592	***0.059***
McNary	4,486	3,062	0.683	382	234	0.613	***0.070***
Ice Harbor	3,577	2,865	0.801	201	113	0.562	***0.239***
Lower Monumental	3,216	2,634	0.819	127	60	0.472	***0.347***
Little Goose	2,995	2,537	0.847	193	118	0.611	***0.236***
Lower Granite	3,092	2,757	0.892	157	97	0.618	***0.274***

[1] Only includes fish released downstream from Bonneville Dam

6.5 BEHAVIORS AT FISHWAYS

The series of fishway use metrics in this section provide information on the number of times that upstream migrants approached, entered, and exited from fishways back to the dam tailrace. When and where fish approach and enter the various fishway openings is a function of attraction flow distribution in the tailrace, water velocity, and geometry of fishway openings, as well as non-operational factors such as predator distribution (e.g., pinnipeds in the Bonneville tailrace). Fish exits from fishways to the tailrace occur often and have been associated with conditions inside fishway collection channels as well as fish turn-around behaviors at sites in transition areas and ladders. Summaries of the spatial distribution of fishway use were not included in this report for two reasons: (1) year-to-year changes in monitoring made multi-year summaries challenging; and (2) among-dam differences in monitoring and fishway configurations also prevented efficient comparisons between years and locations.

6.5.1 FISHWAY APPROACHES

The number of fishway approach events per fish gives an indication of effort required to discover and enter an adult fishway and includes repeated passage attempts if fish entered and exited from a fishway into the tailrace. Approach events were coded when a fish was detected within approximately 10 m of a fishway opening monitored using an underwater coaxial cable antenna mounted to the outside of the fishway. Annual median numbers of approaches were higher and more variable for the Chinook salmon runs than for sockeye salmon and steelhead (Figure 52). Grand medians ranged from ~5-15 fishway approaches per spring–summer Chinook salmon, from ~4-20 approaches per fall Chinook salmon, and from ~2-10 approaches per sockeye salmon and steelhead. The highest annual medians were at John Day Dam for all runs except sockeye salmon. At many sites, the number of approaches may have been underestimated because not all fishway openings were monitored in all years. (See Appendix A for monitoring details).

The numbers of approaches for individual salmon and steelhead (Figure 53) showed broadly similar patterns as the annual median values. Twenty-five percent or more of Chinook salmon approached fishways 10 or more times per fish at most FCRPS dams and ~25% approached 30 times or more at John Day Dam.

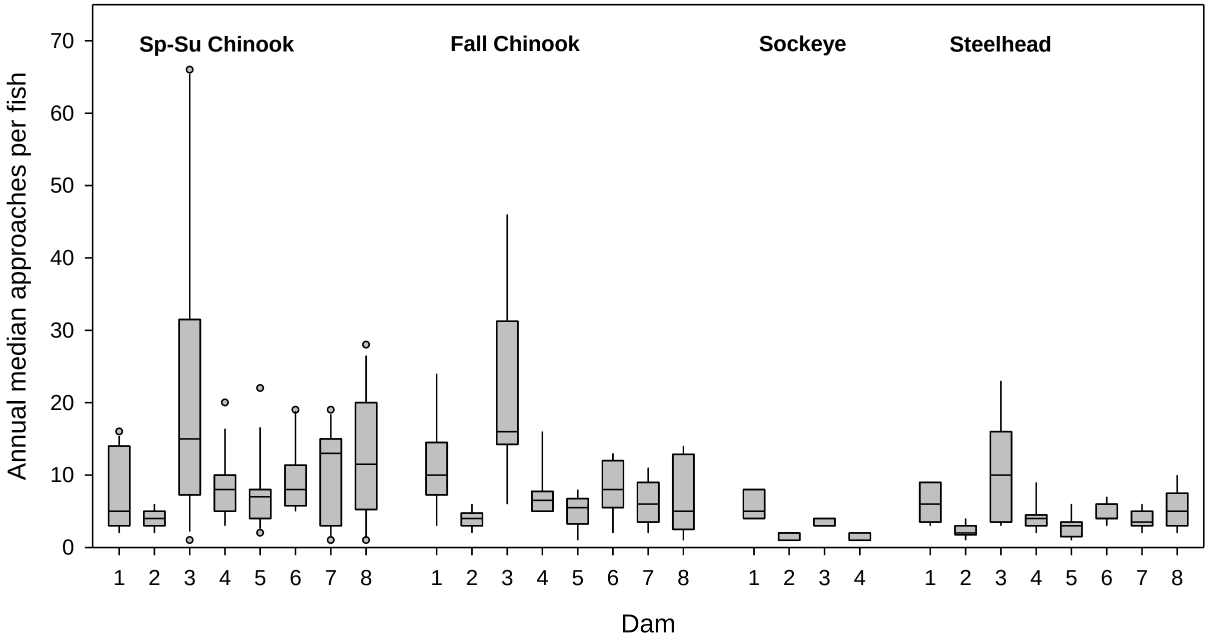


Figure 52. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual median number of fishway approaches, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

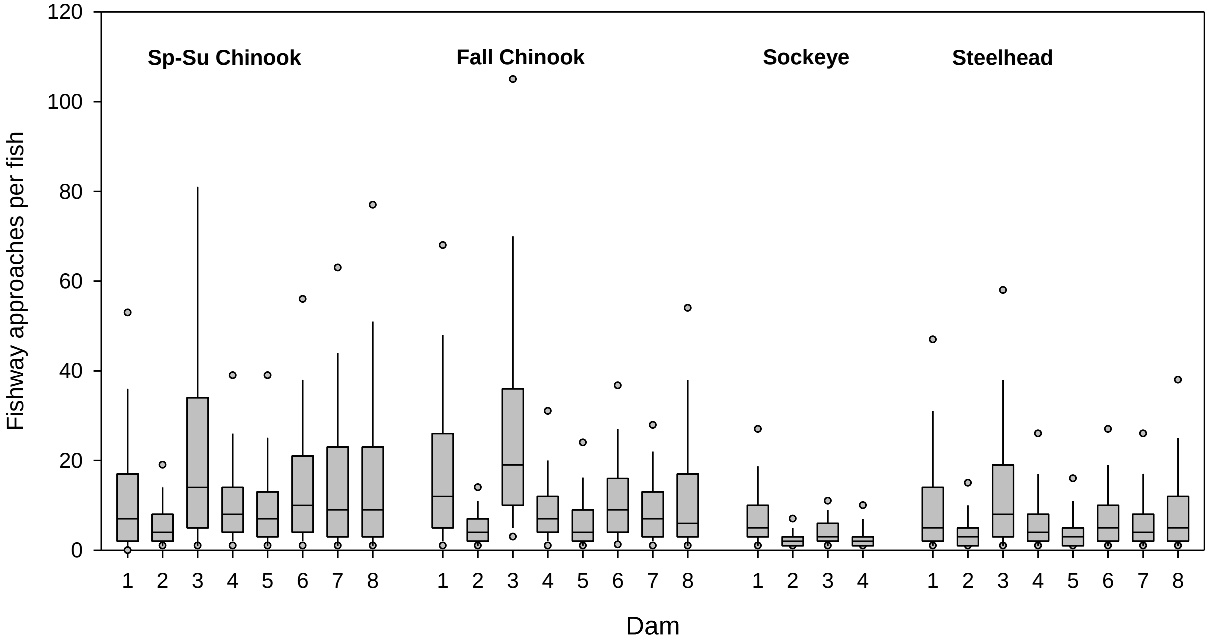


Figure 53. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of number of fishway approaches per individual, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.5.2 FISHWAY ENTRIES

The number of fishway entry events per fish is a useful measure of fishway retention and fishway passage attempt rate. Fishway entry events were coded when a fish was detected on an underwater coaxial cable antenna mounted inside a fishway (i.e., in a collection channel) or at an antenna further up a fishway in a transition area. Annual median numbers of entries were ≤4 per fish for most runs at most FCRPS dams (Figure 54). Entry rates were relatively high for both Chinook salmon runs and steelhead at John Day Dam and for fall Chinook salmon at Little Goose Dam. At many sites, the number of entries may have been underestimated because not all fishway openings were monitored in all years. (See Appendix A for monitoring details).

The numbers of entries for individual salmon and steelhead (Figure 55) showed that ~90% of the fish from all runs entered fishways ≤7 times per dam. Exceptions included John Day Dam, where the number of entries per fish was higher for runs except sockeye salmon, and the lower Snake River dams, where fall Chinook salmon made more entries per fish than the other runs (Figure 55).

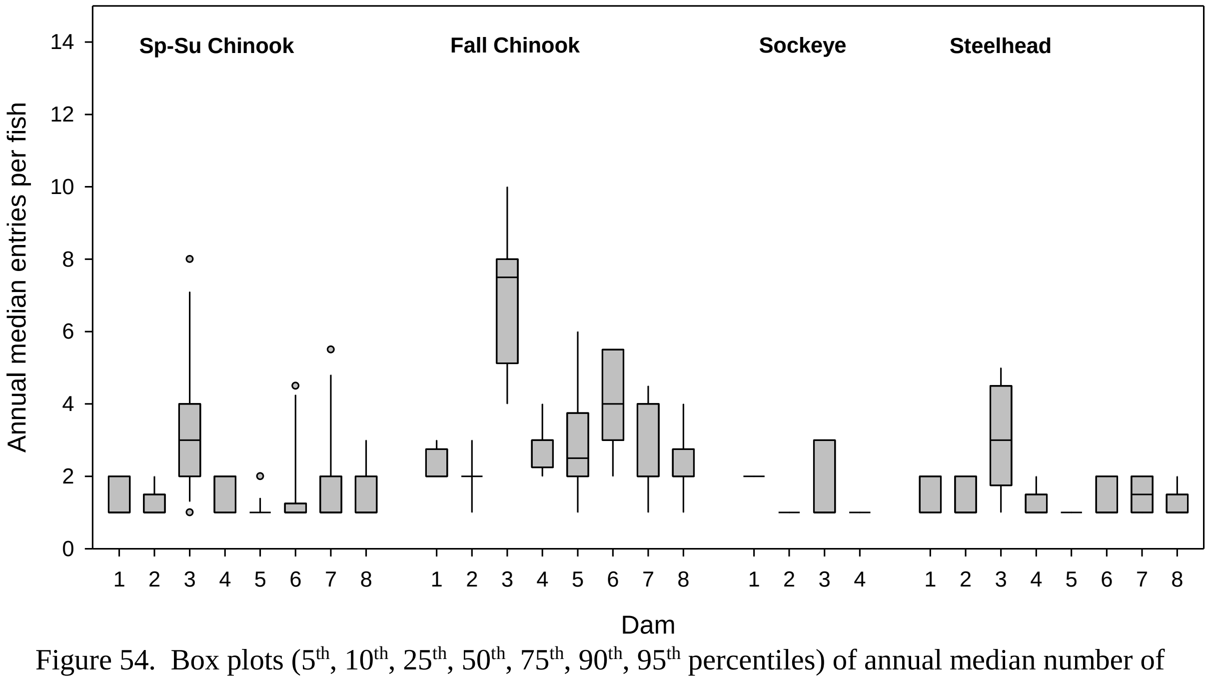


Figure 54. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual median number of fishway entries, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

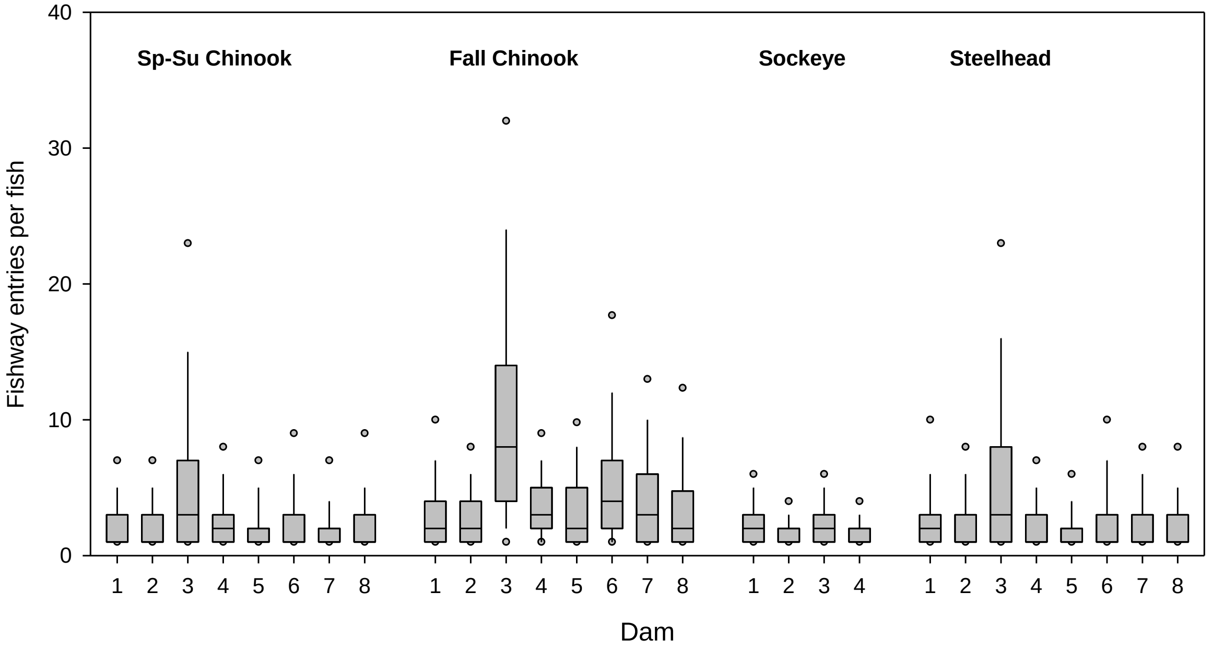


Figure 55. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of number of fishway entries per individual, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.5.3 FISHWAY EXITS TO TAILRACE

The number of fishway exit events per fish closely parallels the fishway entry metric and is a measure of fishway retention and fishway passage attempt rate. An important difference between the entry and exit metrics is that some fish do not exit to the tailrace (i.e., exits = 0). The percentage of fish that entered fishways but made no exits to the tailrace varied widely among years, runs, and FCRPS dams (Figure 56). Annual median ‘did not exit’ values ranged from ~20-70% for spring–summer Chinook salmon, sockeye salmon, and steelhead, but were lower (~5-40%) for fall Chinook salmon. Within run, the ‘did not exit’ percentages were lowest at John Day Dam for all four runs (Figure 56).

Among the fish that did exit a fishway to the tailrace, annual median numbers of exit events were ≤3 per fish for most runs at most FCRPS dams (Figure 57). Exit rates were relatively higher for fall Chinook salmon and at John Day Dam. The numbers of exits for individual salmon and steelhead (Figure 58) showed that ~10% of the fish from all runs exited fishways ≥8 times per dam. Exceptions included John Day Dam, where the number of exits per fish was higher for runs except sockeye salmon, and the lower Snake River dams, where fall Chinook salmon made more exits per fish than fish from the other runs.

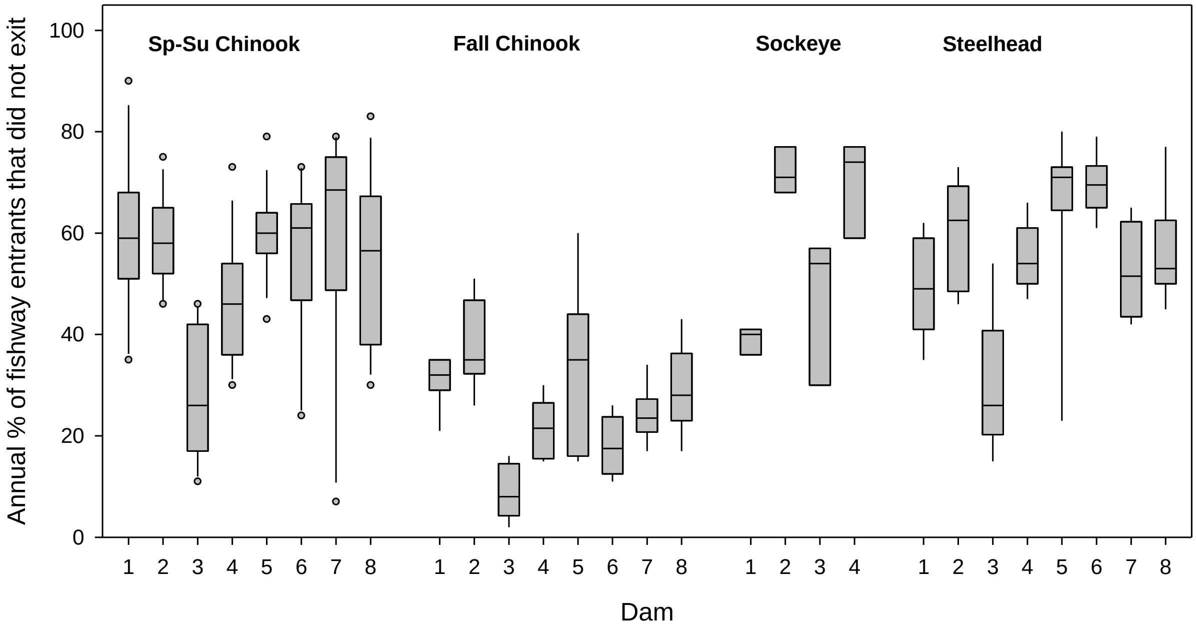


Figure 56. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual percent of individuals that did not exit a fishway to the tailrace, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

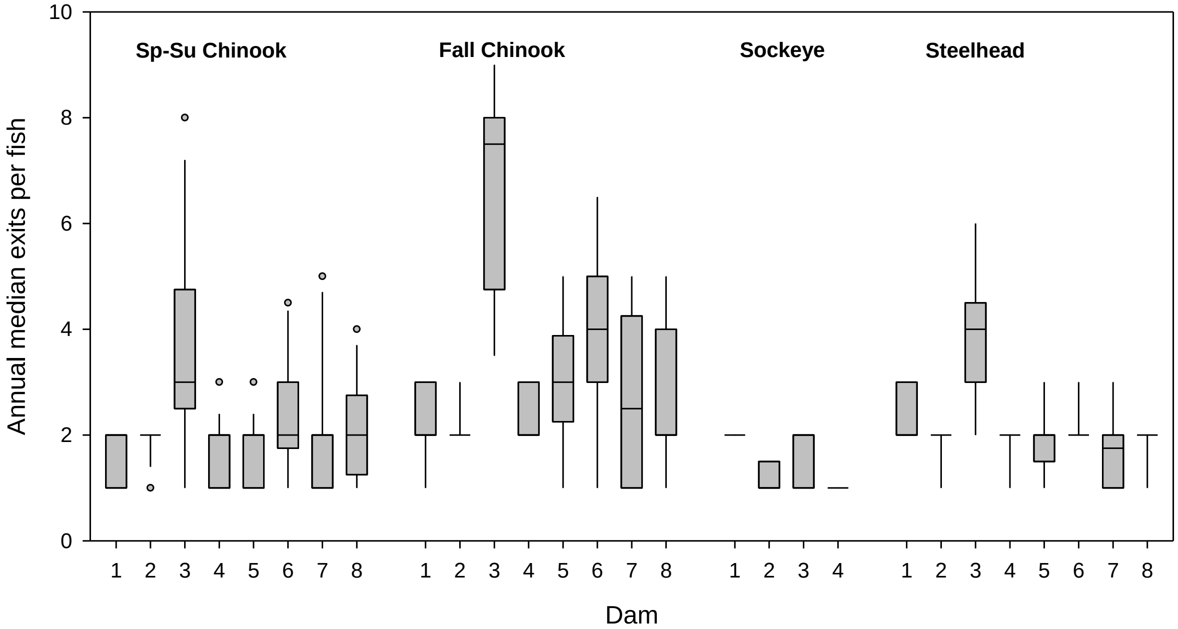


Figure 57. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual median number of fishway exits to the tailrace among fish that exited, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

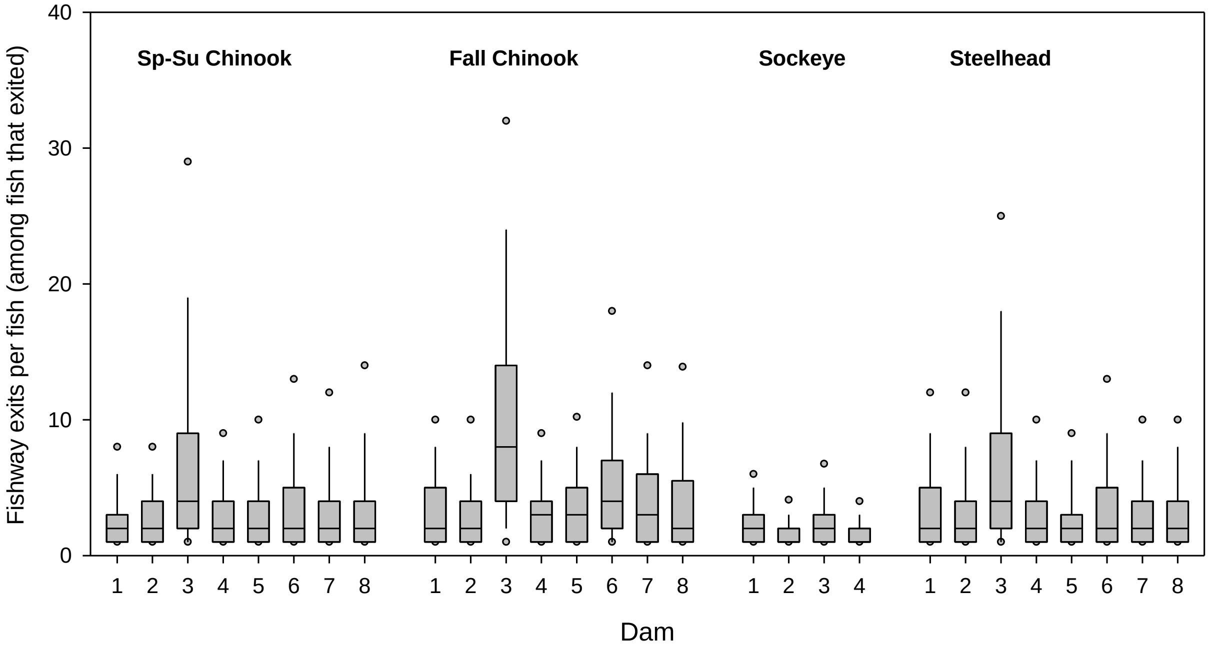


Figure 58. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of number of fishway exits to the tailrace per individual that exited, by species and run, 1996-2014. Dams are ordered from downstream to upstream: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

6.6 DAM-TO-DAM REACH CONVERSION

Dam-to-dam and multi-dam reach conversion estimates have been a primary measure of adult salmon and steelhead survival through the FCRPS. A variety of metrics have been used, with different standards applied based on whether upstream migrants were of known origin (i.e., they were PIT tagged as juveniles or were assigned to population using genetics) or if they were of mixed-stock, run-of-river origin. In addition to the baseline conversion (i.e., the proportion that passed from the downstream site past the upstream site), conversion estimates have been adjusted in several ways to accommodate information about harvest and tributary entry within study reaches.

The summary metrics in this section provide unadjusted annual estimates of dam-to-dam adult conversion along with summaries of the migration outcomes for fish that did not pass the upstream dam in each FCRPS reach. 'Unadjusted' conversion estimates were simply the proportion of the fish that entered a reach that passed the dam at the upstream end of the reach, regardless of their ultimate destination. Fish that were reported harvested in the main stem, those that entered a tributary or hatchery, and those with unknown fate in or downstream from the reach all reduced reach conversion estimates. The proportion of fish in the harvest, tributary, and unaccounted for categories are also presented for each reach and year and these data could be used to adjust reach conversion. For example, fish that entered tributaries could be treated as 'successful' with regards to reach conversion. In a final summary per reach, the final geographic distribution of the fish that did not pass each reach is presented, across study years.

Adult conversion estimates over multi-dam reaches (i.e., Bonneville-McNary, Bonneville-Lower Granite, etc.) are important performance standards in the Biological Opinion. Multi-dam estimates have primarily been calculated using PIT-tag detections of adults that were originally tagged as juveniles. PIT-tagged fish are often referred to as known-source or known-origin fish, and calculating multi-dam conversion metrics for such groups is straightforward because any 'loss' within a reach can be considered true loss from a population that originated upstream from the reach because tributary within the reach can be defined as straying. In contrast to the PIT-based estimates, large majorities of the radio-tagged adults had not been PIT-tagged as juveniles and thus were of unknown natal origin (see Tables 7-9). Consequently, multi-dam conversion estimates using radiotelemetry datasets have required a variety of methods to account for in-reach harvest, natal tributary entry, and unaccounted-for loss, rendering direct comparisons between PIT and radio samples challenging. Previous technical reports and papers provide analysis details and summaries of multi-dam conversion rates.

6.6.1 RELEASE TO PASS BONNEVILLE

Although technically not a dam-to-dam reach, conversion from release downstream from Bonneville Dam past the dam has been an important study metric. Fisheries, pinniped predation, natal site overshoot, and any negative handling effects all may reduce adult conversion from release ~10 km downstream, through the Bonneville tailrace, and past Bonneville Dam. On average, 95-96% of spring–summer Chinook salmon, sockeye salmon, and steelhead and 89% of fall Chinook salmon passed Bonneville Dam after release downstream (Figure 59). In almost all years and runs, ≤2% of the fish recorded entering downstream tributaries or hatcheries or were harvested, whereas ~2-11% were unaccounted for. Note that, with the exception of some early study years, downstream tributaries had very limited radiotelemetry monitoring and estimates of tributary entry is likely considerably underestimated.

Of the fish that did not pass Bonneville Dam, from 0% (sockeye salmon) to 14% (fall Chinook salmon) were last detected in downstream tributaries or hatcheries (Table 44). Reported downstream harvest ranged from 2% (sockeye salmon) to 11% (fall Chinook salmon). Large majorities of the non-passers were unaccounted for in each run: 92% (spring–summer Chinook salmon), 75% (fall Chinook salmon), 98.1% (sockeye salmon), and 89% (steelhead). A handful of fish were reportedly found dead, perhaps as a result of handling and transport (Table 44).

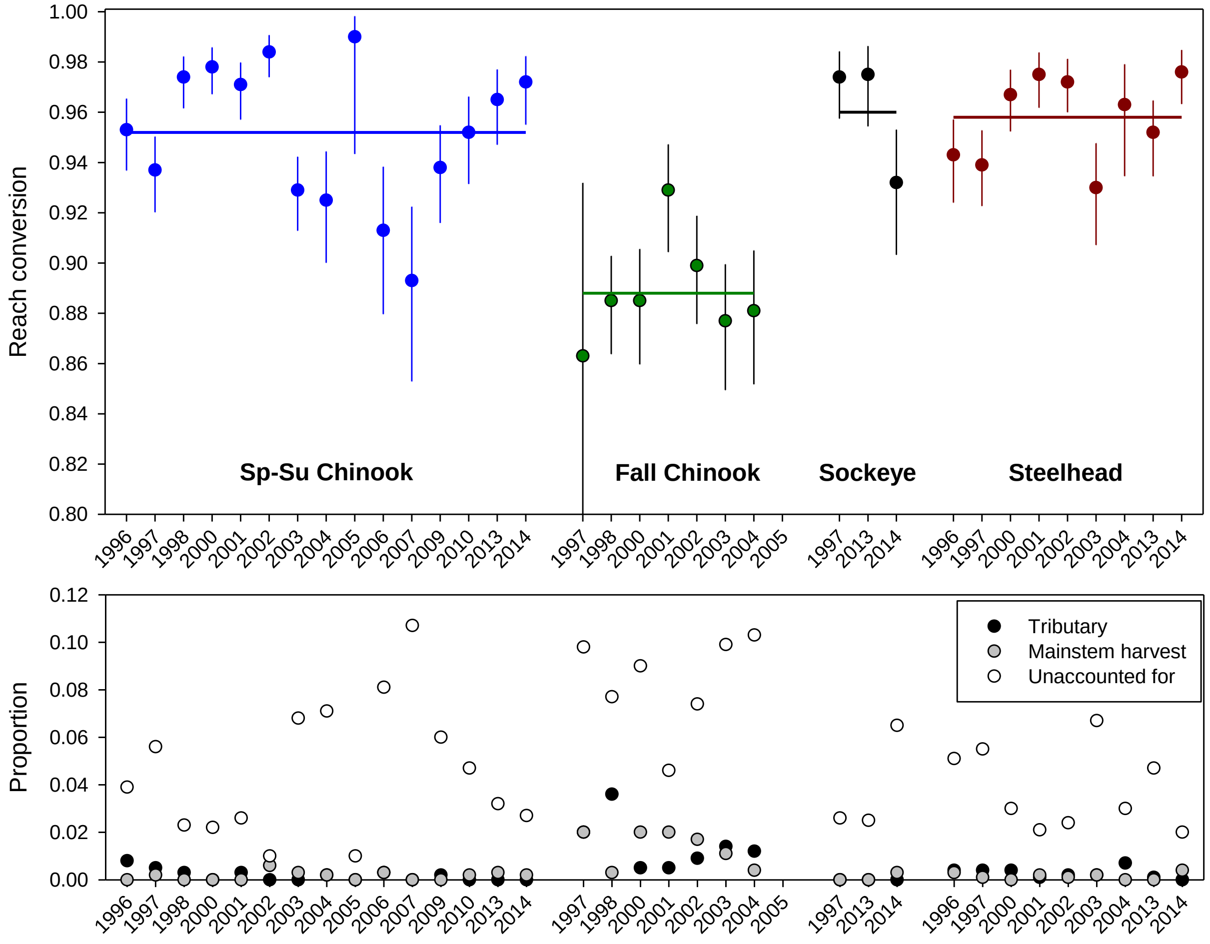


Figure 59. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from release downstream from Bonneville Dam past Bonneville Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream. (Note: fish released in the Bonneville AFF or the Bonneville forebay were excluded.)

Table 44. Estimated fates of radio-tagged salmon and steelhead released downstream from Bonneville Dam that did not pass Bonneville Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**484**	**-**	**478**	**-**	**52**	**-**	**288**	**-**
Tributary / Hatchery	**18**	**3.7**	**68**	**14.2**	**-**	**-**	**16**	**5.6**
Rogue	*1*	*0.2*						
Cowlitz	1	0.2	6	1.3				
Kalama							1	0.3
Lewis	2	0.4	8	1.7			1	0.3
Willamette	3	0.6	2	0.4			4	1.4
Washougal			2	0.4			2	0.7
Sandy	11	2.3	7	1.5			5	1.7
Tanner Creek/BON H			43	9.0			4	1.4
Fishery	**20**	**4.1**	**52**	**10.9**	**1**	**1.9**	**10**	**3.5**
Unaccounted for	**443**	**91.5**	**357**	**74.7**	**51**	**98.1**	**256**	**88.9**
Found dead	**3**	**0.6**	**1**	**0.2**	**-**	**-**	**5**	**1.7**

6.6.2 BONNEVILLE TOP TO PASS THE DALLES

The Bonneville reservoir reach (~73 km long) has extensive tribal and recreational fisheries and many tributaries used by Chinook salmon and steelhead. Conversion estimates through this reach are therefore low relative to other reaches, with considerable harvest and tributary turnoff. On average, 81% of spring–summer Chinook salmon and steelhead, 90% of sockeye salmon, and 72% of fall Chinook salmon passed The Dalles Dam after passing Bonneville Dam (Figure 60). Tributary entry varied considerably, with no sockeye salmon considered viable spawners in this reach, but from ~3 to > 20% of spring–summer and fall Chinook salmon and steelhead last detected in tributaries or hatcheries in the reach. Harvest in the Bonneville reservoir and unaccounted for rates were mostly in the 2-15% range per run per year (Figure 60).

Of the fish that did not pass The Dalles Dam, 35-51% of the Chinook salmon and steelhead were last detected in tributaries or hatcheries in the reach or downstream from Bonneville Dam (Table 45). The largest numbers of fish in tributaries were in the Wind and Little White Salmon rivers (spring–summer Chinook salmon) and the Klickitat River (fall Chinook salmon and steelhead). A few sockeye salmon (~8%) were also last reported in tributaries, but these fish were considered unsuccessful because there are no known spawning populations in the reach tributaries. Reported main stem harvest of the non-passers ranged from 23% (spring–summer Chinook salmon) to 55% (sockeye salmon). The remaining non-passers were unaccounted for in each run: 27% (spring–summer Chinook salmon), 21% (fall Chinook salmon), 30% (sockeye salmon), and 30% (steelhead).

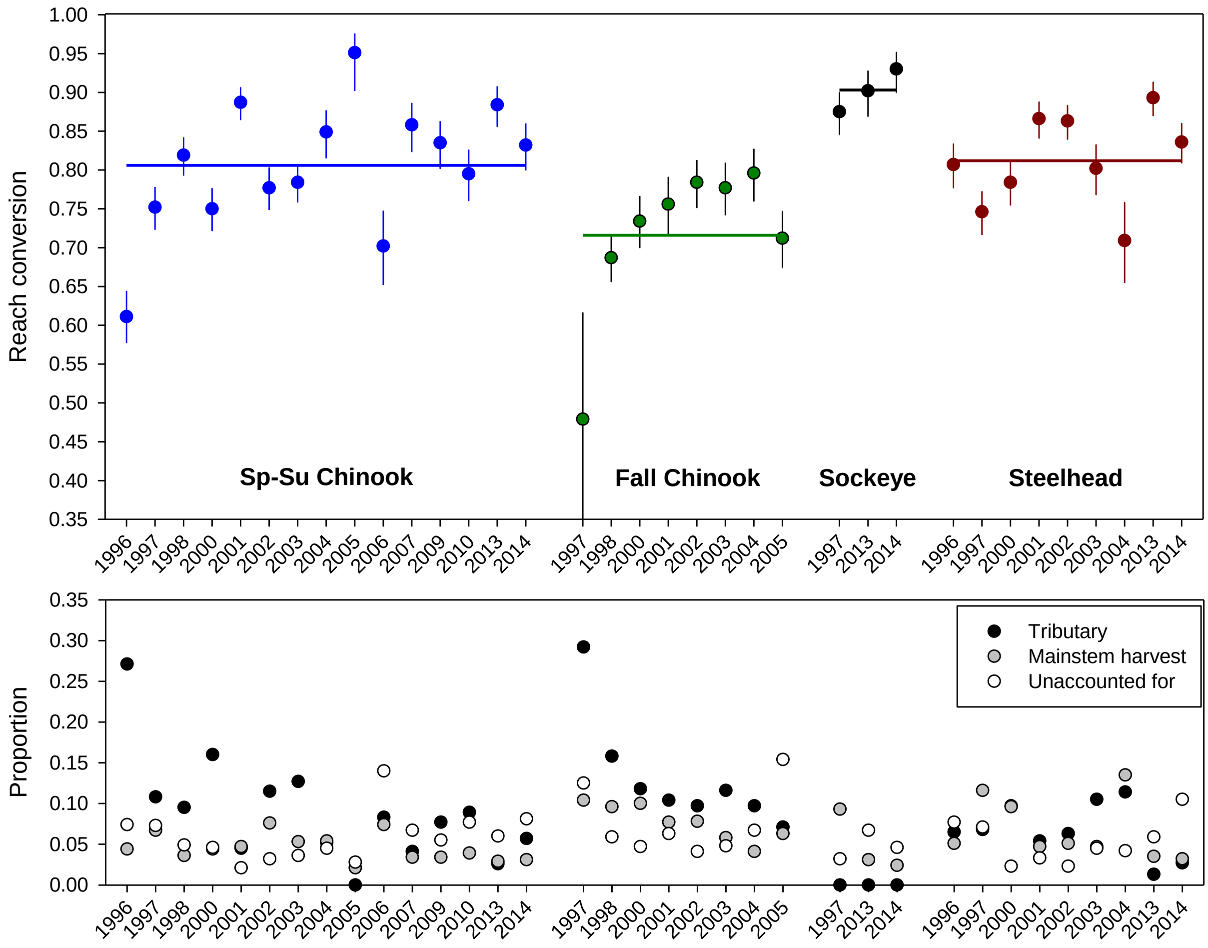


Figure 60. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of Bonneville Dam past The Dalles Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream. (Note: fish released in the Bonneville forebay were excluded.)

Table 45. Estimated fates of radio-tagged salmon and steelhead released downstream from Bonneville Dam or at the Bonneville AFF that passed Bonneville Dam but did not pass The Dalles Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**2,135**	-	**990**	-	**134**	-	1,183	-
Tributary / Hatchery	**1,081**	**50.6**	**474**	**47.9**	**[1]11**	**8.2**	**410**	**34.7**
Lewis	*1*	*<0.1*						
Willamette	*1*	*<0.1*	*1*	*0.1*				
Washougal	*1*	*<0.1*	*1*	*0.1*			*1*	*0.1*
Sandy	*3*	*0.1*	*1*	*0.1*			*2*	*0.2*
Tanner Creek/BON H			*21*	*2.1*				
Eagle Creek	4	0.2	5	0.5				
Rock Creek	10	0.5						
Herman Creek	1	<0.1	9	0.9			16	1.4
Wind	566	26.5	17	1.7	1	0.7	51	4.3
Little White Salmon	315	14.8	102	10.3	4	3.0	99	8.4
Spring Creek H			43	4.3				
White Salmon	39	1.8	76	7.7	3	2.2	61	5.2
Hood	41	1.9	10	1.0			45	3.8
Klickitat	98	6.5	188	19.0	3	2.2	134	11.3
Fifteenmile Creek	1	<0.1					1	0.1
Fishery	**483**	**22.6**	**307**	**31.0**	**73**	**54.5**	**422**	**35.7**
Below Bonneville	*4*	*0.2*	*5*	*0.5*			*2*	*0.2*
Bonneville reservoir	449	21.0	271	27.4	52	38.8	359	30.3
The Dalles tailrace	30	1.4	31	3.1	21	15.7	61	5.2
Unaccounted for	**570**	**26.7**	**208**	**21.0**	**40**	**29.9**	**350**	**29.6**
Below Bonneville	*92*	*4.3*	*50*	*5.1*	*2*	*1.5*	*49*	*4.1*
Bonneville top	72	3.4	12	1.2	20	14.9	57	4.8
Bonneville reservoir	259	12.1	124	12.5	19	14.2	200	16.9
The Dalles tailrace	147	6.9	22	2.2	9	6.7	44	3.7
Found dead	**1**	**<0.1**	**1**	**0.1**	-	-		

[1] Sockeye salmon in tributaries considered unsuccessful

6.6.3 THE DALLES TOP TO PASS JOHN DAY

The Dalles reservoir reach (~39 km long) also has extensive fisheries, but only one significant tributary, the Deschutes River. Conversion estimates through this reach were, on average, 88% for spring–summer Chinook salmon and steelhead, 96% for sockeye salmon, and 80% for fall Chinook salmon (Figure 61). Deschutes River entry varied from ~2 to > 15% of spring–summer and fall Chinook salmon and steelhead. Annual harvest in The Dalles reservoir or further downstream averaged <3% for spring–summer Chinook salmon, sockeye salmon, and steelhead and ~6% for fall Chinook salmon. Unaccounted for rates averaged 3-5% per run (Figure 61).

Of the fish that did not pass John Day Dam, 40-57% of the Chinook salmon and steelhead were last detected in the Deschutes River or in tributaries or hatcheries downstream from The Dalles Dam (Table 46). Reported main stem harvest of the non-passers ranged from 16% (spring–summer Chinook salmon) to 34% (fall Chinook salmon). The remaining non-passers were unaccounted for in each run: 28% (spring–summer Chinook salmon), 26% (fall Chinook salmon), 75% (sockeye salmon), and 25% (steelhead).

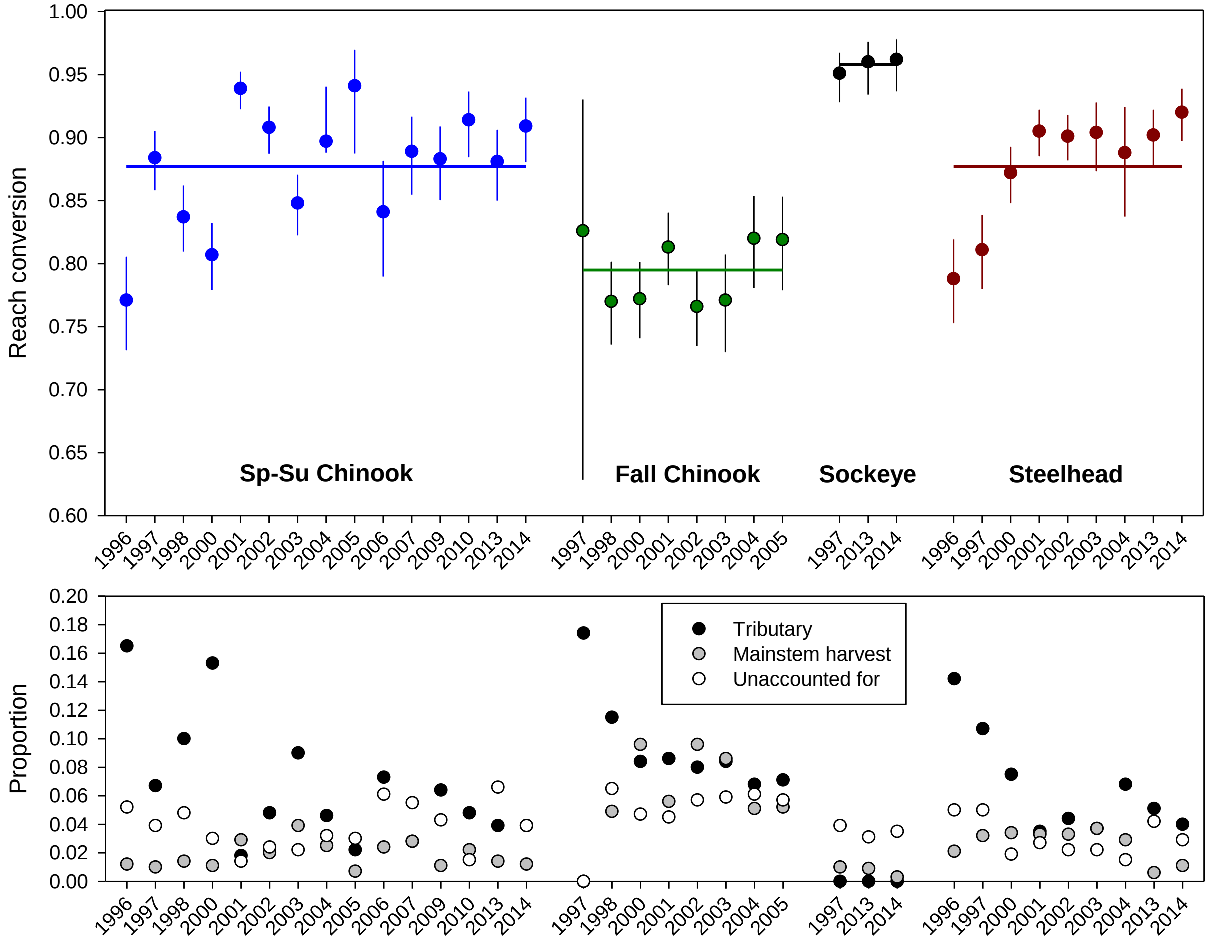


Figure 61. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of The Dalles Dam past John Day Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream.

Table 46. Estimated fates of radio-tagged salmon and steelhead that passed The Dalles Dam but did not pass John Day Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**1,127**	-	**881**	-	**51**	-	749	-
Tributary / Hatchery	**638**	**56.6**	**356**	**40.4**	**[1]4**	**7.8**	**394**	**52.6**
Lewis	*1*	*<0.1*						
Willamette	*1*	*<0.1*						
Sandy							*1*	*0.1*
Tanner Creek/BON H			*6*	*0.7*				
Herman Creek	*1*	*<0.1*	*1*	*0.1*				
Wind	*11*	*1.0*	*2*	*0.2*			*1*	*0.1*
Little White Salmon	*12*	*1.1*	*34*	*3.9*	*1*	*2.0*	*1*	*0.1*
Spring Creek H			*3*	*0.3*				
White Salmon	*6*	*0.5*	*27*	*3.1*	*2*	*3.9*		
Hood	*12*	*1.1*	*5*	*0.6*			*4*	*0.5*
Klickitat	*45*	*4.0*	*64*	*7.3*	*1*	*2.0*	*8*	*1.1*
Fifteenmile Creek	*1*	*<0.1*					*1*	*0.1*
Deschutes	548	48.6	214	24.3			378	50.5
Fishery	**175**	**15.5**	**297**	**33.7**	**9**	**17.6**	**165**	**22.0**
Below The Dalles	*27*	*2.4*	*23*	*2.6*	*1*	*2.0*	*13*	*1.7*
The Dalles reservoir	116	10.3	207	23.5	3	5.9	98	13.1
John Day tailrace	32	2.8	67	7.6	5	8.5	54	7.2
Unaccounted for	**314**	**27.9**	**228**	**25.9**	**38**	**74.5**	**188**	**25.1**
Below The Dalles	*74*	*6.6*	*70*	*7.9*	*7*	*13.7*	*53*	*11.1*
The Dalles top	50	4.4	10	1.1	5	8.5	7	0.9
The Dalles reservoir	90	8.0	90	10.2	14	27.5	63	8.4
John Day tailrace	100	8.9	58	6.6	12	23.6	65	8.7
Found dead	-	-	-	-	-	-	**2**	**0.3**

[1] Sockeye salmon in tributaries considered unsuccessful

6.6.4 JOHN DAY TOP TO PASS MCNARY

The John Day reservoir reach (~123 km long) has main stem fisheries, two major tributaries (John Day and Umatilla rivers), and some smaller creeks. Conversion estimates through this reach were, on average, 92% for spring–summer Chinook salmon, 82% for fall Chinook salmon, 98% for sockeye salmon, and 90% for steelhead (Figure 62). Tributary entry averaged from ~1-4% of spring–summer and fall Chinook salmon and steelhead; no sockeye salmon entered tributaries. Annual harvest in or downstream from John Day reservoir averaged ≤1% for spring–summer Chinook salmon and sockeye salmon, ~10% for fall Chinook salmon, and ~3% for steelhead. Unaccounted for rates averaged 2-7% per run (Figure 62).

Of the fish that did not pass McNary Dam, 49% of spring–summer Chinook salmon, 40% of steelhead, 8% of fall Chinook salmon, and 1 sockeye salmon were last detected in reach tributaries or in tributaries or hatcheries downstream from John Day Dam (Table 47). Reported main stem harvest of the non-passers ranged from 17% (spring–summer Chinook salmon) to 62% (fall Chinook salmon). The remaining non-passers were unaccounted for in each run: 35% (spring–summer Chinook salmon), 31% (fall Chinook salmon), 82% (sockeye salmon), and 33% (steelhead).

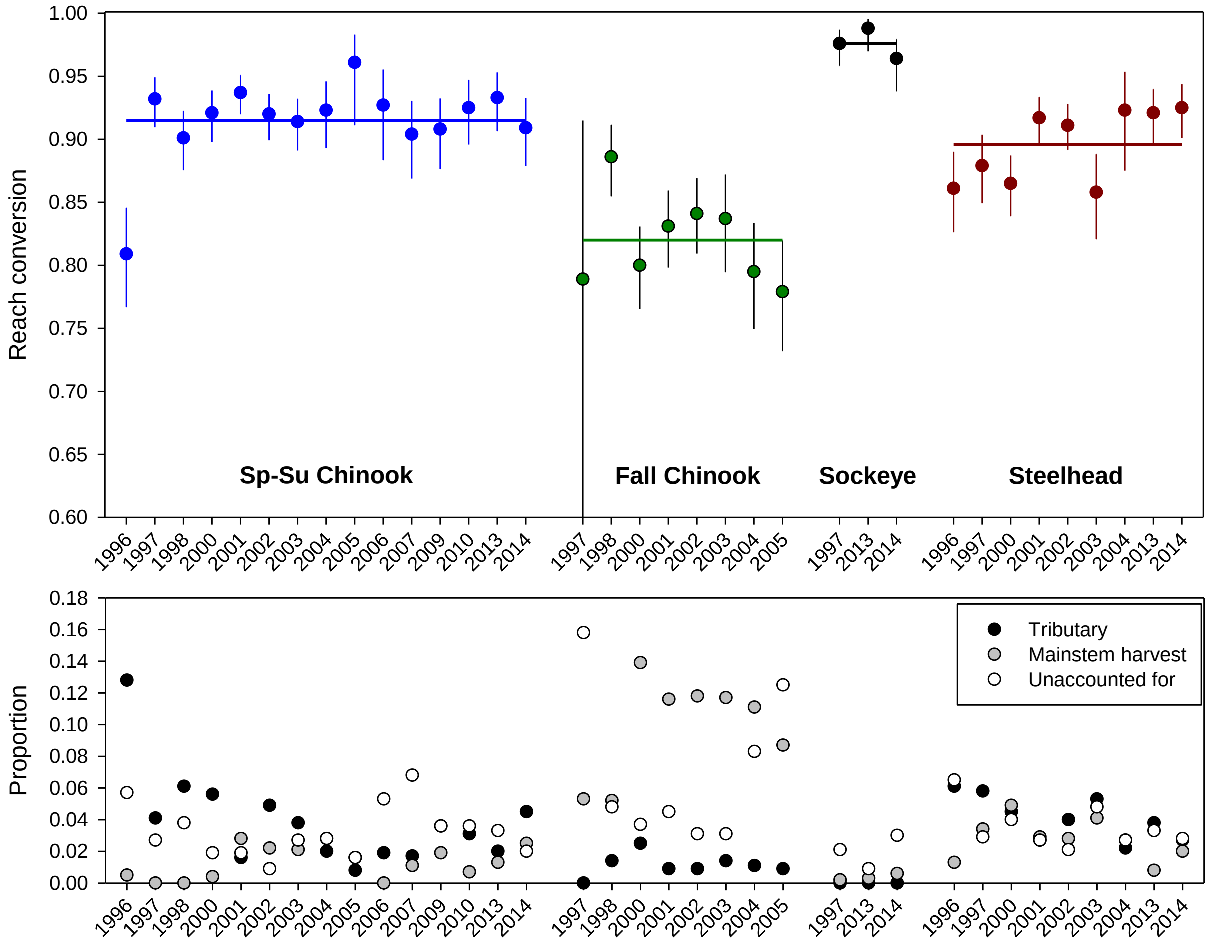


Figure 62. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of John Day Dam past McNary Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream.

Table 47. Estimated fates of radio-tagged salmon and steelhead that passed John Day Dam but did not pass McNary Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**666**	**-**	**567**	**-**	**27**	**-**	**560**	**-**
Tributary / Hatchery	**323**	**48.5**	**43**	**7.6**	**[1]1**	**3.7**	**222**	**39.6**
Sandy	*2*	*0.3*						
Tanner Creek/BON H			*1*	*0.2*				
Wind	*2*	*0.3*						
Little White Salmon	*3*	*0.5*	*2*	*0.4*			*1*	*0.2*
White Salmon			*4*	*0.7*				
Hood	*2*	*0.3*	*1*	*0.2*			*1*	*0.2*
Klickitat	*15*	*2.3*	*6*	*1.1*	*1*	*3.7*	*3*	*0.5*
Deschutes	*25*	*3.8*	*10*	*1.8*			*22*	*3.9*
John Day	212	31.8	5	0.9			151	27.0
Rock Creek			1	0.2			4	0.7
Umatilla	62	9.3	13	2.3			40	7.1
Fishery	**112**	**16.8**	**350**	**61.7**	**4**	**14.8**	**155**	**27.7**
Below John Day	*19*	*2.9*	*7*	*1.2*			*13*	*2.3*
John Day reservoir	87	13.1	341	60.1	4	14.8	138	24.6
McNary tailrace	6	0.9	2	0.4			4	0.7
Unaccounted for	**231**	**34.7**	**174**	**30.7**	**22**	**81.5**	**183**	**32.7**
Below John Day	*62*	*9.3*	*30*	*5.3*			*45*	*8.0*
John Day top	79	11.9	48	8.5	4	14.8	57	10.2
John Day reservoir	30	4.5	66	11.6			58	10.4
McNary tailrace	60	9.0	30	5.3	18	66.7	23	4.1
Found dead	-	-	-	-	-	-	-	-

[1] Sockeye salmon in tributaries considered unsuccessful

6.6.5 MCNARY RESERVOIR REACH

The McNary reservoir reach is distinctive among FCRPS study reaches as it includes the Snake River confluence. The upper end of the reservoir is near Ice Harbor Dam (~68 km upstream from McNary Dam) on the Snake River as well as in the lower end of the Hanford Reach in the Columbia River upstream from the Snake River confluence. Conversion in the McNary reservoir reach included fish that passed Ice Harbor Dam as well as those detected at or upstream from the radio antennas used to monitor the Hanford Reach. The McNary reach has limited fisheries relative to other lower Columbia River reaches, but includes two major tributaries (Walla Walla and Yakima rivers). Conversion estimates through the McNary reach were, on average, 88% for spring–summer Chinook salmon, 84% for fall Chinook salmon, 94% for sockeye salmon, and 91% for steelhead (Figure 63). Tributary entry averaged 9% for spring–summer and fall Chinook salmon and 5% for steelhead; no sockeye salmon entered tributaries. Annual harvest in McNary reservoir averaged ≤1% for spring–summer and fall Chinook salmon and steelhead and averaged 6% for sockeye salmon. Unaccounted for rates averaged 0-7% per run (Figure 63).

Of the fish that did not pass Ice Harbor Dam or enter the Hanford reach, 80% of spring–summer Chinook salmon, 60% of fall Chinook salmon, 47% of steelhead, and 2 sockeye salmon were last detected in reach tributaries or in tributaries or hatcheries downstream from McNary Dam (Table 48). Reported main stem harvest of the non-passers was <2% for all runs except steelhead (harvest ~15%). The remaining non-passers were unaccounted for in each run: 18% (spring–summer Chinook salmon), 38% (fall Chinook salmon), 97% (sockeye salmon), and 38% (steelhead).

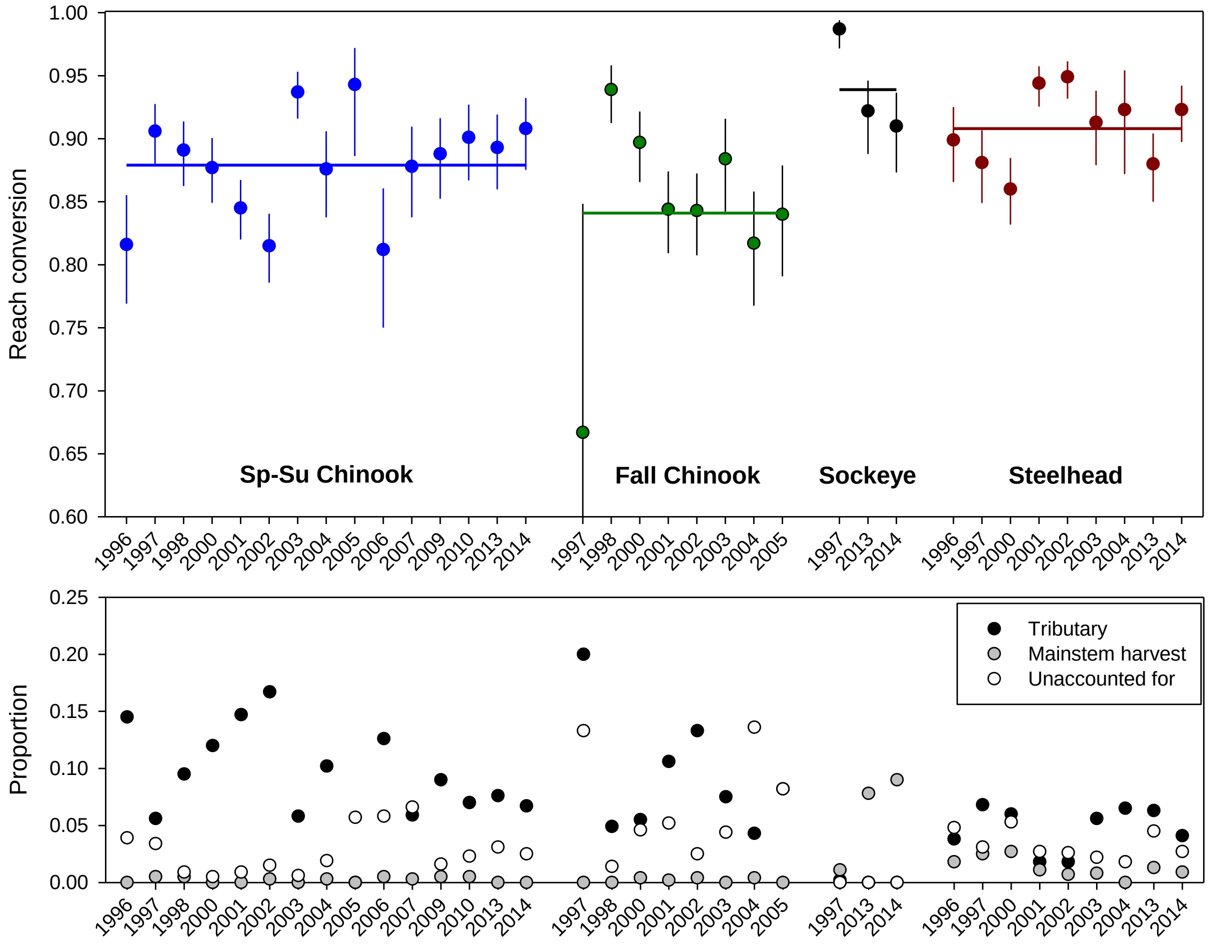


Figure 63. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of McNary Dam through the McNary reservoir, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream.

Table 48. Estimated fates of radio-tagged salmon and steelhead that passed McNary Dam but did not pass Ice Harbor dam or into the Columbia River Hanford Reach, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**875**	**-**	**365**	**-**	**61**	**-**	**440**	**-**
Tributary / Hatchery	**701**	**80.1**	**219**	**60.0**	**2**	**3.3**	**208**	**47.3**
Cowlitz	*1*	*0.1*						
White Salmon			*1*	*0.3*			*1*	*0.2*
Hood								
Klickitat	*6*	*0.7*	*2*	*0.5*			*2*	*0.5*
Deschutes	*11*	*1.3*	*7*	*1.9*			*10*	*2.3*
John Day	*12*	*1.4*					*83*	*18.9*
Umatilla	*68*	*7.8*	*15*	*4.1*			*17*	*3.9*
Walla Walla	8	0.9	2	0.5			44	10.0
Yakima	595	68.0	192	52.6	2[1]	3.3	50	11.4
Fishery	**16**	**1.8**	**6**	**1.6**	**-**	**-**	**67**	**15.2**
Below McNary	*12*	*1.4*	*6*	*1.6*			*18*	*4.1*
McNary reservoir	4	0.5					49	11.1
Ice Harbor tailrace								
Unaccounted for	**158**	**18.1**	**139**	**38.1**	**59**	**96.7**	**165**	**37.5**
Below McNary	*50*	*5.7*	*19*	*5.2*	*7*	*11.5*	*54*	*12.3*
McNary top	78	8.9	113	31.0	51	83.6	66	15.0
McNary reservoir	9	1.0	3	0.8			35	8.0
Ice Harbor tailrace	21	2.4	4	1.1	1	1.6	10	2.3
Found dead	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

[1] Sockeye salmon in tributaries considered unsuccessful

6.6.6 ICE HARBOR TOP TO PASS LOWER MONUMENTAL

The Ice Harbor reservoir reach (~51 km long) has limited fisheries and no major tributaries or hatcheries. Conversion estimates through the Ice Harbor reach were, on average, 99% for spring–summer Chinook salmon, 95% for fall Chinook salmon, and 97% for steelhead (Figure 64). No estimates were made for sockeye salmon through the lower Snake River reaches due to small sample size. A few (~3%, on average) fall Chinook salmon were last recorded in downstream tributaries, including the Hanford reach. Annual harvest in or downstream from Ice Harbor reservoir averaged ≤1% for spring–summer and fall Chinook salmon and steelhead. Unaccounted for rates averaged 1-2% per run (Figure 64).

Of the fish that did not pass Lower Monumental Dam, 33% of spring–summer Chinook salmon, 68% of fall Chinook salmon, and 16% of steelhead were last detected in tributaries or hatcheries downstream from Ice Harbor Dam (Table 49). Reported main stem harvest of the non-passers was 0% for all runs except steelhead (harvest ~26%). The remaining non-passers were unaccounted for in each run: 67% (spring–summer Chinook salmon), 32% (fall Chinook salmon), and 60% (steelhead).

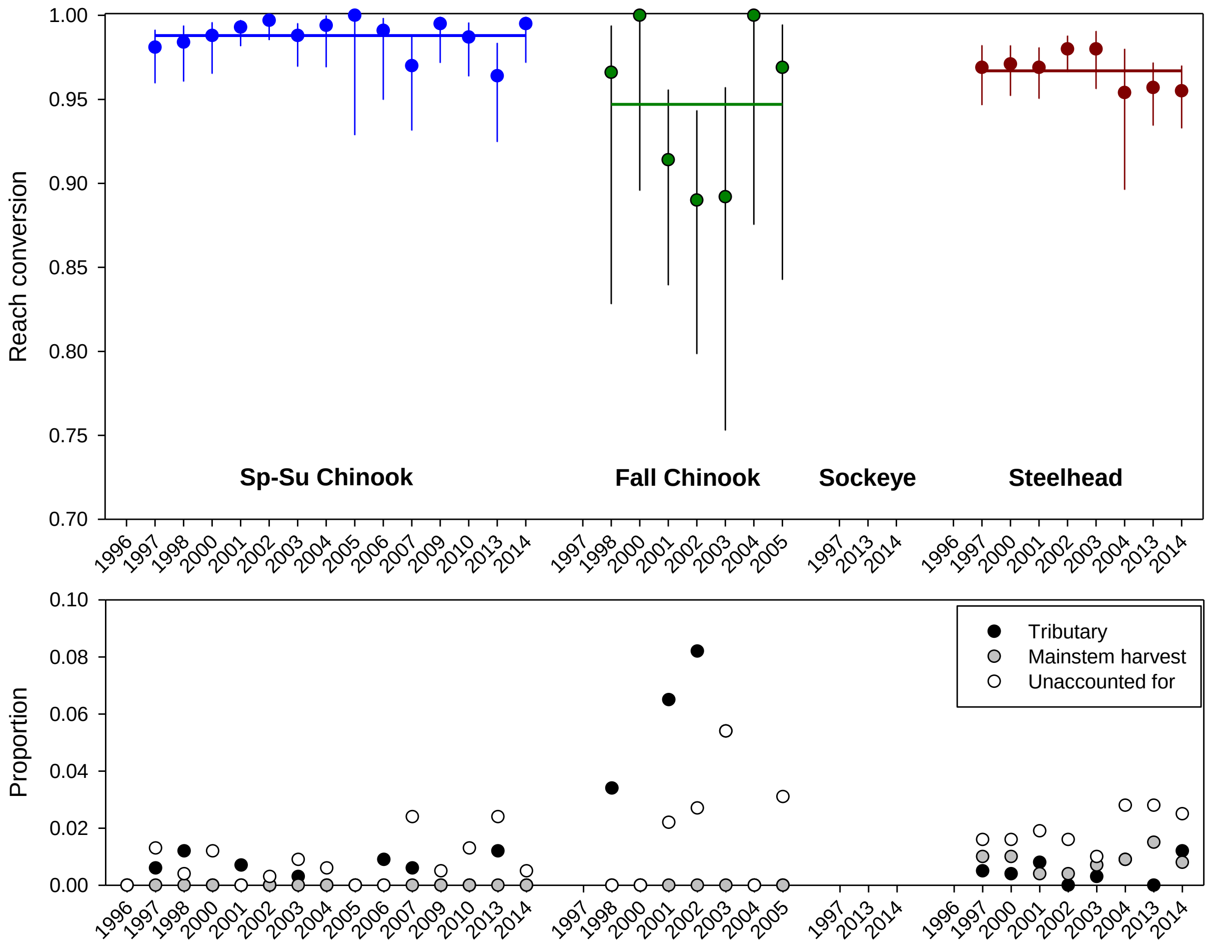


Figure 64. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of Ice Harbor Dam past Lower Monumental Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream. (Notes: Lower Monumental Dam was not monitored in parts of 1996 and 1997; sockeye salmon were excluded in all years due to small sample sizes.)

Table 49. Estimated fates of radio-tagged salmon and steelhead that passed Ice Harbor Dam but did not pass Lower Monumental Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**43**	**-**	**22**	**-**	**2**	**-**	**110**	**-**
Tributary / Hatchery	**14**	**32.6**	**15**	**68.2**	**-**	**-**	**17**	**15.5**
Klickitat			*1*					
Deschutes	*1*	*2.3*						
John Day							*8*	*7.3*
Umatilla	*5*	*11.6*	*4*				*2*	*1.8*
Walla Walla	*1*	*2.3*	*1*				*5*	*4.5*
Yakima	*7*	*16.3*	*6*				*1*	*0.9*
Hanford Reach			*3*				*1*	*0.9*
Fishery	**-**	**-**	**-**	**-**	**-**	**-**	**28**	**25.5**
Below Ice Harbor							*3*	*2.7*
Ice Harbor reservoir							25	22.7
L. Monum. tailrace								
Unaccounted for	**29**	**67.4**	**7**	**31.8**	**2**	**100.0**	**6**	**59.9**
Below Ice Harbor	*16*	*37.2*	*2*		*1*	*50.0*	*19*	*17.3*
Ice Harbor top	6	14.0					31	28.2
Ice Harbor reservoir	1	2.3	4				7	6.4
L. Monum. tailrace	6	14.0	1		1	50.0	8	7.3
Found dead	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

6.6.7 LOWER MONUMENTAL TOP TO PASS LITTLE GOOSE

The Lower Monumental reservoir reach (~46 km long) has limited fisheries, but includes the Tucannon River and Lyons Ferry Hatchery. Conversion estimates through the Lower Monumental reach were, on average, 98% for spring–summer Chinook salmon, 88% for fall Chinook salmon, and 96% for steelhead (Figure 65). About 9%, on average, of fall Chinook salmon were last recorded in Lyons Ferry Hatchery or in downstream tributaries and ~1% of spring–summer Chinook salmon and steelhead entered the hatchery, the Tucannon River, or downstream tributaries or hatcheries. Annual harvest in or downstream from Lower Monumental reservoir averaged ≤1% for spring–summer and fall Chinook salmon and steelhead. Unaccounted for rates averaged 1-2% per run (Figure 65).

Of the fish that did not pass Little Goose Dam, 39% of spring–summer Chinook salmon, 89% of fall Chinook salmon, and 35% of steelhead were last detected in tributaries or hatcheries in the reach or downstream from Lower Monumental Dam (Table 50). Reported main stem harvest of the non-passers was 14% for spring–summer Chinook salmon, 0% for fall Chinook salmon, and 24% for steelhead. The remaining non-passers were unaccounted for in each run: 47% (spring–summer Chinook salmon), 11% (fall Chinook salmon), and 41% (steelhead).

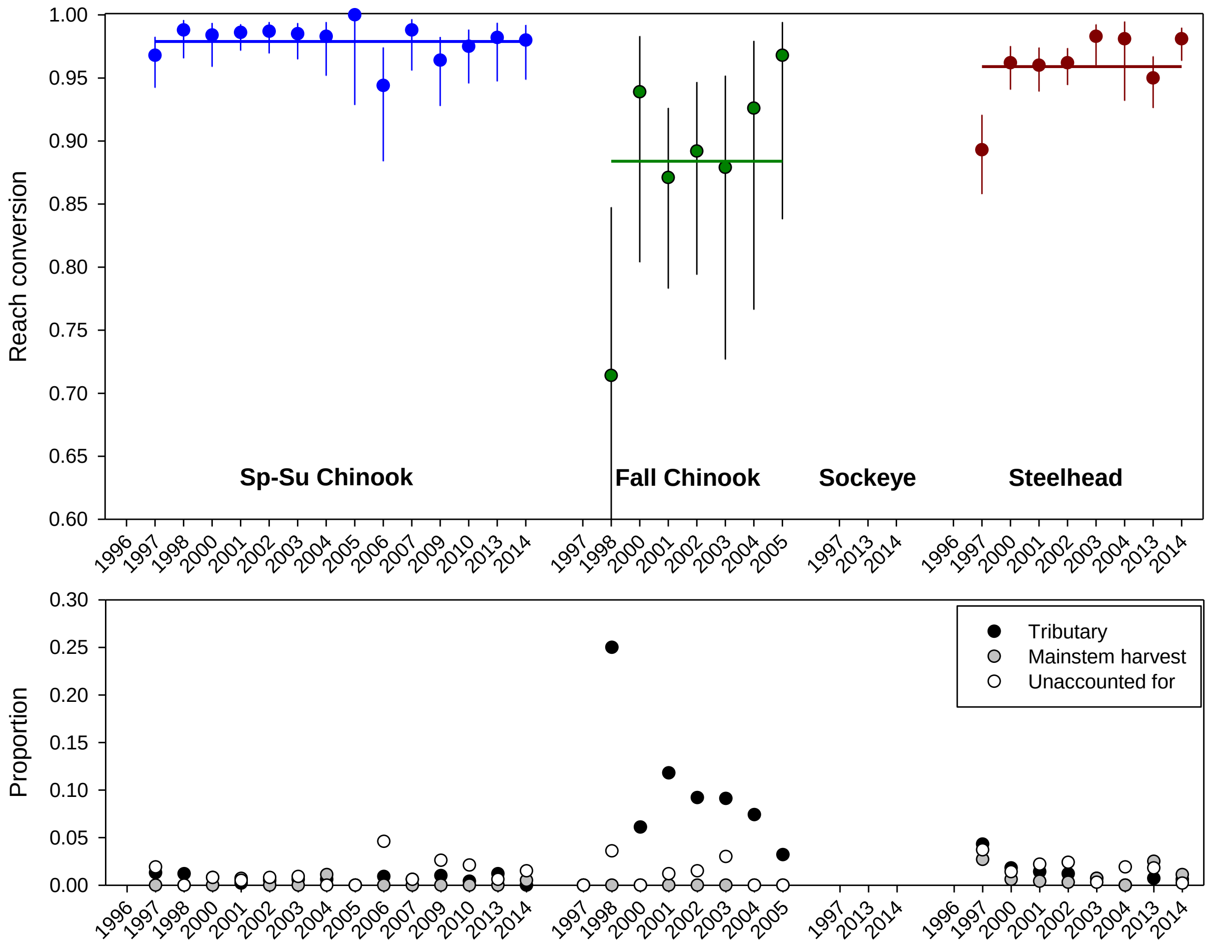


Figure 65. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of Lower Monumental Dam past Little Goose Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream. (Notes: Lower Monumental and Little Goose dams were not monitored in parts of 1996 and 1997; sockeye salmon were excluded in all years due to small sample sizes.)

Table 50. Estimated fates of radio-tagged salmon and steelhead that passed Lower Monumental Dam but did not pass Little Goose Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**78**	**-**	**35**	**-**	**-**	**-**	**144**	**-**
Tributary / Hatchery	**30**	**38.5**	**31**	**88.6**	**-**	**-**	**50**	**34.7**
Wind	*1*	*1.3*						
John Day	*1*	*1.3*					*1*	*0.7*
Umatilla	*3*	*3.8*	*2*	*5.7*			*1*	*0.7*
Walla Walla							*4*	*2.8*
Hanford Reach			*1*	*2.9*			*1*	*0.7*
Wenatchee	*1*	*1.3*						
Lyons Ferry Hatchery	3	3.8	28	80.0			23	16.0
Palouse							1	0.7
Tucannon	21	26.9					19	13.2
Fishery	**11**	**14.1**	**-**	**-**	**-**	**-**	**35**	**24.3**
Below L. Monumental							*2*	*1.4*
L. Monum. reservoir							13	9.0
L. Goose tailrace	11	14.1					21	14.6
Unaccounted for	**37**	**47.4**	**4**	**11.4**	**-**	**-**	**59**	**41.0**
Below L. Monumental	*14*	*17.9*	*1*	*2.9*			*20*	*13.9*
L. Monum. top	8	10.3	1	2.9			10	6.9
L. Monum. reservoir	1	1.3	2	5.7			17	11.8
L. Goose tailrace	14	17.9					12	8.3
Found dead	-	-	-	-	-	-	-	-

6.6.8 LITTLE GOOSE TOP TO PASS LOWER GRANITE

The Little Goose reservoir reach (~60 km long) has limited fisheries and no major tributaries or hatcheries. Conversion estimates through the Little Goose reach were, on average, 98% for spring–summer Chinook salmon, 74% for fall Chinook salmon, and 95% for steelhead (Figure 66). Note that fish transported from Lower Granite trap to Lyons Ferry Hatchery were treated as not passing Lower Granite Dam for this summary. About 17%, on average, of fall Chinook salmon were transported to or last recorded in Lyons Ferry Hatchery or in downstream tributaries and ~1% of spring–summer Chinook salmon and steelhead also entered downstream tributaries or hatcheries. Annual harvest in or downstream from Lower Monumental reservoir averaged ≤1% for all runs. Unaccounted for rates averaged 2-6% per run (Figure 66).

Of the fish that did not pass Lower Granite Dam, 43% of spring–summer Chinook salmon, 89% of fall Chinook salmon, and 55% of steelhead were last detected or in tributaries or hatcheries downstream from Lower Granite Dam, including transport from Lower Granite trap to Lyons Ferry Hatchery (Table 51). Reported main stem harvest of the non-passers was 1% for spring–

summer Chinook salmon, 0% for fall Chinook salmon, and 12% for steelhead. The remaining non-passers were unaccounted for in each run: 46% (spring–summer Chinook salmon), 10% (fall Chinook salmon), and 32% (steelhead).

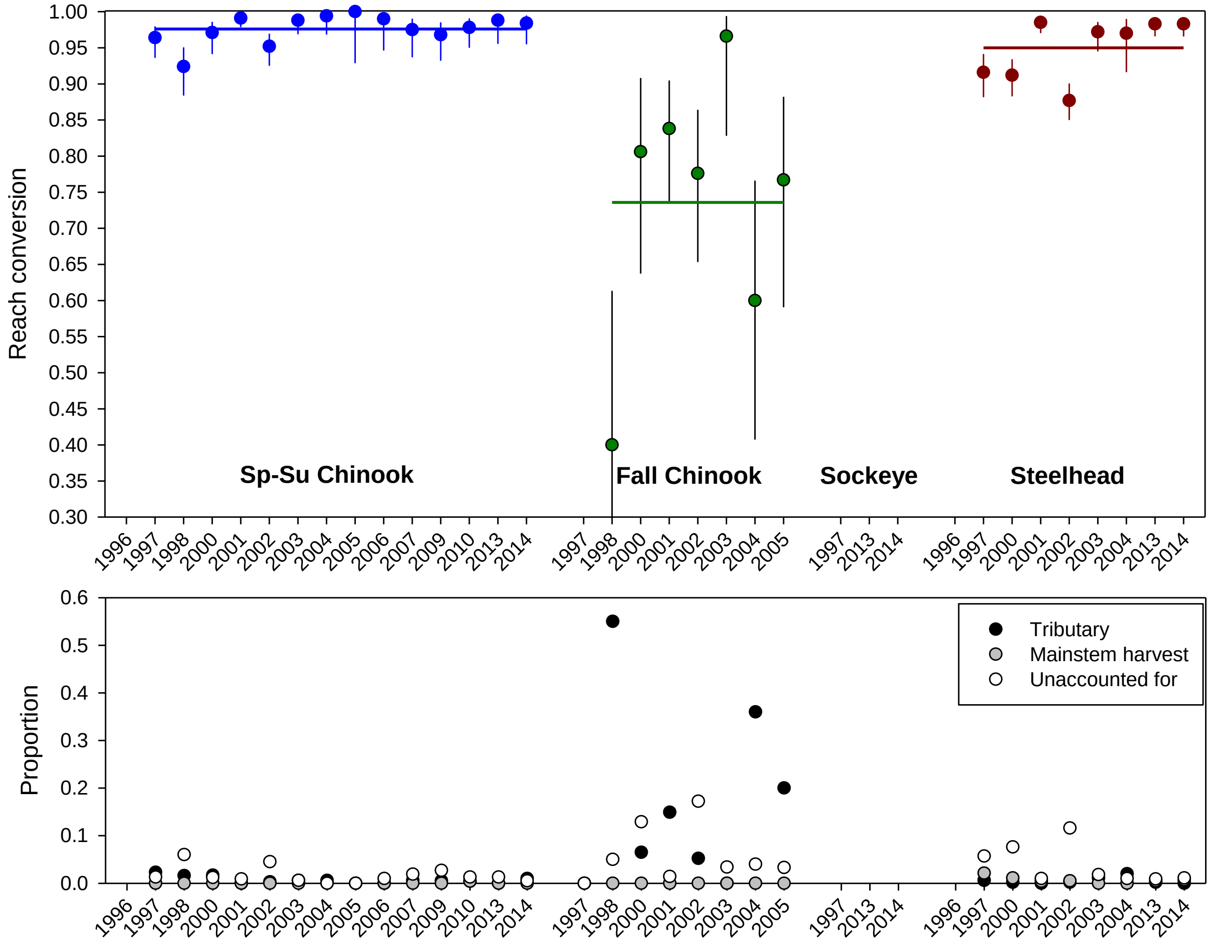


Figure 66. Top: Annual point estimates and 95% confidence intervals of adult salmon and steelhead conversion from the top of Little Goose Dam past Lower Granite Dam, by species and run, 1996-2014. Bottom: proportions of each annual sample that were last recorded in downstream tributaries, reported as downstream main stem harvest, or were unaccounted for downstream. (Notes: Little Goose Dam was not monitored in parts of 1996 and 1997; sockeye salmon were excluded in all years due to small sample sizes.)

Table 51. Estimated fates of radio-tagged salmon and steelhead that passed Little Goose Dam but did not pass Lower Granite Dam, by species and run, 1996-2014.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Did not pass	**94**	**-**	**61**	**-**	**-**	**-**	**183**	
Tributary / Hatchery	**40**	**42.6**	**54**	**88.5**	**-**	**-**	**101**	**55.2**
Wind								
Klickitat								
Deschutes	*1*	*1.1*						
John Day	*1*	*1.1*					*2*	*1.1*
Umatilla	*4*	*4.3*						
Walla Walla								
Yakima	*1*	*1.1*	*1*	*1.6*				
Hanford Reach			*1*	*1.6*			*1*	*0.5*
Priest Rapids Hatch.			*1*	*1.6*				
Wenatchee								
Lyons Ferry Hatchery	*1*	*1.1*	*8*	*13.1*			*3*	*1.6*
Tucannon	*9*						*5*	*2.7*
L. Granite trap[1]	23	24.5	43	70.5			90	49.2
Fishery	**1**	**1.1**	**-**	**-**	**-**	**-**	**22**	**12.0**
Below L. Goose							*3*	*1.6*
L. Goose reservoir	1	1.1					17	9.3
L. Granite tailrace							2	1.1
Unaccounted for	**53**	**56.4**	**6**	**9.8**	**-**	**-**	**59**	**32.2**
Below L. Goose	*11*	*11.7*	*3*	*4.9*			*28*	*15.3*
L. Goose top	3	3.2	1	1.6			7	3.8
L. Goose reservoir	4	4.3					7	3.8
L. Granite tailrace	35	37.2	2	3.3			17	9.3
Found dead	**-**	**-**	**1**	**1.6**	**-**	**-**	**1**	**0.5**

[1] includes transfers from Lower Granite trap to hatcheries

6.6.9 REACH CONVERSION FATES SUMMARY

The summary figures in this section present the same annual data as in Sections 6.6.1-6.6.8, but as box plots so that relative among-reach differences can be assessed. The figures show unadjusted reach conversion estimates (Figure 67), tributary and hatchery entry in or downstream from the reach (Figure 68), reported main stem harvest in or downstream from the reach (Figure 69), and the fish that were unaccounted for in or downstream from the reach (Figure 70).

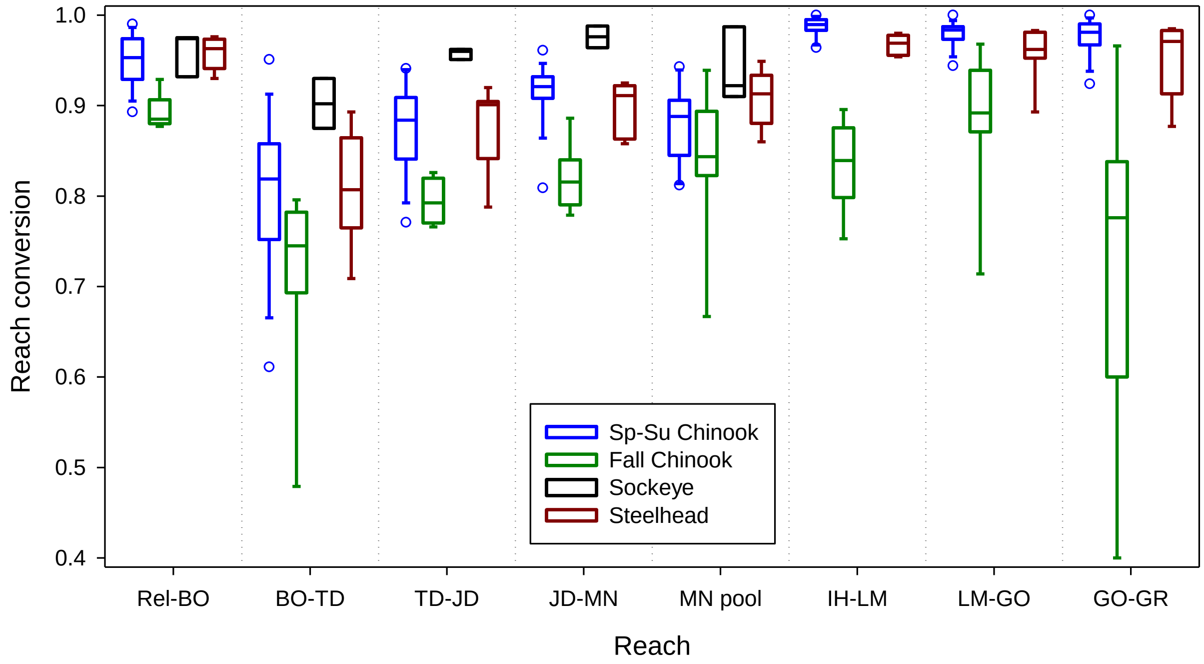


Figure 67. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual reach conversion estimates, by species and run, 1996-2014. Reaches are ordered from downstream to upstream. Rel = release downstream from Bonneville Dam.

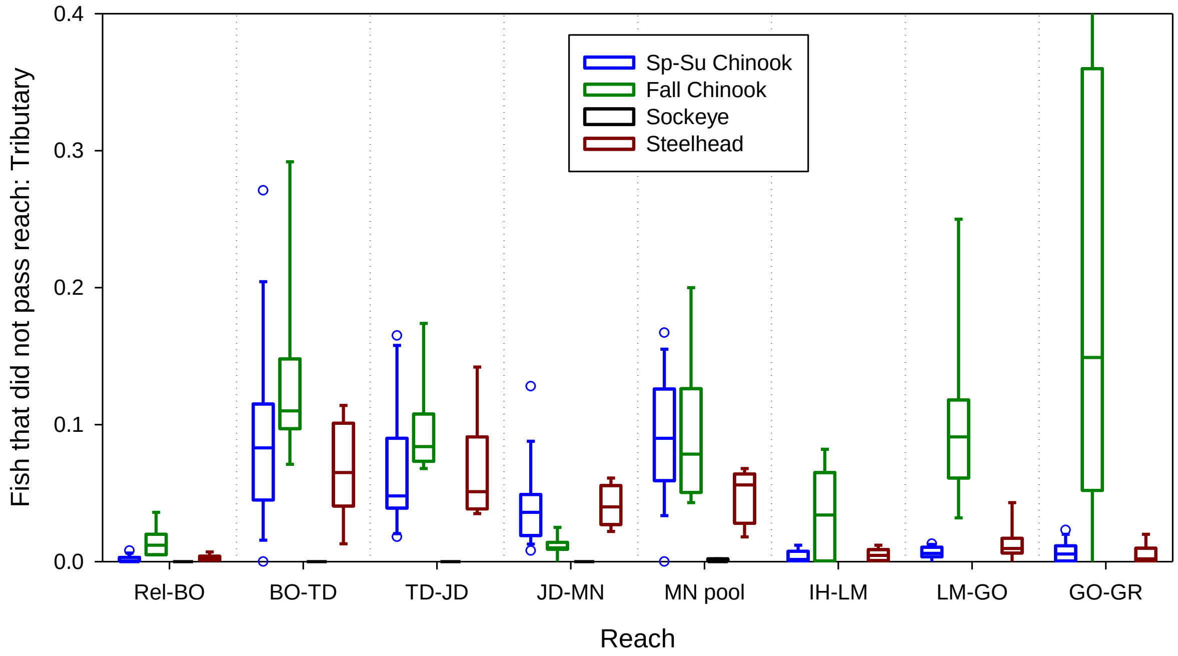


Figure 68. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of **an**nual proportions of fish last recorded in reach tributaries or in downstream tributaries, by species and run, 1996-2014. Reaches are ordered from downstream to upstream. Rel = release downstream from Bonneville Dam.

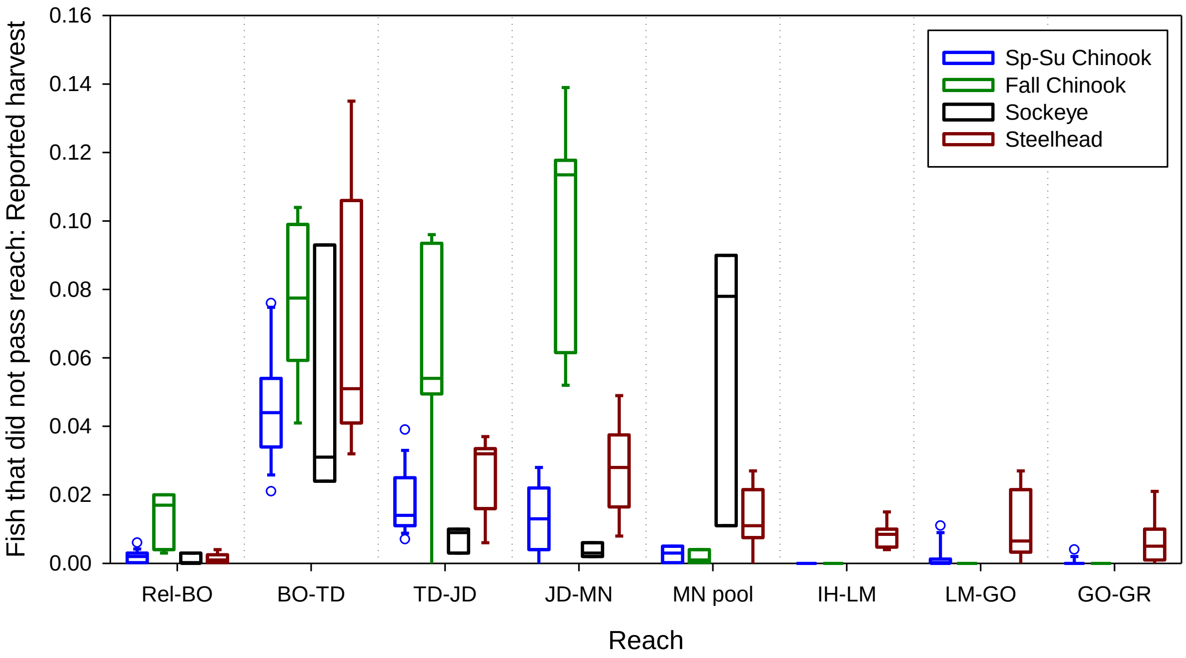


Figure 69. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual proportions of fish reported in reach or downstream fisheries, by species and run, 1996-2014. Reaches are ordered from downstream to upstream. Rel = release downstream from Bonneville Dam.

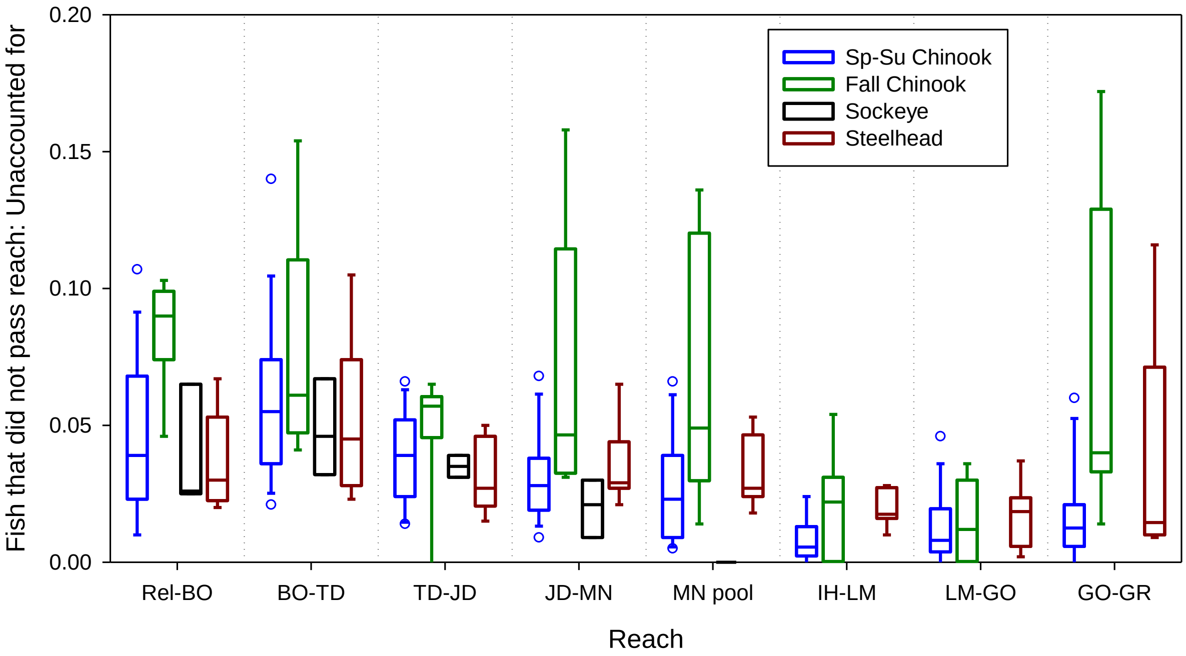


Figure 70. Box plots (5th, 10th, 25th, 50th, 75th, 90th, 95th percentiles) of annual proportions of fish that were unaccounted for in or downstream from reach, by species and run, 1996-2014. Reaches are ordered from downstream to upstream. Rel = release downstream from Bonneville Dam.

6.7 FINAL DISTRIBUTION OF RADIO-TAGGED FISH

Table 52 includes the estimated final distribution of all radio-tagged fish, arranged within four basic categories: (1) tributary or hatchery; (2) in a FCRPS dam tailrace; (3) at a FCRPS dam; and (4) in a FCRPS reservoir. Location assignments were based on all available radiotelemetry, PIT-detection, reported harvest, and transmitter recovery data accumulated during the study. All presumed post-spawn data (e.g., for steelhead kelts) were excluded. Some sites, including the Columbia River Hanford reach, were potentially ambiguous with respect to tributary assignment (e.g., fall Chinook salmon and some steelhead spawn in the Hanford reach, but some spring–summer Chinook salmon and sockeye salmon were last recorded there; the latter fish were likely non-spawners). Similarly, sockeye salmon were last recorded in several lower Columbia River tributaries where there is no known sockeye salmon spawning. Site assignments were independent of fish fate. For example, fish last detected in a reservoir included those reported harvested as well as those with unknown fate. Similarly, fish assigned to tributaries included those that were harvested, that entered hatcheries, that were detected on radio or PIT antennas, and those that were recovered in spawning ground surveys.

Table 52. Final detection locations of radio-tagged salmon and steelhead, by species and run, 1996-2014. The ‘Tributary / Hatchery’ category was organized by watersheds that directly entered hatcheries adjacent to the Columbia or Snake River main stem (additional sub-basin and hatchery details are available in the FATE databases). The ‘At a Dam’ category included fish last detected at underwater radiotelemetry antennas at or inside fishways (including fishway exit sites) and those last detected at fishway PIT-tag antennas. The ‘In a Tailrace’ and ‘In a Reservoir’ categories included fish with final radiotelemetry detections and fish reported harvested at those sites. Blue-shaded cells denote ≥2% of the total sample.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Total release	**12,145**	**-**	**6,134**	**-**	**1,375**	**-**	**7,832**	**-**
Tributary / Hatchery	**7,464**	**61.46**	**3,258**	**53.11**	**876**	**63.71**	**4,471**	**57.09**
Non-Columbia	3	0.02						
Cowlitz	2	0.02	6	0.10				
Kalama							1	0.01
Lewis	5	0.04	8	0.13			1	0.01
Willamette	5	0.04	3	0.05			5	0.06
Washougal	1	0.01	3	0.05			3	0.04
Sandy	17	0.14	8	0.13			8	0.10
Tanner Creek/BON H			94	1.53			3	0.03
Eagle Cr	4	0.03	6	0.10				
Rock Cr	10	0.08	1	0.02				
Herman Cr	2	0.02	17	0.28			17	0.22
Wind	625	5.15	27	0.44	1	0.07	54	0.69
Little White Salmon	357	2.94	184	3.00	5	0.36	122	1.56
Spring Creek Hatch.			62	1.01			1	0.01
White Salmon	47	0.39	121	1.97	5	0.36	71	0.91
Hood	56	0.46	18	0.29	5	0.36	55	0.70

Table 52 Continued.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
Tributary / Hatchery								
Klickitat	174	1.43	293	4.78			156	1.99
Fifteenmile Cr	2	0.02					1	0.01
Deschutes	586	4.83	231	3.77			412	5.26
John Day	226	1.86	5	0.08			246	3.14
Rock Cr							5	0.06
Umatilla	148	1.22	34	0.55			60	0.77
Walla Walla	9	0.07	3	0.05			57	0.73
Lyons Ferry Hatchery	4	0.03	42	0.68			34	0.43
Palouse							1	0.01
Tucannon	35	0.29					41	0.52
Clearwater	724	5.96	84	1.37			1,228	15.68
Snake above LGr	240	1.98	82	1.34	1	0.07	474	6.05
Asotin Cr							4	0.05
Grande Ronde	178	1.47	3	0.05			269	3.43
Salmon	1,826	15.03	1	0.02	2	0.15	803	10.25
Imnaha	199	1.64	1	0.02			43	0.55
Hells Canyon Dam	37	0.30	2	0.03			42	0.54
Oxbow Hatchery							4	0.05
Yakima	603	4.97	199	3.24	2	0.15	50	0.64
Hanford Reach	58	0.48	1,449	23.62	12	0.87	90	1.15
Ringold Hatchery	56	0.46	9	0.15			1	0.01
Near Ringold H	32	0.26						
Priest Rapids Hatchery	3	0.02	248	4.04			1	0.01
Wenatchee	677	5.57	7	0.11	327	23.79	32	0.41
Entiat	48	0.40			3	0.22	6	0.08
Chelan	5	0.04	2	0.03				
Wells Hatchery	102	0.84					14	0.18
Methow	158	1.30	4	0.07	4	0.29	36	0.46
Okanogan	185	1.52	1	0.02	506	36.80	18	0.23
Chief Joseph Hatchery	15	0.12			3	0.22		
Foster Cr							1	0.01
In a Tailrace	**897**	**7.39**	**498**	**8.12**	**100**	**7.27**	**569**	**7.27**
Bonneville	268	2.21	212	3.46	18	1.31	114	1.46
The Dalles	193	1.59	96	1.57	36	2.62	133	1.70
John Day	155	1.28	128	2.09	12	0.87	117	1.49
McNary	60	0.49	30	0.49	14	1.02	47	0.60
Ice Harbor	26	0.21	5	0.08			38	0.49
Lower Monumental	16	0.13	3	0.05			14	0.18
Little Goose	27	0.22					47	0.60
Lower Granite	20	0.16	5	0.08			24	0.31
Priest Rapids	21	0.17	13	0.21	11	0.80	1	0.01
Wanapum	1	0.01	2	0.03	1	0.07		
Rock Island	-	-			8	0.58		
Rocky Reach	2	0.02						
Wells	51	0.42	2	0.03			5	0.06

Table 52 Continued.

	Sp-Su Chinook		Fall Chinook		Sockeye		Steelhead	
	n	%	*N*	%	*n*	%	*n*	%
In a Tailrace								
Chief Joseph	57	0.47	2	0.03			29	0.37
At a Dam	**2,198**	**18.10**	**627**	**10.22**	**260**	**18.91**	**1,143**	**14.59**
Bonneville	179	1.47	73	1.19	23	1.67	115	1.47
The Dalles	108	0.89	25	0.41	5	0.36	26	0.33
John Day	97	0.80	64	1.04	9	0.65	78	1.00
McNary	115	0.95	123	2.01	61	4.44	88	1.12
Ice Harbor	16	0.13			2	0.15	49	0.63
Lower Monumental	11	0.09	1	0.02	1	0.07	14	0.18
Little Goose	8	0.7	1	0.02			11	0.14
Lower Granite	404	3.33	62	1.01	1	0.07	376	4.80
Priest Rapids	227	1.87	155	2.53	43	3.13	167	2.13
Wanapum	30	0.25	11	0.18	4	0.29	4	0.05
Rock Island	184	1.52	24	0.39	9	0.65	23	0.29
Rocky Reach	257	2.12	53	0.86	13	0.95	89	1.14
Wells	562	4.63	35	0.57	89	6.47	103	1.32
In a Reservoir	**1,317**	**10.84**	**1,437**	**23.43**	**102**	**7.42**	**1,455**	**18.58**
Bonneville	828	6.82	688	11.22	70	5.07	702	8.96
The Dalles	223	1.84	307	5.00	17	1.24	178	2.27
John Day	130	1.07	420	6.85	4	0.29	229	2.92
McNary	13	0.11	4	0.07			90	1.15
Ice Harbor	1	0.01	6	0.10			42	0.54
Lower Monumental	2	0.02	3	0.05			53	0.68
Little Goose	7	0.06	3	0.05			33	0.42
Lower Granite	2	0.02	1	0.02			92	1.17
Priest Rapids	3	0.02	1	0.02				
Wanapum	-	-	3	0.05			1	0.01
Rock Island	12	0.10					1	0.01
Rocky Reach	51	0.42			1	0.07	13	0.16
Wells	45	0.37	1	0.02	10	0.73	21	0.27
Release / main stem	**269**	**2.21**	**313**	**5.10**	**37**	**2.69**	**194**	**2.48**
Release site	181	1.49	156	2.54	36	2.62	90	1.15
Below release site	88	0.72	157	2.56	1	0.07	104	1.33