Technical Report 2004-10

MIGRATION OF ADULT SOCKEYE SALMON PAST COLUMBIA RIVER DAMS, THROUGH RESERVOIRS AND DISTRIBUTION INTO TRIBUTARIES, 1997

A report for Project MPE-P-95-1

by

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Preface

Recent studies of adult salmon and steelhead migrations past dams, through reservoirs, and into tributaries with radio telemetry began in 1990 with planning, purchase and installation of equipment for studies at the Snake River dams. Adult spring and summer chinook salmon were outfitted with transmitters at Ice Harbor Dam in 1991 and 1992, at John Day Dam in 1993 and reports of those studies are available (Bjornn et al. 1992; 1994; 1995; 1998; 1999; 2003). The focus of adult salmon passage studies was shifted to the lower Columbia River dams in 1995 when telemetry equipment was set up at the dams and in tributaries. In this report we present information on the overall migration of sockeye salmon from release, past each of the dams in the Columbia River and into tributaries in 1997.

Acknowledgments

Many people assisted in the field work and data compilation for this project and the successful completion was made possible by Bob Dach and Teri Barila, the Corps of Engineers project officers at the time. Michelle Feeley, Brian Hastings, Megan Heinrich, Steve Lee, Mark Morasch and Jay Nance assisted in project operations and data processing and analysis.

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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 r^2 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.

Introduction

Studies of the passage of adult salmon *Oncorhynchus spp.* and steelhead *O. mykiss* at the lower Columbia River dams began in 1995 with the setup of radio telemetry equipment, and fish were outfitted with transmitters in 1996, 1997, 1998, 2000, 2001, and 2002. In this report, we present information on passage of sockeye salmon at each of the dams, beginning with Bonneville Dam, and their migrations through reservoirs and into monitored tributaries throughout the basin in 1997. Sockeye salmon were only tagged during 1997. As in the previous studies, radio telemetry was used to monitor salmon movements at dams, up the rivers, and into tributaries.

The study described herein was undertaken because of concerns of the U.S. Army Corps of Engineers (Corps), state and federal fish agencies and tribes, those expressed in section 603 of the Northwest Power Planning Council's (NPPC) 1987 Columbia River Basin Fish and Wildlife Program, and later reflected in the Biological Opinion on 1994-1998 operation of the Federal Columbia River Power System, that studies were needed to ensure that passage of adult salmon and steelhead past the dams and through the reservoirs was as efficient as possible.

Study plans were developed in consultation with Corps personnel, and with biologists in other federal, state, and tribal fish agencies. Public utility districts (PUDs) for Chelan and Douglas counties supplied one-third of the radio tags and maintained receiver sites at Rock Island, Rocky Reach and Wells dams. Research was conducted by personnel of the Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) and NOAA's National Marine Fisheries Service with logistical support, cooperation, and funding from the Corps, Bonneville Power Administration, US Geological Survey and PUDs.

We set up receivers/antennas in 1997 at dams and tributaries in the lower Columbia River, at Priest Rapids and Wanapum dams on the mid-Columbia River, at lower Snake River dams, at the lower end of the Clearwater River and Snake River near Asotin, WA, and at selected tributaries to the Clearwater and Salmon rivers (Figure 1). Receivers and antennas at mid-Columbia River dams and tributaries upstream from Wanapum Dam were maintained by LGL Limited Environmental Associates for the Public Utility Districts of Douglas and Chelan counties (Alexander et al. 1998; English et al. 1998). LGL Limited also monitored radio-tagged fish in mid-Columbia River tributaries.

Fish with transmitters returned to tributaries, dams, traps, and hatcheries upriver from the uppermost fixed telemetry sites, and we used recaptures of those fish and data from mobile tracking to gain information about distribution of fish in tributaries. In 1997, sockeye salmon passed Bonneville Dam from late May through late August, with peak counts occurring in early and mid-July (Figure 2). Counts at lower Columbia River dams in 1997 were about 70 to 80% of the 10-year average (Table 1), about 90% of the 10-year average at Priest Rapids and Rock Island dams and greater than 100% at Rocky Reach and Wells dams.

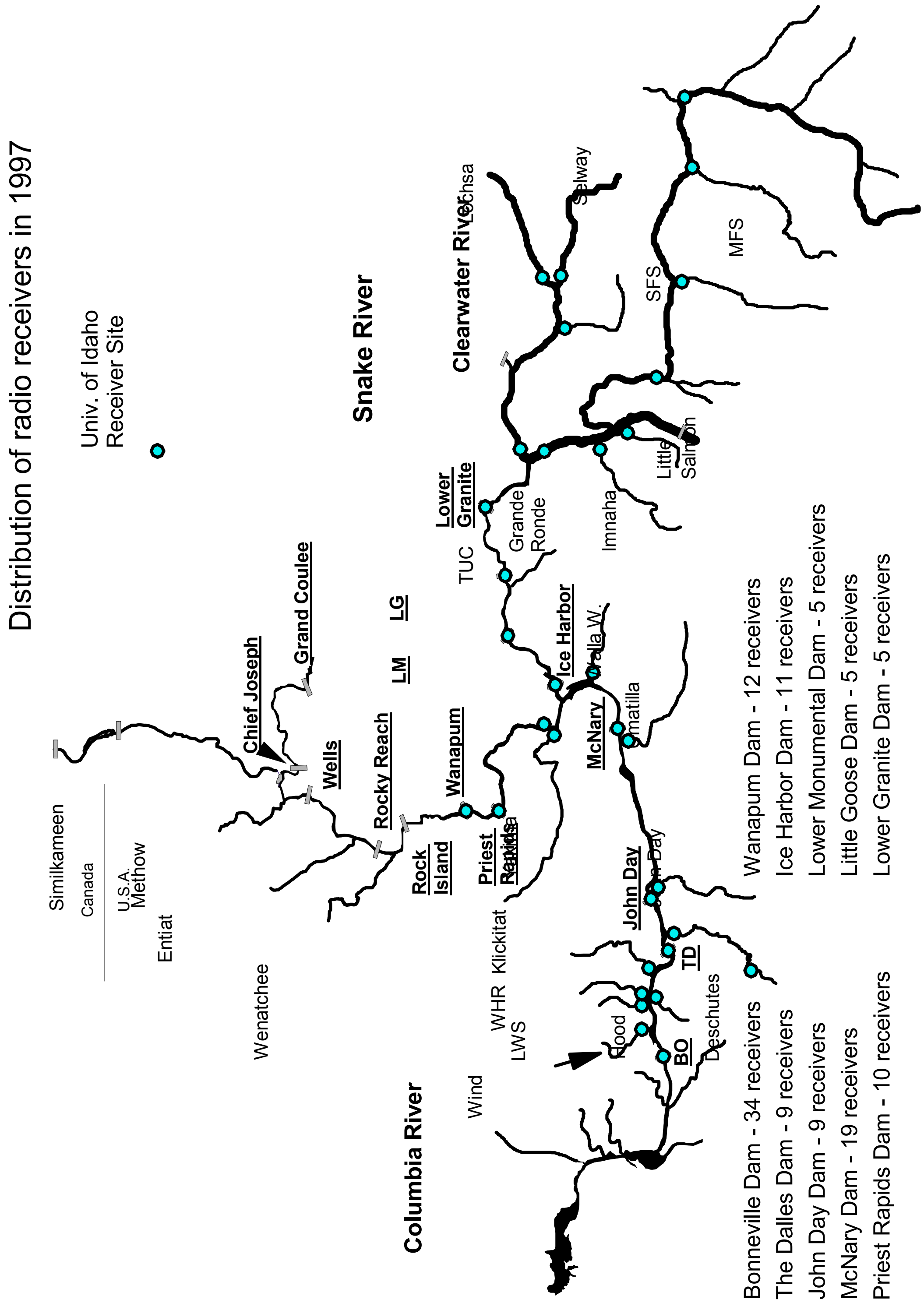

Figure 1. Location of radio receivers at dams and major tributaries within the Columbia River study area in 1997. Does not include mid-Columbia River and tributary sites maintained by Public Utility Districts for Chelan and Douglas counties.

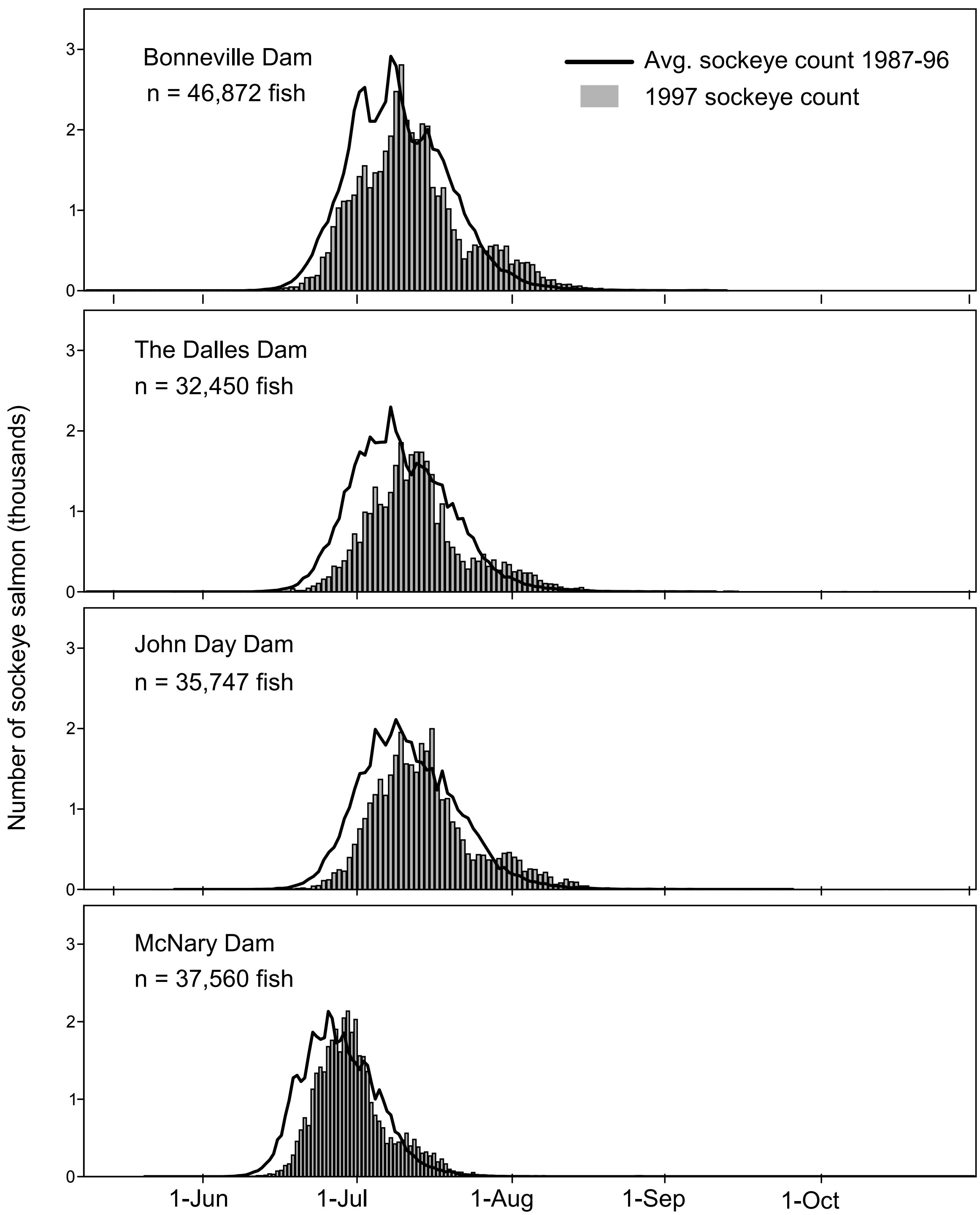

Figure 2. Number of adult sockeye salmon counted at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Rock Island, Rocky Reach and Wells dams in 1997 with 10-year average counts (1987 to 1996).

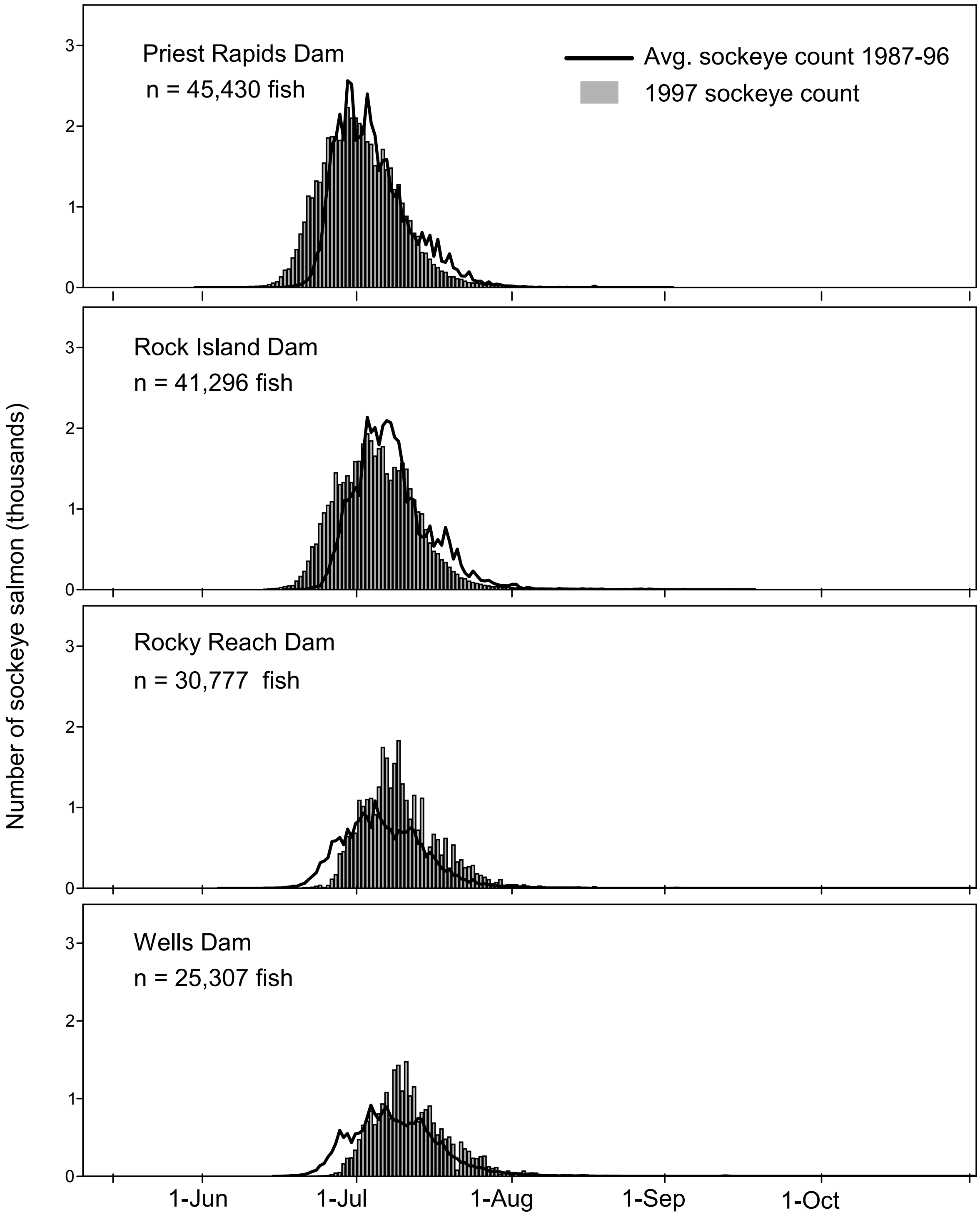

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Table 1. Adult sockeye salmon counted at main stem dams in 1997, and the 1997 counts as a percentage of the 10-year mean (1987 to 1996). Data from USACE Annual Fish Passage reports.

Dams	1997 Count	Percent of 10-year Mean
Bonneville	47,008	81
The Dalles	32,430	71
John Day	35,830	81
McNary	38,043	83
Priest Rapids	45,412	90
Rock Island	41,504	93
Rocky Reach	30,485	135
Wells	25,754	117

For much of the spring and summer of 1997, flow and spill in the Columbia and Snake rivers were nearly double the previous 10-year averages, and peak spill levels in May and June were often several times higher than average (1987 to 1996, Figure 3). Secchi disk visibility was well below average at all monitored dams in 1997 throughout the sockeye salmon migration (Figure 4). Water temperatures were slightly colder than the 10-year average at the lower Columbia and lower Snake river dams until late July, when they were near average; late summer water temperatures at Bonneville Dam were slightly warmer than average (Figure 5). Temperatures at Priest Rapids Dam were similar to average throughout the migration.

This study in 1997 used radio telemetry on a large scale (577 sockeye salmon outfitted with radio transmitters) to assess the proportion of adult sockeye salmon that successfully passed dams in the lower and middle Columbia River, and their passage times at the dams and through reservoirs. Cumulative passage times and minimum escapements from Bonneville Dam past multiple dams were also estimated. The influence of environmental conditions on migration and fallback rates, relations between fallback and passage, final distributions for fallback and non-fallback salmon, and survival rates through reaches and to major tributaries were estimated for salmon tagged in 1997.

General Methods

Monitoring Fish Movements

Radio telemetry was the primary means of assessing movements and passage rates of adult sockeye in the Columbia River in 1997. Priority dams for intensive study in 1997 were Bonneville, McNary, Ice Harbor, Priest Rapids, and Wanapum dams. They were fully outfitted with receivers and antennas to monitor all fishway entrances and exits, as well as the tailraces to determine when salmon with transmitters approached

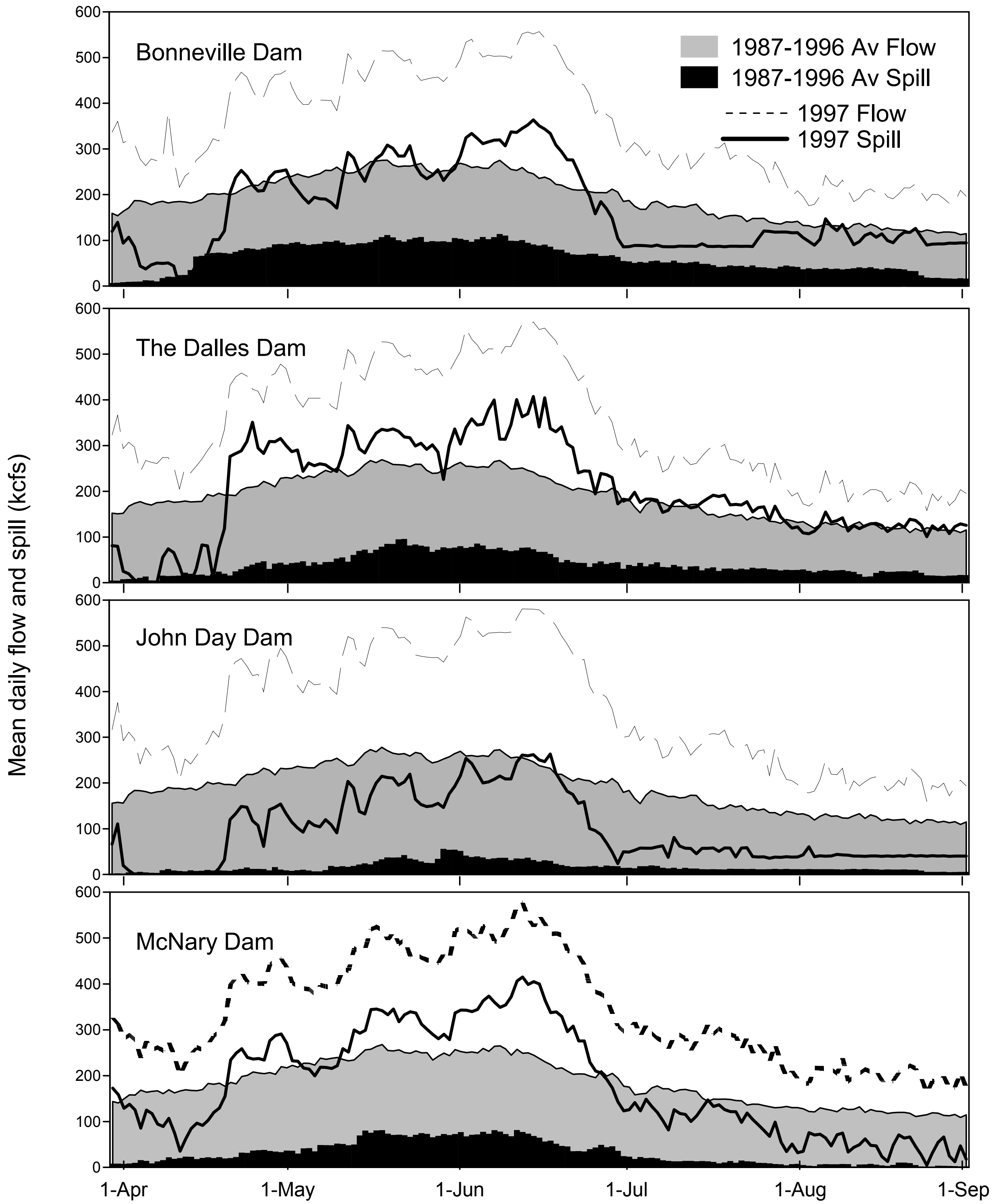


Figure 3. Mean daily flow and spill volumes at Bonneville, The Dalles, John Day, McNary, and Priest Rapids dams in 1997 with 10-year averages (1987 to 1996).

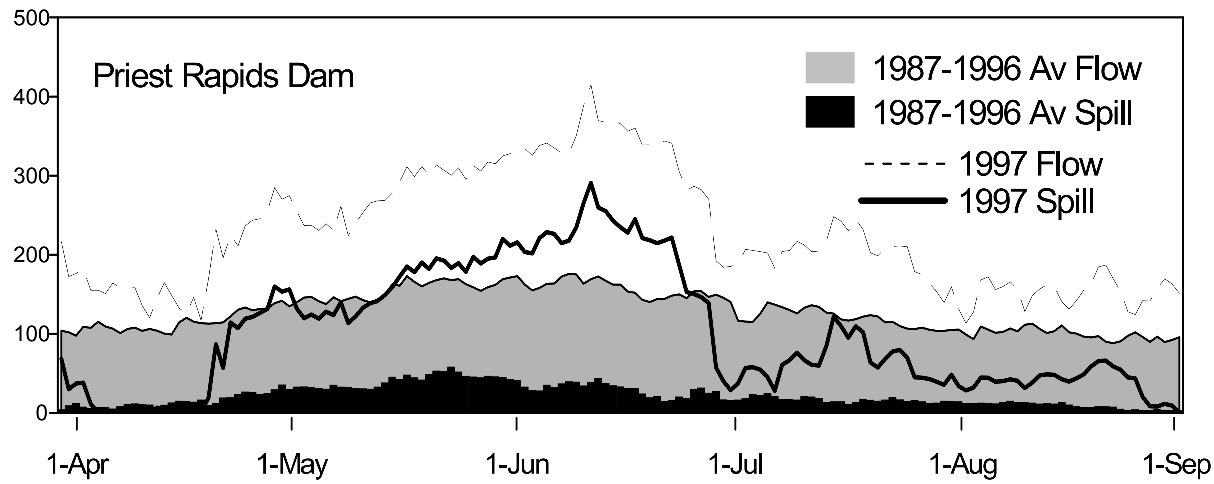


Figure 3. Cont.

dams. We also increased telemetry coverage from 1996 at The Dalles and John Day dams.

In 1997, we set up receivers and antennas on all major tributaries upstream from Bonneville Dam (Figure 1 and Table 2). Receivers/antennas set up on tributaries were near the mouths, but far enough upstream so that transmitter signals from fish in the Columbia or Snake rivers would not be picked up and recorded. At some tributaries we installed receivers/antennas upstream or downstream from the tributary mouths to monitor salmon with transmitters in the main stem as they approached and proceeded upstream past a tributary. We also set up receivers and antennas to monitor passage at main stem sites at the Bridge of the Gods on the lower Columbia River and the Hanford Reach in the mid-Columbia River. Additional receiver sites at dams and tributaries were maintained upstream from Wanapum Dam by Public Utility Districts for Douglas and Chelan counties (see Alexander 1998; English 1998).

We monitored sockeye salmon movements with fixed-site radio receivers at dams and at the mouths of tributaries, and by mobile tracking in areas not covered by fixed-site antennas. Additional information was collected at upriver dams, traps and weirs and from fishers that returned transmitters.

We used SRX receivers with Yagi antennas to determine when fish first entered the tailrace area of a dam. 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 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. We also used SRX receivers connected to Yagi

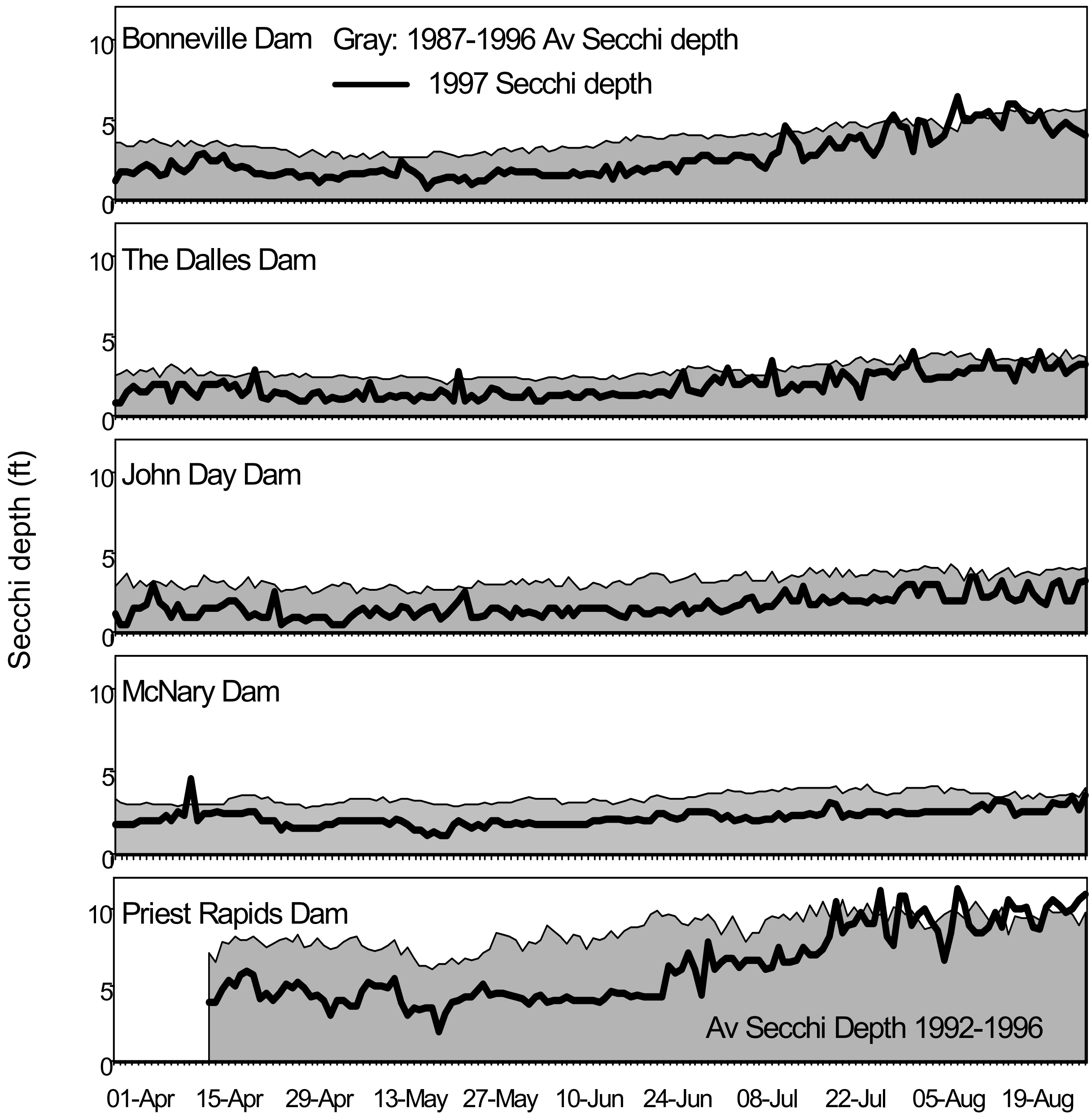


Figure 4. Mean daily Secchi disk visibility at Bonneville, The Dalles, John Day, McNary, and Priest Rapids dams in 1997 with 10-year averages (1987 to 1996).

antennas near the mouths of main stem tributaries, at previously mentioned main stem sites, and on tributaries (Figure 1). For more details on receiver and antenna installation and the evolution of monitoring techniques for the adult passage project, see Bjornn et al. (1998; 2000d).

Three trucks were outfitted with 4-element Yagi antennas and SRX receivers to track fish in areas not covered by fixed-site receivers. Two boats were similarly outfitted to facilitate mobile tracking in reservoirs, as well as the free-flowing section of the

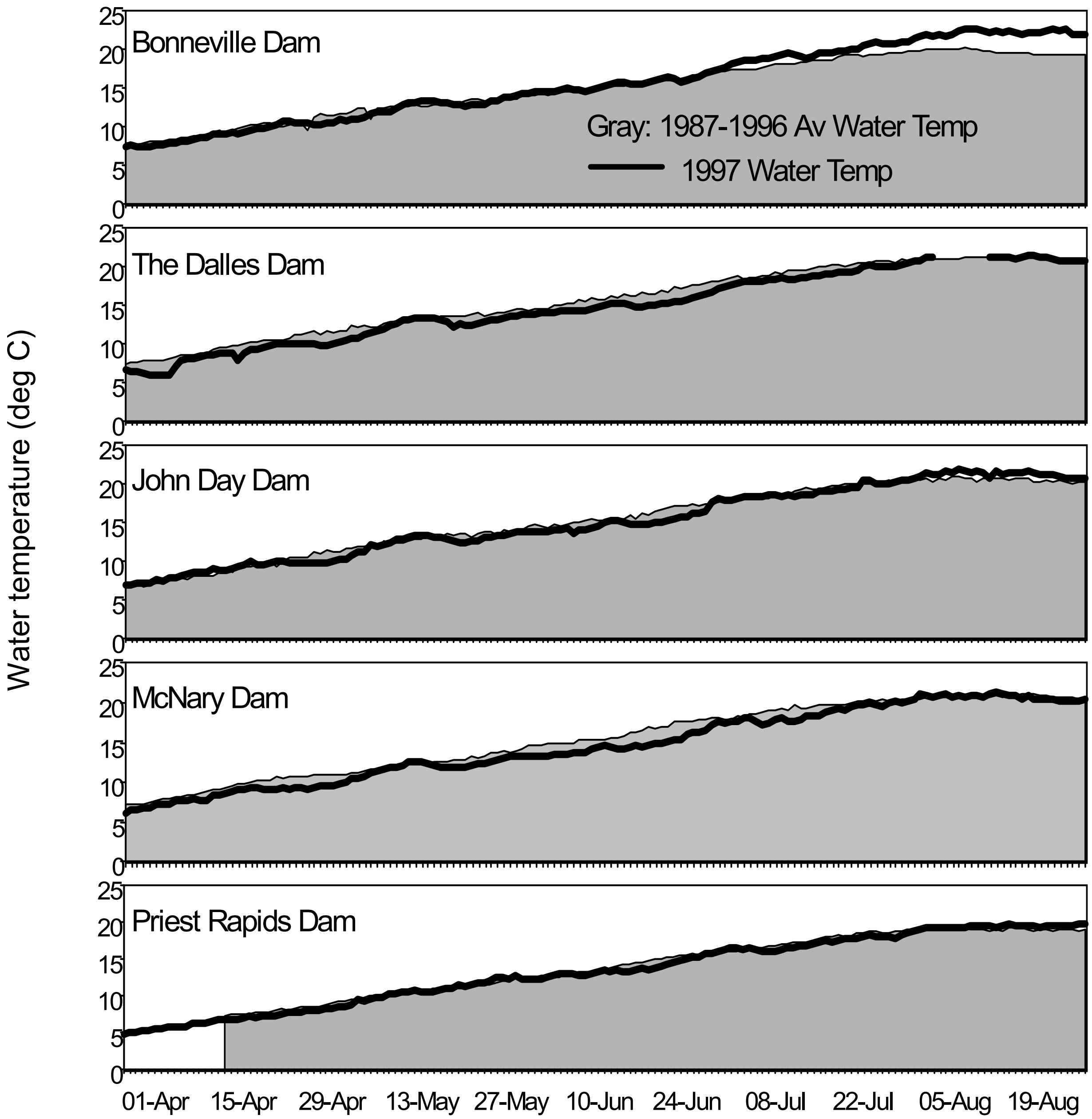


Figure 5. Mean daily water temperature at Bonneville, The Dalles, John Day, McNary, and Priest Rapids dams in 1997 with 10-year averages (1987 to 1996).

Columbia River between Pasco and Priest Rapids Dam. In 1997, sections of the lower Columbia River were mobile-tracked approximately twice each month during the sockeye salmon migration. Segments of the Wind, White Salmon, Little White Salmon, Klickitat, and Deschutes rivers were also mobile-tracked occasionally. Additional tributaries, including those upstream from Priest Rapids Dam and downstream from Bonneville Dam were mobile tracked by cooperating agencies, primarily during the fall of 1997.

Table 2. Location of receivers at dams and tributaries in 1997, with site codes, number and type of aerial (A) and underwater (U) antennas at each site, description of site, and river kilometers from Columbia River mouth for some sites.

Location	Site Code	Antennas	Type	Site description
Bonneville Dam	1BO	1	A	Tailrace, south side
	2BO	1	A	Tailrace, north side
	3BO	1	A	Downstream end of navigation lock
	4BO	3	U	Powerhouse 1, south end entrances
	5BO	3	U	Powerhouse 1, sluice gates
	6BO	6	U	Powerhouse 1, sluice gates
	7BO	4	U	Powerhouse 1, sluice gates
	8BO	5	U	Powerhouse 1, sluice gates
	ABO	1	U	Top of Bradford Island ladder
	BBO	4	U	South end of spillway ladder entrance
	CBO	4	U	North end of spillway ladder entrance
	DBO	7	U	Powerhouse 2, south shore entrances
	EBO	5	U	Powerhouse 2, orifice gates
	FBO	4	U	Powerhouse 2, orifice gates
	GBO	5	U	Powerhouse 2, orifice gates
	HBO	5	U	Powerhouse 2, orifice gates
	JBO	4	U	Powerhouse 2, orifice gates
	KBO	5	U	Powerhouse 2, orifice gates
	LBO	5	U	Powerhouse 2, north shore entrances
	MBO	5	U	North shore ladder transition pool
	NBO	4	U	North shore ladder and transition pool
	OBO	3	U	Washington ladder/UMT channel junction
	PBO	1	U	Top of Washington shore ladder
	QBO	3	U	Top of navigation lock
	RBO	1	A	Spillway forebay, facing north
	SBO	1	A	Spillway forebay, facing south
	TBO	1	U	Powerhouse 1, ice and trash sluiceway
	UBO	1	U	Powerhouse 2, ice and trash sluiceway
	VBO	3	U	A-Branch ladder transition pool
	WBO	3	U	B-Branch ladder transition pool
	XBO	4	U	Cascades Island ladder transition pool
	YBO	1	A	Upstream from navigation lock
	ZBO	3	U	UMT channel
The Dalles Dam	1TD	1	A	Tailrace, south side
	2TD	1	A	Tailrace, north side
	ATD	2	U	South spillway entrance
	BTD	3	U	West powerhouse entrance
	CTD	4	U	South shore ladder entrance
	DTD	3	U	South shore transition pool
	ETD	6	U	North shore ladder entrance
	5TD	1	U	Top of Washington shore ladder
	FTD	1	U	Top of Oregon shore ladder
John Day Dam	1JD	1	A	Tailrace, south side
	2JD	1	A	Tailrace, north side
	AJD	5	U	Oregon shore ladder and transition pool
	BJD	3	U	North powerhouse entrance
	CJD	6	U	Washington shore ladder, transition pool
	DJD	2	U	Wash. shore ladder, near diffuser pool

Table 2. Continued.

Location	Site code	Antennas	Type	Site description
	EJD	2	U	Oregon shore ladder, near diffuser pool
	6JD	1	U	Top of Oregon shore ladder
	7JD	1	U	Top of Washington shore ladder
McNary Dam	1MN	1	A	Tailrace, south side
	2MN	1	A	Tailrace, north side
	3MN	3	U	Oregon shore ladder entrance
	4MN	6	U	Oregon shore ladder transition pool
	5MN	4	U	Orifice gates
	6MN	6	U	Orifice gates
	7MN	6	U	Orifice gates
	8MN	6	U	Orifice gates
	9MN	5	U	Orifice gates
	AMN	5	U	Orifice gates
	BMN	3	U	North powerhouse entrance
	CMN	3	U	Washington shore ladder entrance
	DMN	3	U	Washington shore ladder transition pool
	EMN	1	U	Top of Oregon shore ladder
	FMN	1	U	Top of Washington shore ladder
	GMN	1	A	Bottom of navigation lock
	HMN	5	U	Top of navigation lock
	JMN	1	U	Exit from juvenile bypass
	KMN	2	A	Upstream end of juvenile bypass
Priest Rapids Dam	1PR	1	A	Tailrace, east side
	2PR	1	A	Tailrace, west side
	4PR	5	U	East shore ladder entrance
	5PR	5	U	Orifice gates
	6PR	6	U	Orifice gates
	7PR	6	U	Orifice gates
	8PR	5	U	West powerhouse entrance
	APR	1	U	Top of West shore ladder
	BPR	6	U	East shore ladder and transition pool
	CPR	1	U	Top of East shore ladder
Wanapum Dam	1WP	1	A	Tailrace, east side
	2WP	1	A	Tailrace, west side
	3WP	4	U	East ladder entrance
	4WP	4	U	East ladder transition pool
	5WP	3	U	Orifice gates
	6WP	4	U	Orifice gates
	7WP	5	U	Orifice gates
	8WP	3	U	Orifice gates
	9WP	3	U	Orifice gates
	AWP	2	U	West ladder entrance
	BWP	1	U	Top of east shore ladder
	CWP	1	U	Top of west shore ladder
Ice Harbor Dam	1IH	1	A	Tailrace, north side
	3IH	4	U	South shore ladder entrance
	4IH	4	U	Orifice gates
	5IH	4	U	Orifice gates
	6IH	4	U	Orifice gates

Table 2. Continued.

Location	Site code	Antennas	Type	Site description
	7IH	2	U	North powerhouse entrance
	8IH	4	U	North shore entrance, transition pool, top
	9IH	2	U	Top of south shore ladder
	TIH	5	U	South shore ladder transition pool
	1CHAR	1	A	Forebay, 3 km upstream from dam
	2CHAR	1	A	Forebay, 3 km upstream from dam
Lower Monumental Dam	1LM	1	A	Tailrace south side
	2LM	4	U	South shore ladder entrance, exit
	3LM	4	U	South powerhouse entrances
	7LM	3	U	North ladder entrance
	8LM	1	U	Top of north ladder
Little Goose Dam	1GO	1	A	Tailrace south side
	2GO	4	U	South shore ladder entrance
	5GO	6	U	North powerhouse entrances
	6GO	4	U	North shore entrance
	7GO	1	U	Top of south shore ladder
Lower Granite Dam	1GR	1	A	Tailrace, south side
	6GR	6	U	North powerhouse entrances
	8GR	2	U	Top of south shore ladder
	1WI	1	A	Forebay, 2 km upstream from dam
	2WI	1	A	Forebay, 2 km upstream from dam
Bridge of Gods	BOG	1	A	RKM 238.6
Wind River	WIN	1	A	River mouth (RKM 249.2)
	WNM	1	A	River mouth (RKM 109.4)
Little White Salmon R.	LWS	1	A	River mouth (RKM 261.0)
	LWD	1	A	Down Columbia from LWS (RKM 260.1)
	LWU	1	A	Up Columbia of LWS (RKM 261.3)
White Salmon River	WHR	1	A	River mouth (RKM 270.9)
	WHD	1	A	Down Columbia from WHR (RKM 270.3)
	WHU	1	A	Up Columbia from WHR (RKM 271.0)
Hood River	HDR	1	A	River mouth (RKM 272.6)
Klickitat River	KTR	1	A	River mouth (RKM 290.7)
Deschutes River	DES	1	A	River mouth (RKM 328.9)
	DSM	1	A	Down Columbia from DES (RKM 327.1)
	SHF	1	A	Sherars Falls (RKM 396.3)
John Day River	JDR	1	A	River mouth (RKM 355.7)
Umatilla River	UMR	1	A	River mouth (RKM 467.1)
Walla Walla River	WWR	1	A	River mouth (RKM 506.0)
Yakima River	YAK	1	A	River mouth (RKM ~540)
Hanford Reach	HFL	1	A	RKM 571.2
	HFR	1	A	RKM 571.2
Snake River	SNR	1	A	River mouth (RKM 762.3)
Clearwater River	CWR	1	A	River mouth (RKM 753.3)
	SFC	1	A	South Fork Clearwater River (RKM 867.6)
Selway River	SEL	1	A	River mouth (RKM 906.1)
Lochsa River	LOC	1	A	River mouth (RKM 903.8)
Grande Ronde River	GRR	1	A	River mouth (RKM 794.7)
Imnaha River	IMR	1	A	River mouth (RKM 867.6)
Salmon River	LSR	1	A	Near Riggins (RKM 963.2)
	SFS	1	A	South Fork (RKM 1094.8)

Table 2. Continued.

Location	Site code	Antennas	Type	Site description
	MFS	1	A	Middle Fork (RKM 1142.8)
	USR	1	A	Upper Salmon River (RKM 1204.3)
Sites maintained by Public Utility Districts of Douglas and Chelan counties				
Rock Island Dam	RI			
Wenatchee River	WEN			River mouth
	TM1			Tumwater Dam
Entiat River	ENR			River mouth
Rocky Reach Dam	RR			

Outfitting Salmon with Transmitters

Radio transmitters were placed in 577 adult (no jacks) sockeye salmon trapped in the adult fish facility at Bonneville Dam in 1997 as they migrated upstream to natal streams or hatcheries. The salmon were transported to release sites at Dodson and Skamania Landings about 9.5 km downstream from Bonneville Dam. Tagging of adult sockeye salmon in 1997 began on 9 June and ended on 5 August (Figure 6).

Each day fish were tagged, the fish diversion weir in the Washington-shore ladder was lowered into place in the morning to divert fish from the main portion of the ladder into the fish lab via a short section of ladder. Salmon entered the lab into a large tank with two false weirs at the top of chutes that led to a channel back to the ladder or into anesthetic tanks. As salmon swam through the water flowing over the false weirs and slid down the chutes, a person would divert the fish into the anesthetic tank by operating a hydraulic gate if the fish was one we wanted to tag, otherwise the fish entered the channel that led back into the main ladder. In this way fish were not handled prior to be anesthetized, reducing stress during the tagging process. We had no sockeye salmon mortalities during tagging, transport, or release in 1997.

Tricane-methane-sulphonate (MS-222) was used to anesthetize fish at a concentration of 100 mg/L. When fish were anesthetized, they were moved to a tagging tank in a wet plastic sleeve where their length and sex (if possible) and presence of injuries, old scars, and fin clips was noted. We then outfitted fish with a transmitter that had been dipped in glycerin, by inserting it into the stomach through the mouth. The transmitter antenna was bent at the corner of the mouth and allowed to trail along the side of the fish. We used 3-volt transmitters developed and supplied by Lotek Engineering[1] that transmitted a signal every 5 s that included the frequency and code of the transmitter. The code set we used allowed us to monitor up to 170 fish on each frequency. Transmitters were powered by a lithium battery and had a rated operating life of 278 d, but usually lasted a year or more. Transmitters used in sockeye were cylindrical, 43 mm long, 14-mm in diameter and had a 47-cm long antenna, and weighed 11 g.

[1]The use of this product does not constitute an endorsement by the authors.

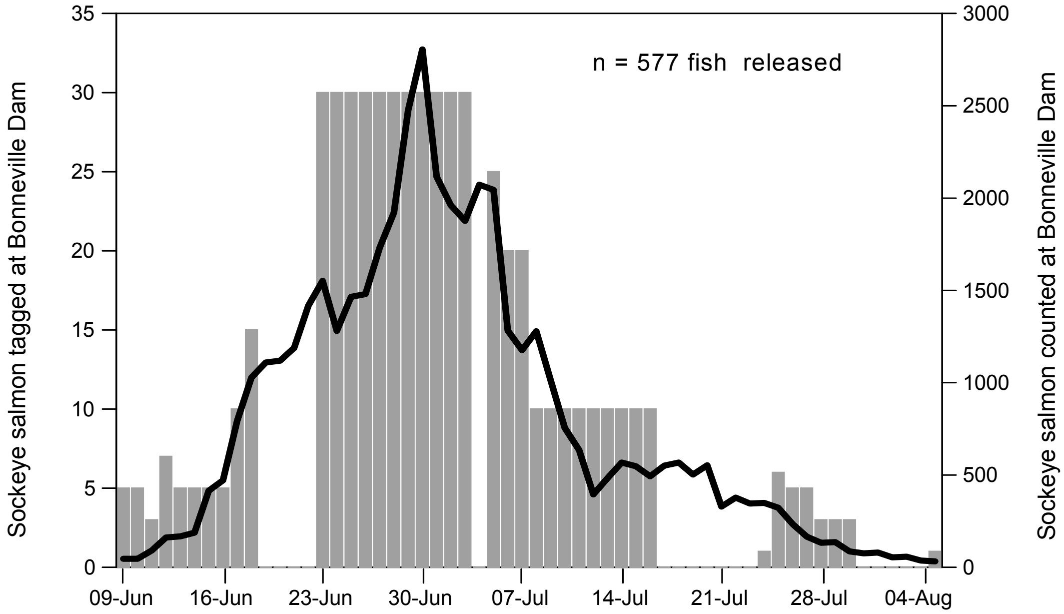


Figure 6. Number of sockeye salmon outfitted with radio transmitters at the Bonneville Dam adult trap (bars), and the number counted passing the dam at the counting stations (line) during the migration in 1997.

We inserted a unique secondary visual implant (VI) tag into the clear tissue posterior to the eye (left usually), and a 1 mm-long piece of magnetic wire was inserted into the muscle near the dorsal fin to trigger the coded-wire detector at Lower Granite Dam. Fish were then placed in the wet sleeve and moved to the transport tank where they were held until released (usually less than 3 hours). The length of the trapping period each day depended on the number of sockeye salmon to be outfitted with transmitters and the number of fish moving up the ladder. The transport tank was a 300 gal, insulated, fiberglass tank with a large trap door on the end for fish release. Air stones in the tank bottom supplied oxygen from bottles mounted on the side of the tank. An overhead crane was used to move the transport tank in and out of the fish facility. Once trapping was finished each day, we removed diversion weir pickets from the ladder and fish in the trapping system were allowed to proceed up the ladder.

The 577 sockeye salmon we tagged represented 1.2%, or 1 in 81, of the 46,665 fish counted passing Bonneville Dam during the period. We unselectively outfitted with transmitters what we believe was a near-random sample of adult sockeye salmon. The sample was not truly random because only fish passing via the Washington-shore ladder were sampled, the proportion sampled each day varied, more fish were sampled in the morning than afternoon, and no fish were sampled at night. Fish were tagged as they were trapped, and we tagged almost all fish regardless of minor injury or fin clip.

We evaluated our overall sampling effort by calculating proportions of radio-tagged fish to total counts of sockeye salmon passing Bonneville Dam for consecutive 5-d blocks. Between 9 June and 5 August, the time when 99.2% of the tagged fish were recorded passing the dam, the proportion of radio-tagged fish that passed was about 1.2% (Figure 7). Overall, however, our sampling effort through time was generally close to the overall sampling rate.

In 1997, 572 (99%) of sockeye salmon outfitted with transmitters had no fin clips and 5 (1%) had adipose or ventral fin clips. Adult sockeye salmon we outfitted with transmitters in 1997 were classified as 72.3% male and 27.7% female. Fork lengths of fish tagged ranged from 38 cm to 63 cm with a median length of 49.5 cm (Figure 8). Sockeye salmon without fin clips had median fork length of 49.2 cm and those with clips had a median length of 51.0 cm.

Sixty-seven percent of the 577 sockeye salmon tagged had no descaling, 30% less than 10%, 2% were 10-25% descaled, and <1% were more than 25% descaled. We recorded the prevalence of injuries on the heads of the fish and 96% had none, 1% had scrapes, and less than 1% had skinned areas, fungus, cuts, hook marks, or eye injuries. Sixty percent of the fish had no marks from marine mammals, 31% had fresh marine mammal scrapes, and 9% had fresh bite injuries. None of the 577 sockeye salmon had what we thought were gill net marks.

Receiver and Antenna Outages

During 1997, individual sequentially scanning receivers (SRX) and Yagi antennas installed at tailrace sites downstream from dams operated satisfactorily 82.1% to >99.9% of the time (mean of 92.6%, Tables 3 and 4). Tailrace receivers operated satisfactorily an average of 93.9% of the time at lower Columbia River dams and 83.8% of the time at Priest Rapids and Wanapum dams. We did not measure receiver efficiency information for sites upstream from Wanapum Dam. SRX/DSP (SRX connected to a digital scanning processor) receivers that were used to monitor the tops of ladders operated satisfactorily 83.8% to 100% of the time (mean of 95.3%). Top-of-ladder receivers operated satisfactorily an average of 95.9% of the time at lower Columbia River dams and 87.7% of the time at Priest Rapids and Wanapum dams (Table 4). SRX receivers at tributary mouths operated satisfactorily 73.4% to 100% of the time (mean 95.4%). Antennas and receivers that monitored entrances to fishways and within fishways operated at similar or slightly lower rates, but data from those receivers were typically not used for the passage studies in this report.

Reported receiver operations and outages include time both before and after the sockeye salmon migration in 1997, and percentages reported above do not necessarily reflect operation efficiency during the sockeye migration. Many receivers were in operation for the entire year, to monitor steelhead tagged in both 1996 and 1997. Receiver outages throughout the year occurred primarily because of power loss, receiver malfunction, vandalism, and full memory banks. In a few additional cases, receivers were operating but were not accurately recording data or were recording data incompletely. Cut or damaged antenna wires, malfunctioning receivers or downloading errors accounted for most other data gaps (Table 4).

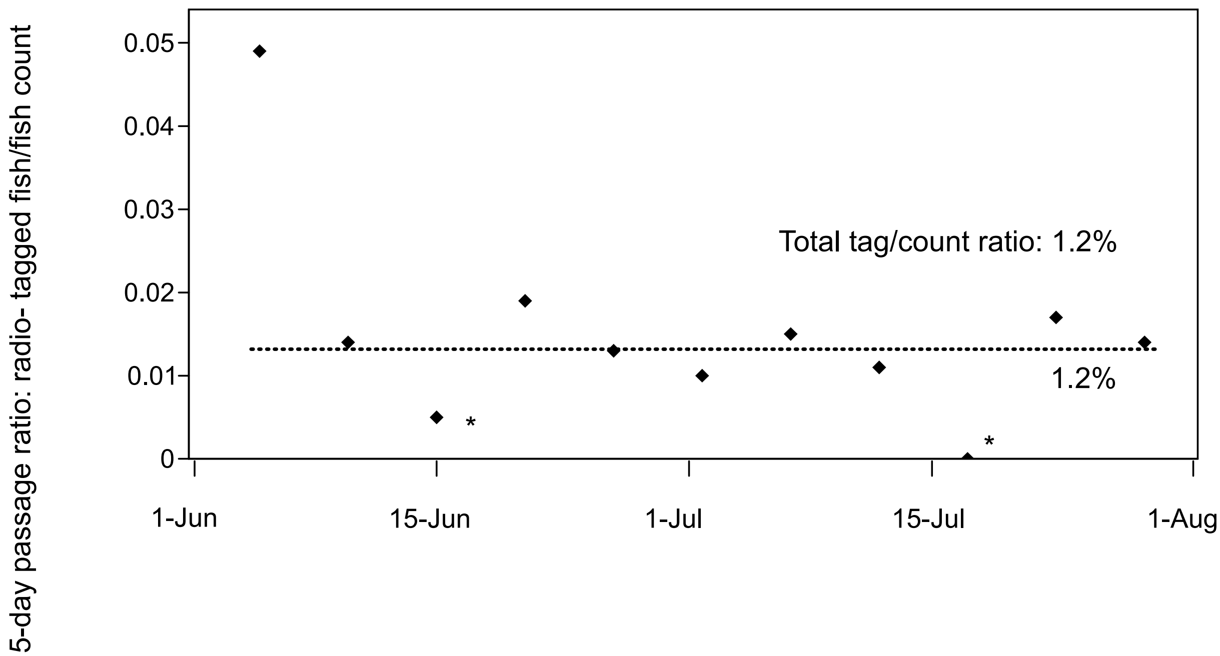


Figure 7. Proportion of radio-tagged sockeye salmon passing Bonneville Dam to the total counts at the dam during 5-d blocks in 1997. Blocks that include less than 2.5% of the total run noted with an asterisk.

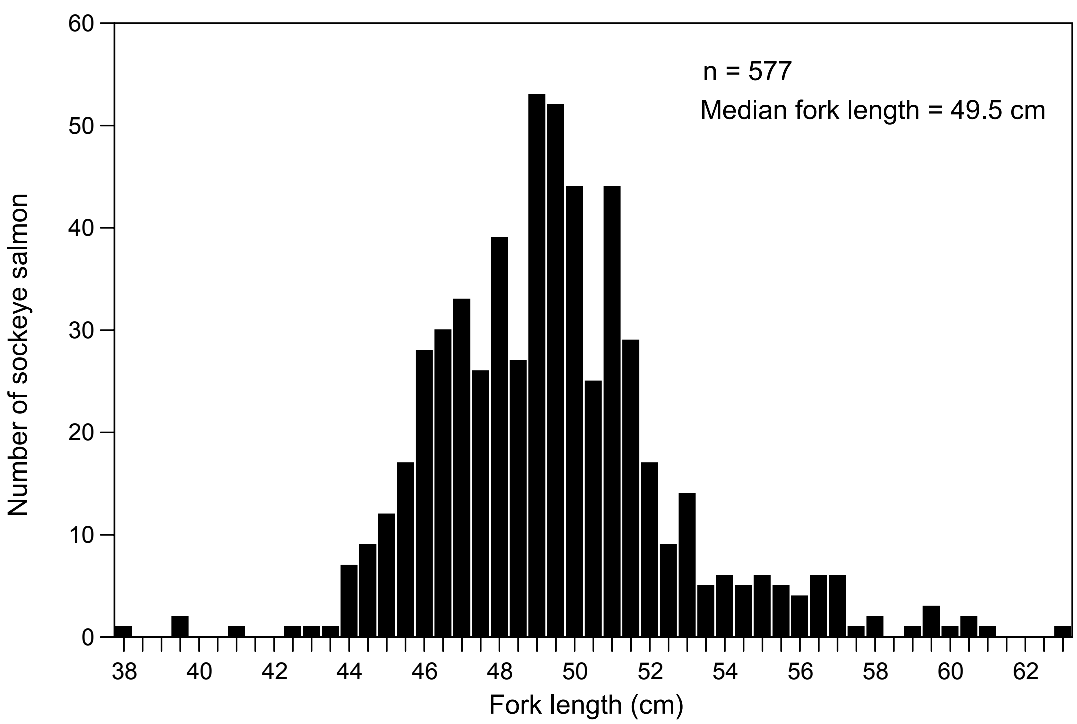


Figure 8. Length frequency distribution of sockeye salmon outfitted with transmitters at the Bonneville adult trap in 1997.

Table 3. Receiver power outages and hours of operation at dams, tributaries and other fixed sites in 1997. Operation percentages do not measure data collection gaps that occurred for reasons other than power outages. * tailrace receiver; ** top-of-ladder receiver

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
Bonneville Dam				
1BO*	8,473	8,186	287	96.6
2BO*	8,760	8,279	481	94.5
3BO	8,760	8,254	506	94.2
4BO	8,760	7,977	783	91.1
5BO	8,759	8,736	23	99.7
6BO	8,760	8,729	31	99.6
7BO	8,760	8,735	25	99.7
8BO	8,760	8,733	27	99.7
9BO	8,694	8,489	205	97.6
ABO**	4,904	4,280	624	87.3
AB2	3848	3,529	319	91.7
BBO	8,760	8,585	175	98.0
CBO	7,664	7,485	179	97.7
DBO	8,760	8,065	695	92.1
EBO	8,760	6,646	2114	75.9
FBO	8,760	7,984	776	91.1
GBO	8,759	8,648	111	98.7
HBO	8,760	8,735	25	99.7
JBO	8,760	8,584	176	98.0
KBO	8,760	8,086	25	92.3
LBO	8,760	8,735	674	99.7
MBO	8,760	8,736	24	99.7
NBO	8,760	8,572	188	97.9
OBO	8,760	7,782	978	88.8
PBO**	7,753	7,495	258	96.7
QBO	8,760	8,730	30	99.7
RBO	8,760	6,759	2001	77.2
SBO	8,760	6,658	2102	76.0
TBO	6,848	6,836	12	99.8
UBO	8,760	6,720	2040	76.7
VBO	6,704	6,701	3	99.9
WBO	6,776	6,774	2	99.9
XBO	6,779	6,533	246	96.4
YBO	1,381	1,280	101	91.7
ZBO	1,509	1,507	2	99.9
The Dalles Dam				
1TD*	8,760	8,448	312	96.4
2TD*	8,760	7,310	1,450	83.4
3TD	1,026	717	309	69.9
5TD**	8,760	8,747	13	99.9
ATD	6,798	6,797	1	99.9
BTD	6,798	6,798	0	100
CTD	6,797	6,383	414	93.9
DTD	7,733	7,415	318	95.9
ETD	6,795	6,643	152	97.8
FTD**	6,795	6,556	239	96.5
John Day Dam				
1JD*	8,458	8,399	59	99.3

Table 3. Continued.

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
JD*	8,459	8,290	169	98.0
6JD**	8,760	8,716	44	99.5
7JD**	8,760	8,342	418	95.2
AJD	7,439	6,580	859	88.5
BJD	6,825	6,815	10	99.9
CJD	7,329	7,140	189	97.4
DJD	8,287	7,780	507	93.9
EJD	357	261	96	73.1
McNary Dam				
1MN*	8,760	8,586	174	98.0
2MN*	8,625	7,354	1,271	85.3
3MN	8,760	7,715	1,045	88.1
4MN	8,760	8,754	6	99.9
5MN	8,760	8,748	12	99.9
6MN	8,532	8,058	474	94.4
7MN	8,760	8,577	183	97.9
8MN	8,760	7,858	902	89.7
9MN	8,759	8,247	512	94.2
AMN	8,760	8,756	4	99.9
BMN	8,626	7,841	785	90.9
CMN	8,760	8,747	13	99.9
DMN	8,760	8,291	469	94.6
EMN**	8,760	8,630	130	98.5
FMN**	8,760	8,753	7	99.9
GMN	6,822	6,669	153	97.8
HMN	6,917	6,911	6	99.9
JMN	6,583	6,121	462	93.0
KMN	6,900	6,114	786	88.6
Priest Rapids Dam				
1PR*	5,617	4,916	701	87.5
2PR* 5,638	4,626	1,012	82.1	
4PR	2,616	2,456	160	93.9
5PR	2,647	2,493	154	94.2
6PR	2,642	2,636	6	99.8
7PR	2,618	2,410	208	92.1
8PR	2,643	2,311	332	87.4
APR**	5,612	4,792	820	85.4
BPR	2,644	2,088	556	79.0
CPR**	5,611	4,704	907	83.8
Wanapum Dam				
1WP*	5,686	4,577	1,109	80.5
2WP*	5,610	4,777	833	85.2
3WP	2,809	2,531	278	90.1
4WP	2,041	2,038	3	99.9
5WP	2,617	2,607	10	99.6
6WP	2,617	2,601	16	99.4
7WP	2,331	2,321	10	99.6
8WP	2,616	2,237	379	85.5
9WP	2,332	2,278	54	97.7
AWP	2,328	2,316	12	99.5
P**	5,589	5,036	66	90.1
CWP**	5,597	5,110	487	91.3

Table 3. Continued.

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
Ice Harbor Dam				
3IH	6,270	6,267	3	99.9
4IH	6,272	6,270	2	99.9
5IH	6,269	6,264	5	99.9
6IH	3,231	3,228	2	99.9
7IH	6,265	6,043	222	96.5
8IH**	8,760	8,745	15	99.8
9IH**	8,759	8,757	2	99.9
TIH	missing outage data			
Lower Monumental Dam				
1LM*	6,169	5,988	181	97.1
2LM**	6,175	6,154	21	99.7
3LM	6,147	6,143	4	99.9
7LM	6,149	6,129	20	99.7
8LM**	6,177	6,174	3	99.9
Little Goose Dam				
1GO*	6,082	6,064	18	99.7
2GO	6,031	5,360	671	88.9
5GO	3,027	3,024	3	99.9
6GO	2,038	2,038	0	100
7GO**	6,080	6,077	3	99.9
Lower Granite Dam				
1GR*	8,760	7,837	923	89.5
6GR	5,885	4,999	886	84.9
8GR**	8,760	8,055	705	92.0
1WI	2,211	2,210	1	99.9
2WI	2,211	2,211	0	100
Tributaries				
Bridge of Gods (BOG)	6,079	5,845	234	96.2
Wind (WIN)	8,760	8,198	562	83.6
WNM	8,760	6,326	2,434	72.2
L. Wh. Salmon (LWS)	8,456	7,957	499	94.1
LWD	8,760	3,701	5,059	42.2
LWU	8,760	6,385	2,375	72.9
White Salmon (WHR)	8,760	7,789	971	88.9
WHD	6,264	3,269	2,995	52.2
WHU	6,356	4,029	2,327	63.4
Hood (HDR)	8,760	8,608	152	98.3
Klickitat (KTR)	8,760	8,524	236	97.3
Deschutes (DES)	8,760	8,643	117	98.7
DSM	8,760	6,523	2,237	74.5
SHF	8,760	8,408	352	96.0
John Day (JDR)	8,458	7,217	1,241	85.3
Umatilla (UMR)	8,760	9,781	9	99.9
Walla Walla (WWR)	8,760	8,563	197	97.8
Yakima (YAK)	8,760	8,386	374	95.7
Hanford left (HFL)	6,205	5,885	320	94.8
Hanford right (HFR)	6,206	5,070	1,136	81.7
Snake (SNR)	8,552	6,277	2,275	73.4
Clearwater (CWR)	8,123	8,119	4	99.9
SFC	5,503	5,499	4	99.9
Lochsa (LOC)	4,894	4,893	1	99.9

Table 3. Continued.

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
Selway (SEL)	5,382	5,379	3	99.9
Imnaha (IMR)	4,702	4,699	3	99.9
Salmon (LSR)	5,528	5,220	308	94.4
SFS	3,550	3,550	0	100
MFS	4,666	4,665	1	99.9
USR	4,452	4,045	407	90.9

Data Collection and Processing

Members of the study team downloaded data from receivers into portable computers periodically, with the frequency depending on the number of fish passing a site. Some sites were downloaded daily during the peak of the run, and some every two weeks. Each night files of downloaded data were transmitted to a computer at the NMFS lab in Seattle and added to databases. Records consisted of transmitter frequency (channel), code, date, time, power of signal received, and site. In 1997, we created databases for all the records of each fish at each dam and each species. After each day of tagging, a member of the tagging crew transmitted a file with records of fish tagged that day to the Seattle computer. When records were uploaded to the databases, the records were evaluated and good records added to the databases, and bad records were placed in a bad-record table. Bad records were those with channels and codes for fish that had not been released. As the season progressed, files of data for each dam were sent to the University of Idaho for coding by study team members.

Coding of the records consisted of going through all records for a fish at a dam and assigning specific codes to identify fish activity. For example, one code would be assigned to the first record of a fish at a tailrace site downstream from a dam and another would be assigned to the last record at the tailrace site. Similarly each approach and entry into the fishways was coded, as were exits back into the tailrace and exits from the top of ladders. When all the fish had been coded for a dam, coded records were returned to Seattle and added to the databases. We had a program written to assist in coding that incorporated a decision tree that a coder would use in coding records manually. The program speeded up the coding process but still required project personnel to make final designations for behavioral codes.

When all fish had been coded at each dam, all coded records for each radio-tagged salmon were combined into a file with records from tributary receivers, records of fish found by mobile trackers, and records of fish that were recaptured at weirs, hatcheries, spawning grounds, or in fisheries. Records in the file that had not been previously coded were then coded to create the “general migration” file, the file that contained most of the data presented in this report.

Above, we referred to records of fish found by mobile trackers, and of those of fish recaptured in fisheries, at adult traps, weirs and hatcheries, and those recovered in spawning areas. Separate data files were created for mobile track records and recapture records at the University of Idaho, and data in those files were added to the databases in Seattle prior to coding the general migration file.

Table 4. Dates, duration (days) and explanation for significant gaps in data collection in 1997 by receivers and antennas.

Location	Start Date	End Date	Duration	Explanation
Bonneville Dam				
RBO and SBO	22-Jan?	24-Mar	62	Broken by ice storm
ABO and CBO	?	15-Feb	?	Unplugged
JBO	?	23-Apr	?	Memory full
UBO	24-Apr	25-Apr	<1	Power problem
BBO and XBO	26-Apr	27-Apr	<1	Memory full
JBO-Antenna 1	?	29-Apr	?	Antenna crushed
NBO-Antenna 4	?	29-Apr	?	Cable short
BBO	29-Apr	2-May	4	Memory full
XBO	1-May	2-May	<1	Memory full
EBO and FBO	7-May	15-May	8	Power outage
ABO	31-May	2-Jun	2	Power disconnected
ZBO	24-Jul	10-Aug	17	Replace receiver
KBO	?	31-Jul	?	Power disconnected
PBO	25-Aug	2-Sep	8	Unknown
ABO	22-Sep	2-Oct	10	Receiver malfunction
CBO	24-Sep	29-Sep	5	Memory full
DBO	?	20-Oct	?	Memory full and power outage
RBO	14-Dec	15-Dec	1	Dead battery
The Dalles Dam				
3TD	?	6-Feb	?	Memory full
2TD	23-Feb	27-Feb	?	Receiver stolen
DTD	15-Apr	19-Apr	4	Temporarily removed
CTD	start	6-May	?	Bad receiver
2TD	31-Aug	1-Oct	31	Receiver not scanning
ETD	27-Aug	4-Sep	8	Antenna out of water
5TD	4-Aug	8-Oct	65	Receiver not scanning
ETD	10-Aug	9-Oct	60	Line amps cut
John Day Dam				
CJD	?	1-Mar	?	Unplugged by contractor
AJD	10-May	11-May	1	Memory full
CJD	?	2-Sep	?	Receiver not recording
DJD	10-Nov	11-Nov	1	Memory full
CJD	20-Nov	25-Nov	5	Unknown
McNary Dam				
3MN	22-Mar	1-Apr	10	Receiver running open
JMN	17-Apr	22-Apr	5	Receiver running open
BMN	22-Aprl	30-Apr	23	Receiver running open
CMN	start	14-May	?	Bad cable
8MN	7-May	13-May	6	Memory full
2MN	19-May	30-Jun	42	Site flooded
4MN	2-Jul	?	>90	No power
DMN	4-Jun	12-Jun	8	Temporarily removed
CMN	?	4-Jun	?	Receiver malfunction
FMN	?	4-Jun	?	Not in DSP mode 8MN 6-Jun
11-Jun	5	Memory full		
1MN	12-Jun	16-Jun	4	Loose power cord
KMN	21-Jun	30-Jun	9	Unplugged
EMN	14-Jul	15-Sep	60	Unknown

Table 4. Continued.

Location	Start Date	End Date	Duration	Explanation
JMN	20-Jul	21-Jul	1	Memory full
6MN	3-Oct	15-Oct	12	Download error
7MN	12-Oct	15-Oct	3	No power
8MN	15-Oct	23-Oct	8	Bad power strip
FMN	28-Aug	15-Sep	18	Receiver problem
EMN	29-Aug	15-Sep	17	Not is DSP mode
KMN	15-Sep	22-Sep	7	Memory not cleared
8MN	15-Oct	23-Oct	8	No power to SRX
GMN	23-Oct	31-Oct	8	Bad receiver
2MN	30-Oct	10-Nov	12	Monitor not restarted
KMN	5-Nov	10-Nov	5	No power to receiver
FMN	10-Nov	25-Nov	15	Loose power cord
9MN	14-Dec	22-Dec	8	Unknown
Priest Rapids Dam				
1PR and 2PR	?	30-Apr	?	Dead batteries
4PR	30-Apr	1-May	1	Switched
1PR and 2PR	7-May	14-May	7	Dead batteries
6PR-Antenna 3	22-May	26-May	5	Antenna out of place
2PR	3-Jun	5-Jun	3	Not scanning
7PR	30-May	5-Jun	7	Not scanning
2PR	25-Jun	26-Jun	1	Receiver locked up
5PR	10-Jul	12-Jul	2	Memory full
8PR	11-Jul	12-Jul	1	Memory full
BPR	7-Jul	16-Jul	9	Memory full
CPR	6-Jul	16-Jul	10	Memory full
8PR	14-Jul	16-Jul	3	Memory full
CPR	18-Jul	21-Jul	3	Memory full
BPR	21-Jul	29-Jul	8	Memory full
2PR	18-Sep	23-Sep	5	Battery outage
Wanapum Dam				
8WP	1-May	13-May	13	Temporarily moved
BWP	?	4-May	?	Not scanning
3WP	?	4-May	?	No power
AWP-Antenna 1	?	30-May	?	Antenna broken
AWP	7-Jun	12-Jun	5	Antenna out of place
1WP	7-Jun	12-Jun	5	Receiver locked up
1WP	5-Jul	12-Jul	7	Not scanning
9WP	14-Jul	16-Jul	2	Not scanning
4WP	28-Jul	1-Aug	4	Not scanning
9WP-Antenna 5	1-Aug	6-Aug	6	Antenna broken
1WP	20-Oct	27-Oct	7	No power
1WP	23-Nov	24-Nov	1	no power
Tributaries and other fixed sites				
LWS	?	22-Apr	?	Memory full
HDR	21-Apr	22-Apr	1	Blown breaker
SNR	?	24-Apr	?	Cut power cable
LWS	?	1-May	?	Memory full
WIN	27-May	28-May	1	Low battery
JDR	?	2-Jun	?	Cows chewed cable
UMR	start	4-Jun	?	Defective receiver
HFR	12-Jun	19-Jun	7	Flooded

Table 4. Continued.

Location	Start Date	End Date	Duration	Explanation
LSR	?	6-Sep	?	Power out
WHU	9-Aug	12-Aug	3	Dead battery
WIN	19-Sep	22-Sep	3	Memory full
LWD	20-Sep	22-Sep	3	Dead battery
WHR	27-Sep	29-Sep	2	Memory full
KTR	21-Sep	30-Sep	9	Cable cut
SNR	23-Sep	9-Oct	16	Cable cut
JDR	25-Aug	14-Oct	50	Receiver locked up
LWD	1-Nov	3-Nov	2	Not scanning
LWS	3-Nov	4-Nov	1	Antenna knocked over
MFS	?	13-Nov	?	Cable cut
WHD	1-Dec	12-Dec	12	Dead battery

Data for Rock Island, Rocky Reach and Wells dams provided by PUDs

Statistical Methods

Our sampling effort was restricted in space and time due to the location of the trapping facility and the trapping schedule (daytime only with approximately 10 d of sampling and 4 d no sampling). From early June to early August, we unselectively outfitted sockeye salmon with transmitters, but sampling rates varied (see Figure 7) due to fluctuations in the run and in tagging effort. Although not strictly random, we believe our sampling was mostly representative of the sockeye run. We did not analyze fish based on tagging schedule or release date because stocks of sockeye salmon migrated as a relatively homogenous unit to the middle Columbia River. Sockeye salmon destined for the Wenatchee and Okanogan rivers comprised 97% of fish last recorded in tributaries. Median tag dates for Wenatchee and Okanogan river stocks was 29 June. Arrival at mid-Columbia River dams was also similar for both stocks. Wenatchee River stocks passed Rock Island Dam on median date of 17 July, while the median arrival date at Wells Dam for Okanogan River was 20 July.

We used flow, spill, temperature, turbidity, and dissolved gas data collected at each dam to develop models on the influence of environmental conditions on sockeye passage. Most environmental conditions varied continuously at monitored dams during the study period, and several were highly autocorrelated through time and were not independent random variables (i.e. total flow and spill). We used reported daily mean values in all models, but conditions encountered by individual fish likely differed from daily means, and some fish encountered a range of conditions at a given dam. Given these statistical limitations, we believe results from modeling related to environmental conditions should be used as indicators of general trends. The study was not designed to experimentally test hypotheses related to in-river conditions (i.e. using discreet spill or flow patterns).

Because sockeye salmon passage times tended to be right-skewed, we used nonparametric Wilcoxon scores and Kruskal-Wallis chi-squared (K-W X^2) tests (PROC NPAR1WAY, SAS Institutes Inc., 1990) in time comparisons. If distributions were near normal we used parametric tests in addition to nonparametric tests. We used standard Z tests, chi-squared (X^2) tests of independence or X^2 goodness-of-fit tests for proportional data. All tests were two-tailed unless otherwise noted.

We initially used graphical methods for exploring univariate regression data to identify linear and non-linear trends, using loess and other data smoothing techniques. We examined residuals from univariate models for outlying data points and for non-normality of residuals; non-normal errors were relatively common due to covariance and autocorrelation in environmental variables. Prior to building multiple regression models, we created scatterplot matrices of independent variables and identified outlying data groupings using SAS/INSIGHT. We chose forward stepwise regression to identify the most influential variables affecting passage time past projects and reservoirs, and also compared groups of models using subsets of independent variables (PROC REG, SAS Institutes Inc., 1990). We chose a *P* cutoff value of 0.15 for multiple regression models because univariate correlations were relatively low in many cases. Our objectives in model building were to identify general trends and influential variables rather than to produce fully predictive models.

Methods and Results

For sockeye salmon tagged in 1997, we tested whether fish bound for specific tributaries or released at different sites passed Bonneville Dam via the Bradford Island and Washington-shore fishways at different than expected rates. We released 287 (49.7%) sockeye salmon with transmitters at Dodson Landing (south shore) and 290 (50.3%) at Skamania Landing (north shore). More than three-quarters of fish from both release sites were first recorded at the south-shore tailrace antenna (Table 5). About 54% of all sockeye salmon with transmitters first approached Bonneville Dam at powerhouse I, 21% first approached at powerhouse II, and 25% first approached at entrances adjacent to the spillway. Proportions were significantly different for fish from both release sites ($P = 0.01$, X^2 test).

Table 5. Number of sockeye salmon with transmitters released downstream from Bonneville Dam by location, percentage[1] that were first recorded at south- and north-shore tailrace receivers and percentage that passed ladders that were recorded passing the Bradford Island and Washington-shore ladders in 1997. Total ladder counts provided for comparison.

	Number released	First tailrace (%) south	First tailrace (%) north	First approach (%) PH1	First approach (%) PH2	First approach (%) spill	Ladder passed (%) Bradford	Ladder passed (%) WA-shore
Sockeye salmon with transmitters								
All	577 (100%)	77.6	22.4	49.8	26.9	23.3	65.9	34.1
Dodson	287 (50.3%)	74.2	25.8	54.4	20.6	25.0	69.0	31.0
Skamania	290 (49.7%)	81.0	19.0	45.3	32.9	21.7	63.1	36.9
Total sockeye salmon counts in ladders								
All sockeye salmon 9 June to 5 August[2]							54.9	45.1

[1] percentage of those recorded at tailrace sites, not percentage of those released
[2] time period that radio-tagged fish were passing Bonneville Dam

Among sockeye salmon that eventually passed Bonneville Dam via ladders, 66% used the Bradford Island ladder and 34% used the WA-shore ladder (Table 5). We also compared total ladder passage by fish with transmitters to passage proportions for all sockeye salmon counted at the dam based on daily ladder passage reports (USACE 2001 DART electronic database). During the time radio-tagged fish were passing the dam (11 June to 6 August), 54.9% of all sockeye salmon and 65.9% of radio-tagged sockeye salmon passed via the Bradford Island ladder (Table 5).

Radio- tagged fish from both release sites passed via the Bradford Island ladder at significantly higher than expected rates ($P < 0.01$, X^2 goodness-of-fit test). Although not always significantly higher, the proportion of radio-tagged salmon passing via the Bradford Island ladder was higher than the proportion of all fish passing the ladder during much of the migration (Figure 9). Proportions were more variable for radio-tagged fish during times in the migration when relatively few tagged fish passed the dam. We separately tested proportions passing during each month during the time that radio-tagged fish were passing the dam, and found tagged fish passed the Bradford Island ladder at significantly higher than expected proportions in June and July ($P < 0.01$, X^2 goodness-of-fit test), but not in August ($P = 0.61$; Table 6).

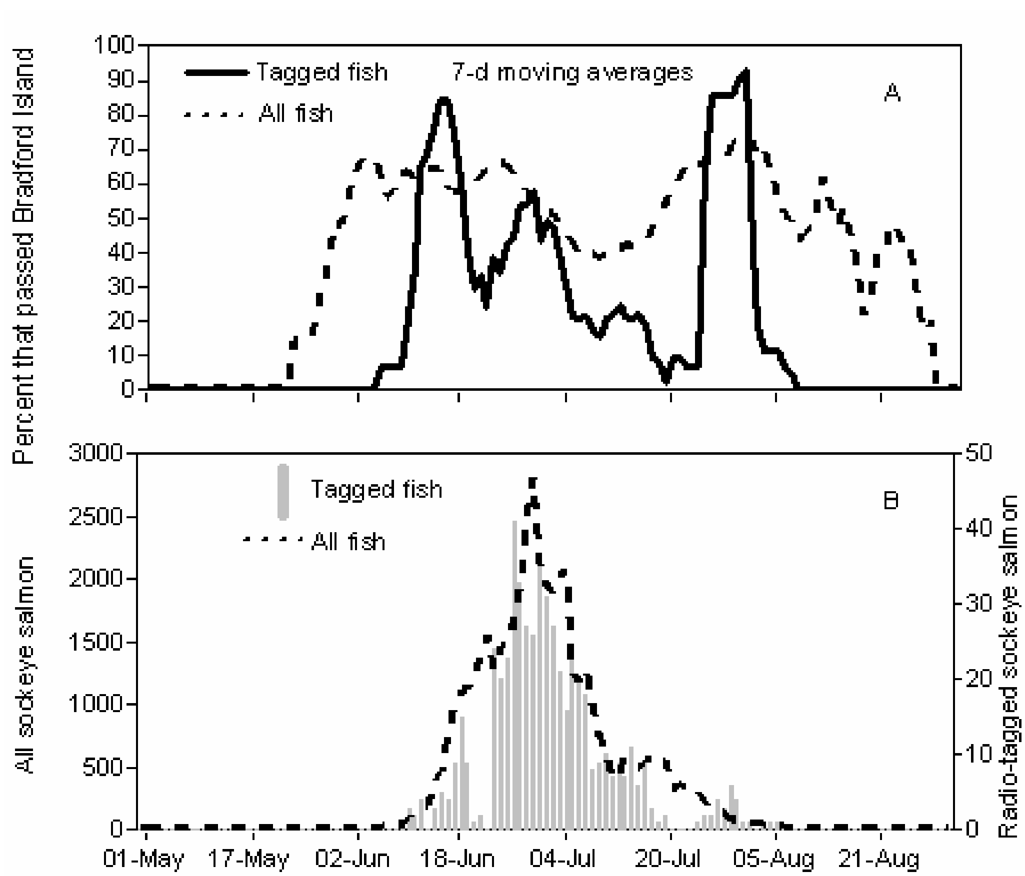


Figure 9. (A) Proportion of radio-tagged sockeye salmon and of all sockeye salmon that passed Bonneville Dam via the Bradford Island ladder in 1997, based on 7-d moving averages. (B) Number of radio-tagged sockeye salmon and all sockeye salmon counted passing Bonneville Dam via ladders in 1997.

We found little evidence that ladder preference affected upstream passage or final distribution of sockeye salmon with transmitters. Similar proportions of radio-tagged fish passed upstream dams as untagged fish, based on ladder counts (Figure 10). A higher proportion of radio-tagged fish than untagged fish passed The Dalles (88.0% versus 69.0%), John Day (83.0% versus 76.0%) and Rock Island (74.0% versus 66.0%). A lower proportion of radio-tagged fish than untagged fish passed Priest Rapids (96.0% versus 77.0%), Wanapum (88.0% versus 76.0%) and Rocky Reach (54.0% versus 43.0%) dams. Similar proportions of radio-tagged and untagged fish passed McNary Dam (81.0% versus 80.0%).

We also tested if fish last recorded in specific tributaries passed the Bradford Island ladder in different than expected proportions. We derived expected proportions from counts of all fish that passed the Bradford Island ladder each month. Proportions ranged from 55.0% in July to 83.3% in August (Table 6). As stated previously, radio-tagged fish passed via Bradford Island at higher that expected rates in June and July and for the entire range of dates that tagged fish were passing the dam. Fish that returned to the Wenatchee and Okanogan rivers passed the Bradford Island ladder at higher than expected rates in June and July ($P < 0.01$).

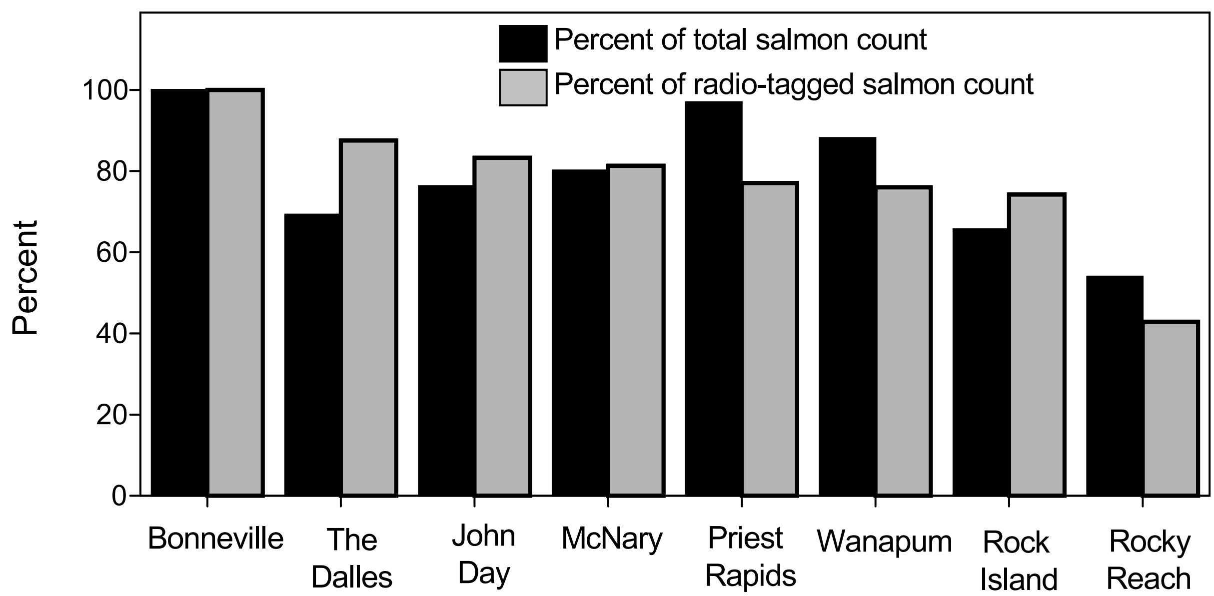


Figure 10. Percent of all sockeye salmon counted at Bonneville Dam and radio-tagged sockeye salmon recorded passing Bonneville Dam that were recorded at Columbia River dams in 1997.

Table 6. Number and percentage of all sockeye salmon with transmitters that passed the Bradford Island ladder at Bonneville Dam during each month that radio-tagged fish were passing in 1997. For returns to specific tributaries, proportions that passed via the Bradford Island ladder were compared to expected proportions based on total counts using X^2 goodness-of-fit tests.

	June-Aug[1]	June[1]	July	Aug[1]
Number that passed Bradford Island ladder				
All fish	**25,700**	14,110	11,391	199
All tagged fish	340	174	161	5
Wenatchee	115	66	48	1
Okanogan/Wells Dam	117	66	51	0
Percent that passed Bradford Island ladder				
All fish	**54.9**	**61.3**	**48.5**	**74.1**
All tagged fish	64.0	74.5	55.0	83.3
Wenatchee	68.0**	75.0**	60.0	100
Okanogan	61.3**	74.1**	60.5	0.0

[1] data from 9 June to 5 Aug
† $P < 0.10$; * $P < 0.05$; ** $P < 0.005$, X^2 goodness-of-fit test

Passage, Migration History, and Final Distribution of Sockeye Salmon

Methods

In this report of the general migration of adult sockeye salmon, we classified passage at a dam as successful for any radio-tagged fish recorder at top-of-ladder receivers or at sites upriver from a dam, regardless of whether they subsequently fell back over a dam or their final destination was downstream from a dam. Times to pass a dam were calculated from tailrace receiver sites (0.5 to 3.2 km downstream from each dam) to a fish's exit from the top of a ladder or the upstream end of a navigation lock. Times were calculated from the first record on the first trip past the tailrace receiver to the last record at the top of a ladder for fish that were recorded at both sites. The percentage of adult sockeye salmon with transmitters that passed each dam successfully was calculated from the number released and the number known to have passed each dam. The number known to have passed a dam was determined primarily from records of fish passing receivers at the tops of ladders or locks, but also included fish recorded at sites upriver from a dam because receivers at the tops of ladders were not 100% efficient and some fish passed via unmonitored navigation locks. Fish that were not recorded at the top of a ladder, but were recorded at another site further upriver, were treated as successfully passing the dam; they were not included in passage-time analyses for the missed dam.

Passage at Dams

We believe 18 of 577 sockeye salmon (3.1%) outfitted and released with transmitters regurgitated transmitters before reaching spawning areas or hatcheries. Two sockeye salmon regurgitated transmitters that were recovered at or near the release sites downriver from Bonneville Dam, 1 fish regurgitated a transmitter that was recovered at John Day Dam and 15 fish regurgitated transmitters after being recorded at one or more fixed receivers at dam or tributary sites (Table 7). Some of the 18 fish we believe regurgitated transmitters after release were recaptured later and identified as fish that had transmitters by the secondary tag, or their transmitters were recovered in reservoirs, near dams, or in tributaries. We located other presumably regurgitated transmitters by repeated mobile-track records in one main stem location prior to spawning and usually downstream from spawning areas. Some transmitters found in this manner may have been from fish that died prematurely or were regurgitated. Overall, 3 (17%) were known to have regurgitated transmitters based on tag recoveries and 15 (83%) were presumed to have regurgitated transmitters based on circumstances associated with the transmitter.

We included sockeye salmon that regurgitated transmitters in analyses where their telemetry records were valid, i.e. fish that regurgitated transmitters after passing Bonneville Dam were included in passage time calculations at Bonneville Dam. We also included fish that regurgitated transmitters in certain analyses and summaries if fish were later recovered upstream and identified by the secondary tag. Wherever appropriate we distinguished between fish recorded passing receivers, those known to have passed receivers but were not recorded while they retained transmitters, and those that we know passed after regurgitating transmitters.

Of the 570 sockeye salmon we believed retained transmitters beyond the release site, 567 (98.3 %) were recorded on their first passage of the Bonneville tailrace receiver and all fish were known to have reached the tailrace (Table 8). Of the 570 fish, 556 (97.5%) were recorded passing top-of-ladder or top-of-navigation lock receivers, and 562 (98.6%) were known to pass the dam. At least 492 (86%) of the 570 sockeye salmon that retained transmitters after release were known to have passed The Dalles Dam, 468 (82%) passed John Day, 457 (80%) passed McNary, 433 (76%) passed Priest Rapids, 427 (74.9%) passed Wanapum dams (Table 8). Seventy-three percent (417 fish) were known to have passed Rock Island Dam, and 42% (241 fish) passed Rocky Reach Dam. At all dams, the percentage of sockeye salmon known to have passed tailrace and top-of-ladder receivers was greater than the percentage recorded by receivers at those sites (Table 8). The proportion of sockeye salmon recorded at tailrace receivers on their first passage ranged from 79.2% to 99.5% of those that were known to pass tailrace sites at all dams. Tailrace receivers were least efficient at The Dalles (79.2%) and John Day dams (86.4%;Table 8). Tailrace receivers were most efficient at Bonneville (99.5%) and Rocky Reach dams (96.5%).

Table 7. Summary of 577 sockeye salmon outfitted with transmitters in 1997 that likely regurgitated their transmitters, by category based on circumstances associated with the transmitter.

Number			Description
577			sockeye salmon outfitted and released with transmitters
	7		regurgitated transmitters at or near release site, no records at other sites
		1	found at or near release site
		6	fish not recorded at any location after release
	4		regurgitated transmitters found after passing one or more fixed receiver sites
		1	transmitter found in the Bonneville north shore ladder
		1	transmitter found at John Day Dam
		1	transmitter with last telemetry record at The Dalles pool
		1	transmitter with last telemetry record at Priest Rapids Dam
	7		repeatedly mobile-tracked/recorded at same location in 1997 or 1998
		1	in the Bonneville tailrace
		1	in the Bonneville pool
		1	in The Dalles Dam
		1	in the Hanford Reach
		3	at Priest Rapids Dam

At top-of-ladder sites maintained by ICFWRU, the proportion of radio-tagged sockeye salmon recorded on first passage of the dam was 88% or more at all but McNary Dam (42%) and Priest Rapids dams (40%), where top-of-ladder receivers were not operating correctly or memory banks were full during peak passage times (see Table 4). Top-of-ladder efficiency at Rock Island and Rocky Reach dams was about 90%. Most sockeye salmon with transmitters known to have passed a dam's tailrace receiver eventually passed that dam. However, 11.7% of the fish known to have entered John Day Dam tailrace and 7.3% that entered the Rocky Reach Dam tailrace did not pass (Table 8).

Median, first and third quartile passage dates, taken from the last record at the top of a ladder (or navigation lock) at each dam, were progressively later as sockeye salmon outfitted with transmitters moved upriver in 1997 (Figure 11). Median first passage dates for all fish were 1 July at Bonneville Dam, 3 July at The Dalles, 4 July at John Day, and 7 July at McNary dams. Median first passage dates were 14 July at Priest Rapids, 15 July at Wanapum Dam, and 19 July and Rock Island and Rocky Reach dams (Figure 11).

Table 8. Number of adult sockeye salmon released downstream from Bonneville Dam, number that regurgitated transmitters at or near the release site, number and percentage of 570 fish that retained transmitters that were recorded at the tailrace and ladder receivers at each dam, and number and percentage of fish known to have passed the dam.

Rocky		Bonn.	The Dalles	John Day	McNary	Priest Rapids	Wan.	Rock Island	Reach
Sockeye salmon released with transmitters									
	Num.	577	---	---	---	---	---	---	---
Number that regurgitated transmitters at or near the release site[1]									
	Num.	7							
Number and percentage of 570 recorded at first passage of tailrace receiver(s)									
	Num.	567	439	385	429	442	400	394	251
	Per.	99.5	77.0	67.5	75.3	77.5	70.2	69.1	44.0
Number and percentage of 570 known to have passed tailrace receiver(s)									
	Num.	570	508	486	465	446	433	423	260
	Per.	100	89.1	85.3	81.6	78.2	76.0	74.2	45.6
Percentage of those known to pass tailrace that were recorded on first passage of receivers									
		99.5	86.4	79.2	92.3	90.7	92.4	93.1	96.5
Number and percentage of 570 that were recorded at tops of ladders[2]									
	Num.	556	485	429	193	172	413	399	212
	Per.	97.5	85.1	75.3	33.9	30.2	72.5	70.0	37.2
Number and percentage of 570 known to have passed dam									
	Num.	562	492	468	457	433	427	418	240
	Per.	98.6	86.3	82.1	80.2	76.0	74.9	73.3	42.1
Percentage of those known to pass dam that were recorded at tops of ladders[2]									
		98.9	98.6	91.7	42.2	39.7	96.7	95.7	88.0
Number and percent known to pass tailrace receiver(s) that did not pass dam									
	Num.	8	16	57	8	13	6	6	19
	Per.	1.4	3.1	11.7	1.7	2.9	1.4	1.4	7.3

[1] includes fish that were not recorded at any location after release
[2] includes fish recorded at top of navigation locks at Bonneville and McNary dams

At lower Columbia River dams, passage date distributions were approximately the same as the distribution when fish were tagged at Bonneville Dam with a lag of several days for each project (Figure 12). At Bonneville, The Dalles, John Day and McNary dams, passage distributions peaked in early July. Passage distributions peaked in mid-July at middle Columbia River dams. Sockeye salmon with transmitters first passed tailrace receivers throughout the day and night in 1997, although fish tended to pass during daylight hours. Passage of tailrace receivers at Bonneville dam was bimodal,

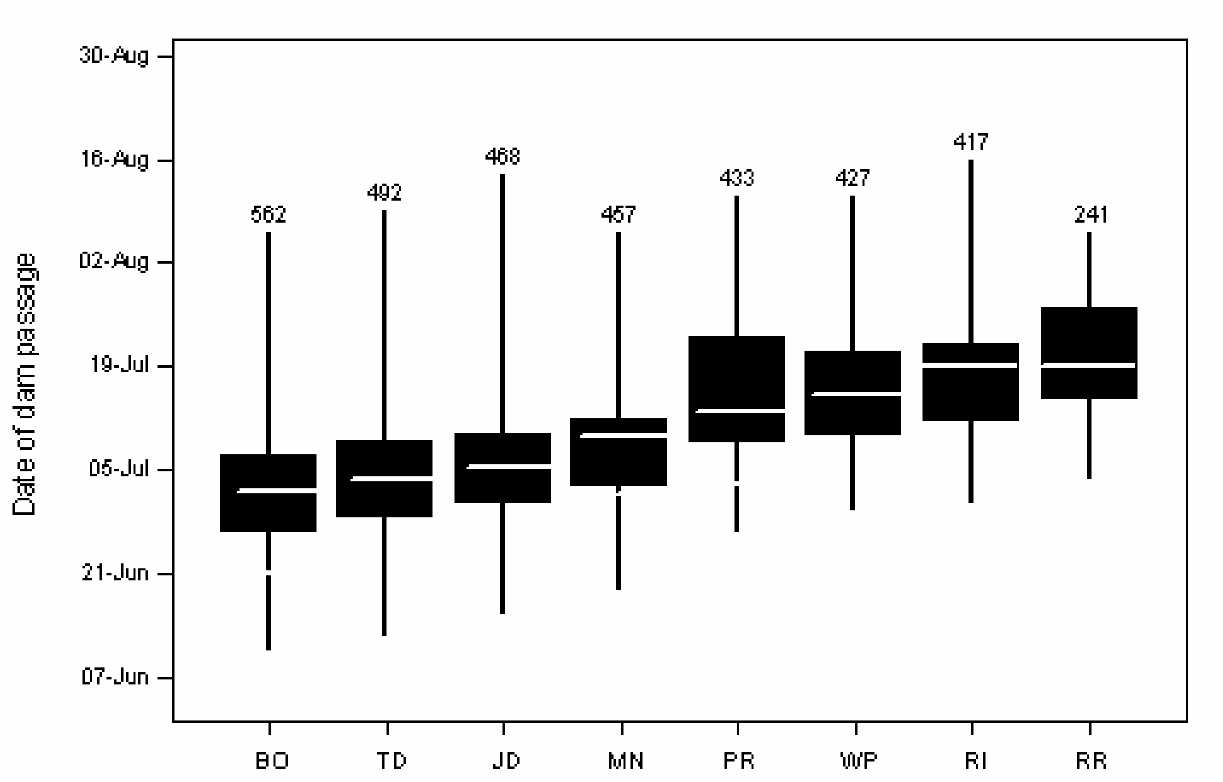


Figure 11. Median, first quartile, third quartile and range of passage dates for all sockeye salmon with transmitters that passed Columbia River dams in 1997. Numbers of fish recorded at each dam adjacent to each range line.

with peaks at 0900 and 1800 hours (Figure 13). By comparison, sockeye salmon tended to pass top-of-ladder receivers primarily during daylight hours, with a small number of fish passing dams after 2100 hours.

Between 0.2% and 3% of sockeye salmon that passed lower Columbia River dams took more than 5 d to pass, and between 0% and 1% took more than 10 d to pass (Figure 14 and Table 9). At mid-Columbia River dams, from 2% to 8% took more than 5 d and from 0.3% to 2% took more than 10 d to pass.

Effects of Environmental Conditions on Sockeye Salmon Passage at Dams

Mean daily flow and spill volumes at Columbia River dams were generally higher than average in 1997, and both spill volume and dissolved gas levels tended to fluctuate with total flow. Mean daily Secchi disk visibility and water temperatures were lower than average through most of the sockeye salmon migration (see Figures 3, 4, and 5). Peak flow and spill conditions occurred during mid-June at Columbia River dams. Peak counts of sockeye salmon occurred in early and mid July at lower Columbia River dams (Figure 15). Peak counts at middle Columbia River dams occurred in early August.

Despite higher-than-average mean daily flow and spill in 1997 and fluctuations in salmon passage with total flow conditions, relationships of flow and spill with passage times of sockeye salmon at individual dams were limited. Univariate correlations of

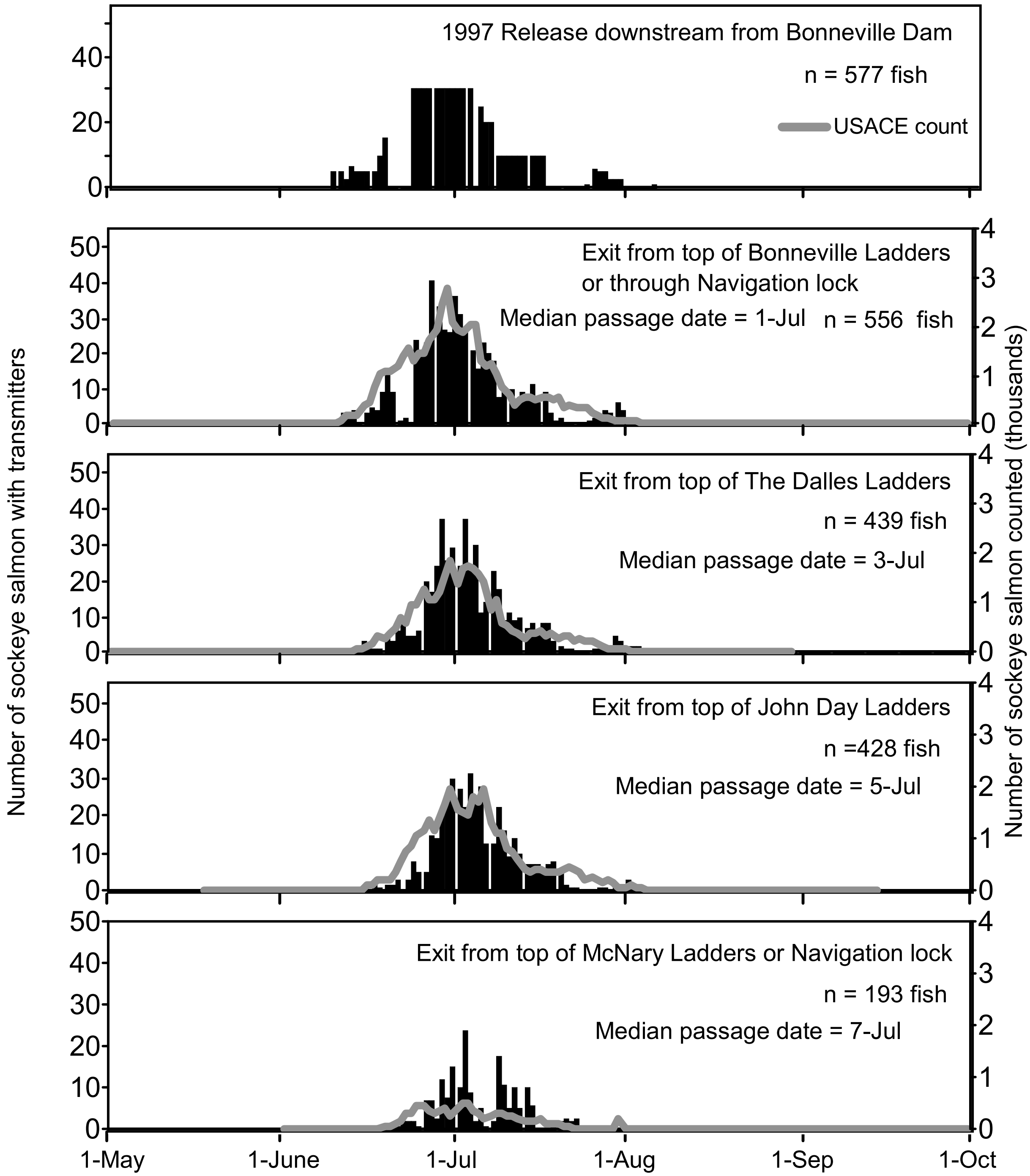


Figure 12. Frequency distributions for the date that sockeye salmon were tagged at Bonneville Dam, and the date they first were recorded at the tops of ladders or navigation locks at Columbia river dams in 1997. Solid line indicates total USACE counts of adult sockeye salmon passing ladders.

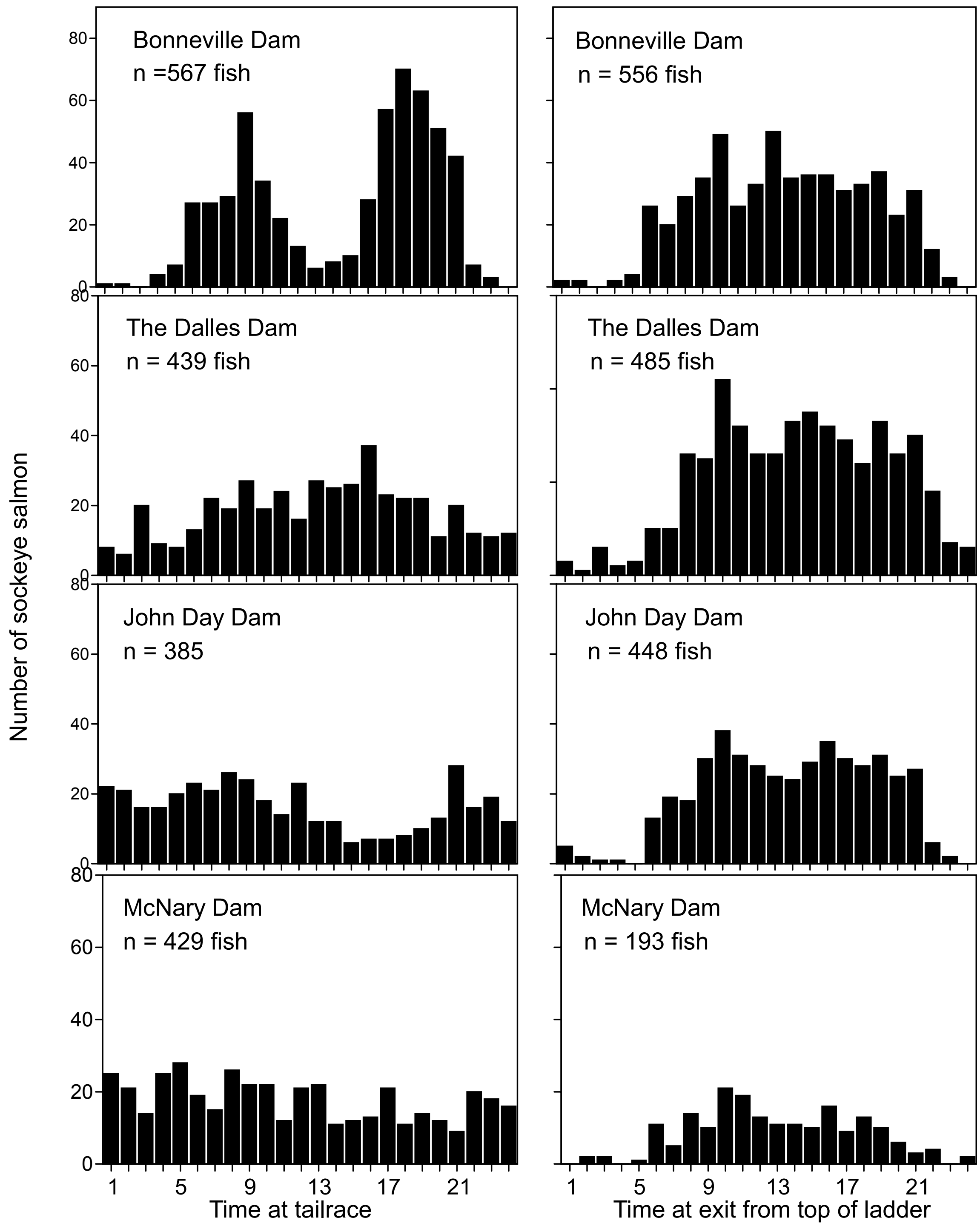
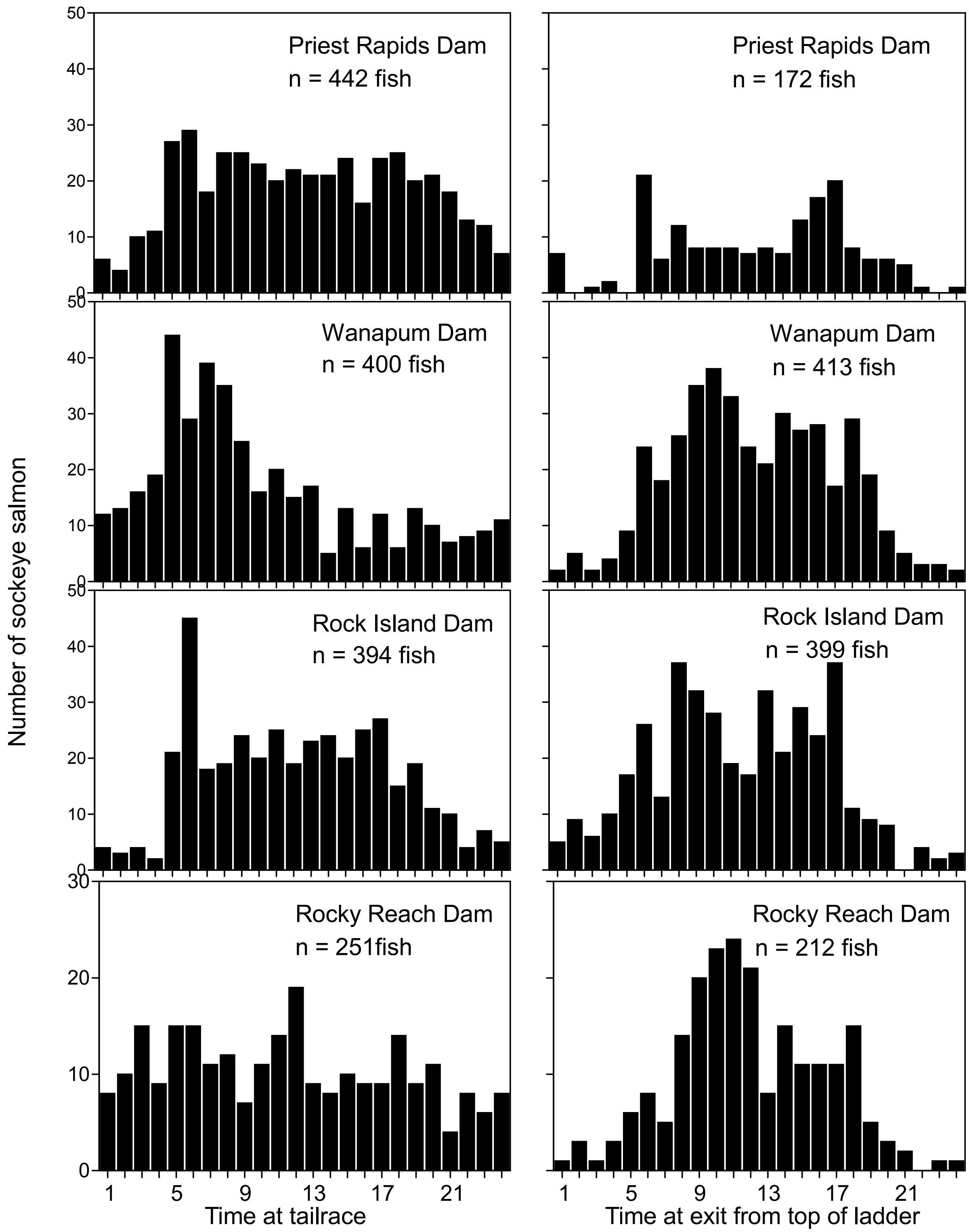


Figure 13. Frequency distribution of time of day that sockeye with transmitters were first recorded at tailrace receivers and last recorded at top-of-ladder receivers at Columbia River dams in 1997.



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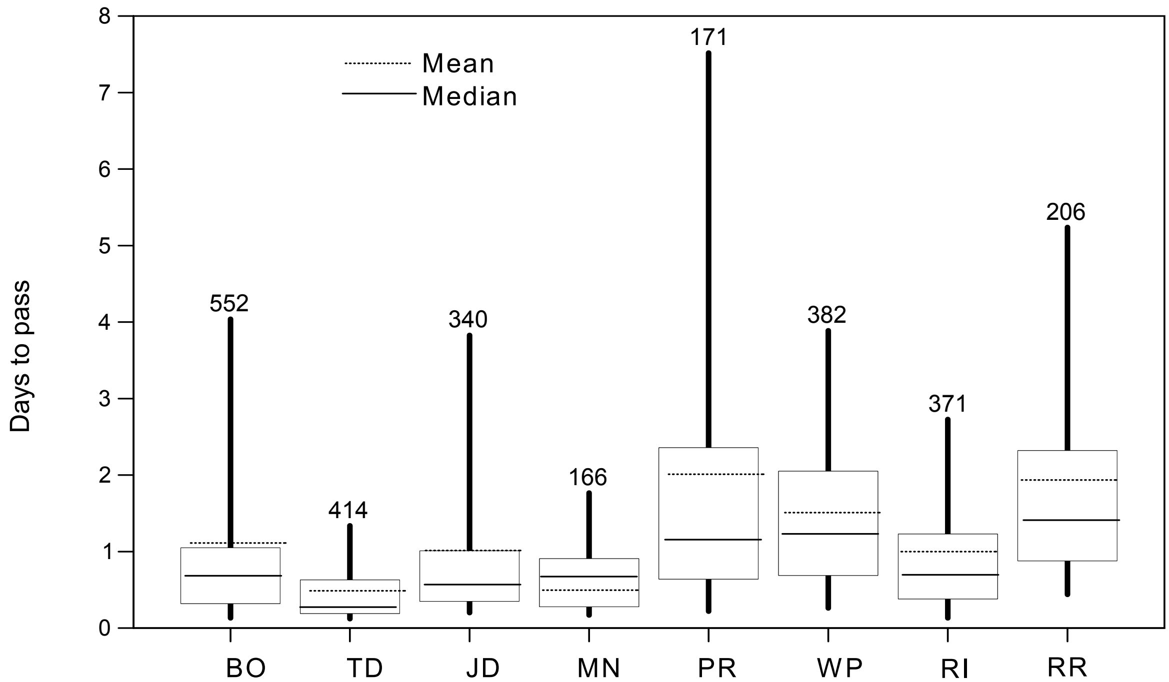


Figure 14. Mean, median, 5% and 95% percentiles, and quartile days sockeye salmon with transmitters took to pass from tailrace receivers to top-of-ladder receivers at dams monitored in 1997.

Table 9. Mean, median and quartile values for sockeye salmon to pass each dam from tailrace receiver sites to tops of ladders, with standard deviations and percentages of fish that took more than 5 and 10 days to pass dams monitored in 1997[1].

	Bonn.	The Dalles	John Day	McNary	Priest Rapids	Wan.	Rock Island	Rocky Reach
Number of fish	552	414	340	142	171	382	371	206
Mean days to pass dam	1.11	0.49	1.04	0.71	2.07	1.59	1.03	1.96
Median days to pass dam	**0.65**	**0.33**	**0.56**	**0.51**	**1.20**	**1.24**	**0.72**	**1.39**
Quartile values								
1st	0.35	0.19	0.35	0.27	0.64	0.69	0.38	0.88
3rd	1.03	0.63	1.01	0.83	2.36	2.05	1.23	2.32
Standard deviations	1.87	0.51	1.50	0.77	2.78	1.57	1.20	1.71
Percentage of fish that took more than 5 days to pass dam	2.2	0.2	2.9	1.4	8.2	2.6	1.6	6.8
Percentage of fish that took more than 10 days to pass dam	1.0	0.0	0.6	0.0	2.3	0.8	0.3	0.5

[1] includes top of navigation lock at Bonneville and McNary dams

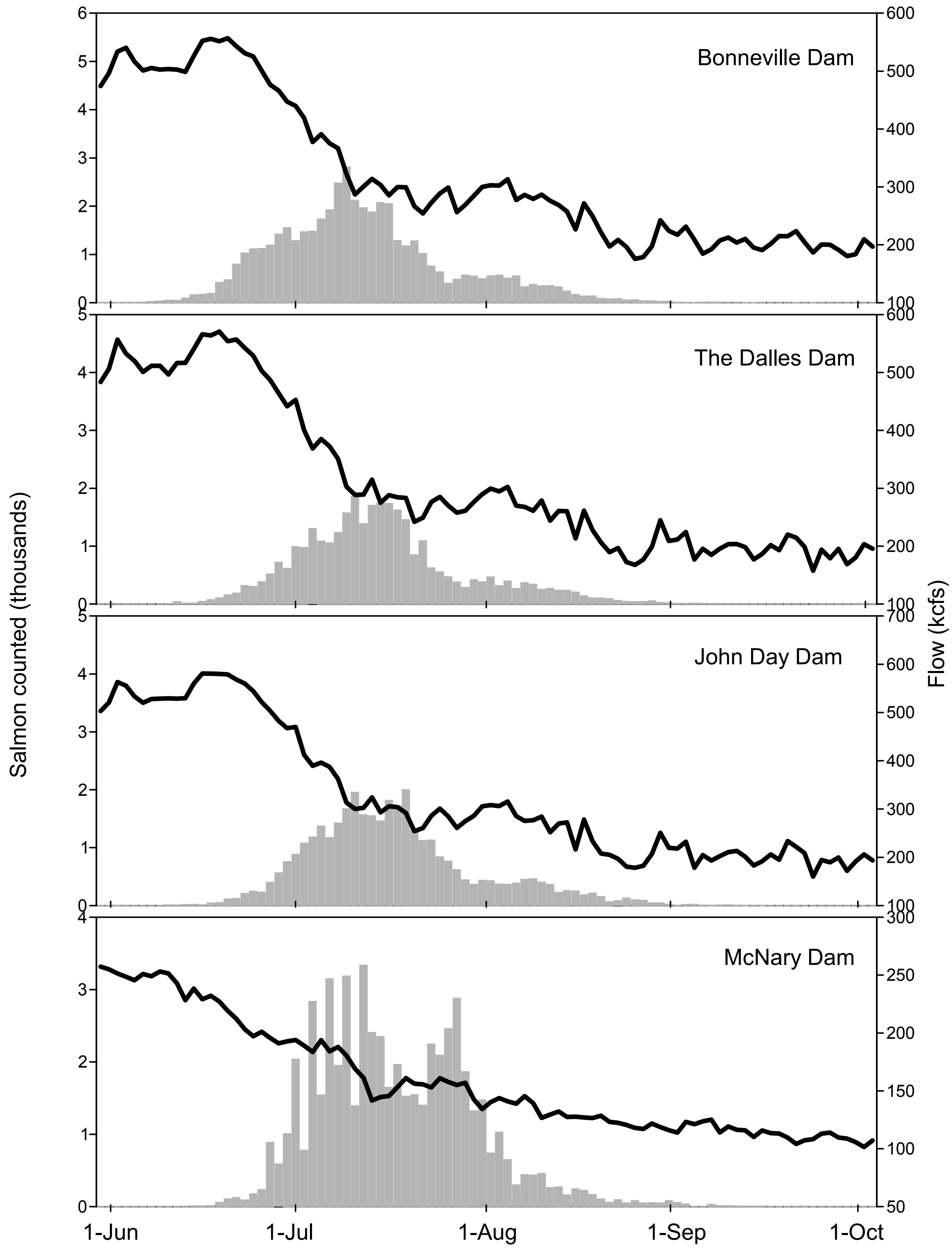


Figure 15. Mean total flow (kcfs) at Bonneville, John Day, and McNary dams during the 1997 sockeye salmon migration, and the number of sockeye salmon counted passing each dam.

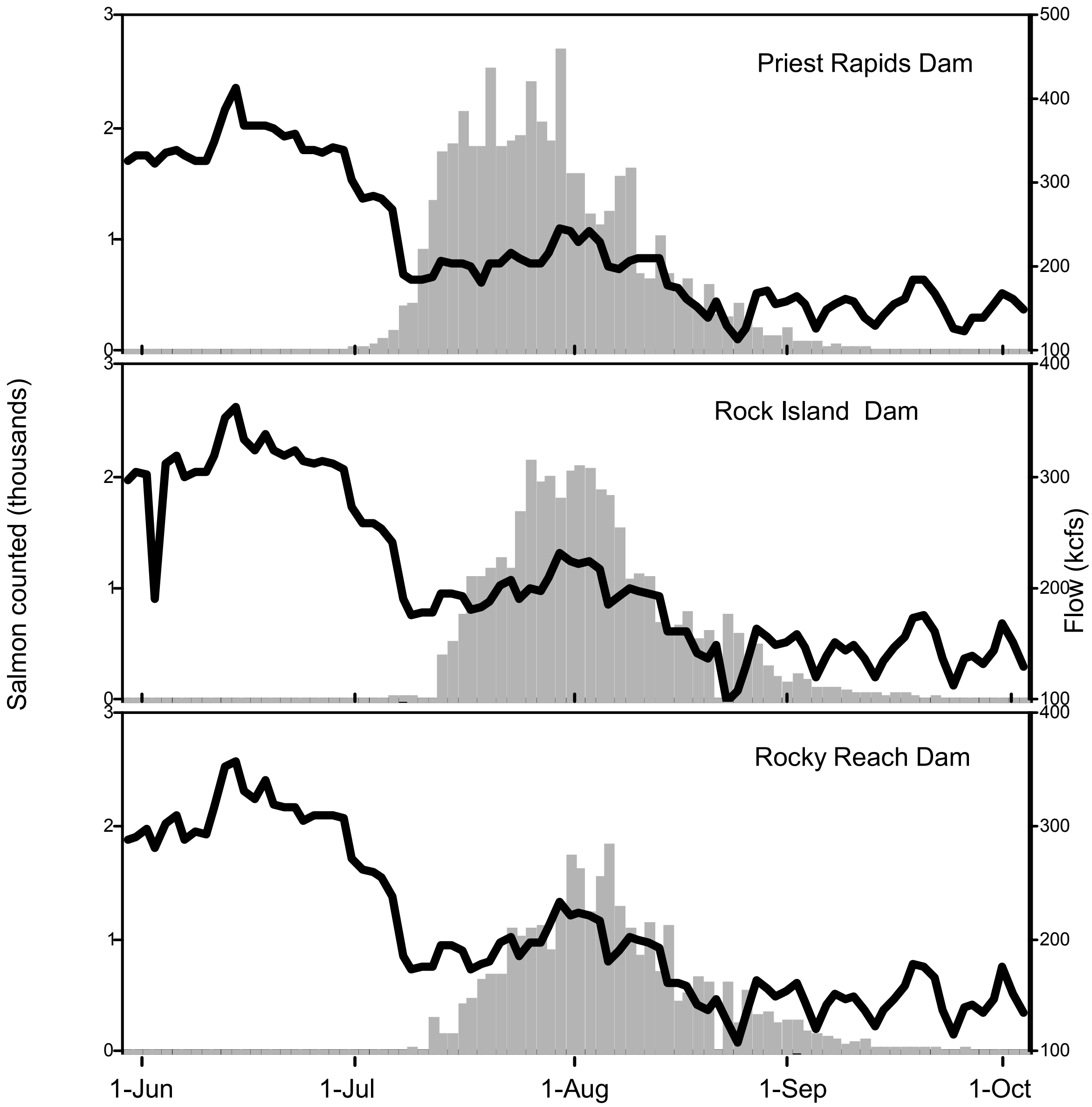


Figure15. Cont.

time to first pass a dam with flow and spill at the time fish passed tailrace receivers were low (r^2 = 0.00 to 0.11 at lower Columbia River dams), and were very low (r^2 < 0.03) at middle Columbia River dams when all fish were included. When we excluded fish with dam passage times > 5 d, correlations were similar at lower Columbia River dams and middle Columbia River dams. At all lower Columbia and middle Columbia river dams, mean daily Secchi disk visibility was correlated with passage times at very low levels (r^2 = 0.00 to 0.03) when all fish were included and when we limited the sample to those that passed in < 5 d. Correlations between mean daily water temperature and dam passage times were very low at lower Columbia River dams. With all data included, passage times decreased with increasing water temperatures, but r^2 values were 0.00 at

Bonneville, The Dalles, and McNary dams and 0.06 at John Day dam. Passage time correlations with water temperature were also low (r^2 < 0.04) at middle Columbia River dams.

We also used grouping methods to decrease passage time variability in univariate models for lower Columbia River and Priest Rapids, Rock Island and Rocky Reach dams. With flow and spill, fish were grouped based on 10 kcfs increments and mean and median passage times were calculated for each group. We used weighted means based on the number of fish in each group. We included all but a small number of outliers in each analyses; the impact of fish with passage time > 5 d was minimized by the use of median times for each block.

For sockeye salmon, median first passage times at dams increased with flow at all dams except McNary and Priest Rapids dams, however sample sizes were small (Table 10). Weighted models were significant at P < 0.05 at Bonneville and John Day dams. Median passage times at dams increased with spill at all dams except McNary Dam (Table 10). Median passage times increased significantly at Bonneville Dam (P < 0.005) and at John Day Dam (P < 0.05).

Multivariate models.**--**We used stepwise multiple regression models to evaluate effects of environmental conditions on passage time from tailrace to top-of-ladder sites at Bonneville, The Dalles, John Day, Rock Island, and Rocky Reach dams. We did not run multiple regression models for McNary or Priest Rapids dams due to receiver outages. Although there was considerable covariance among environmental variables at all dams, in a first series of models we included total flow, spill, Secchi disk depth, dissolved gas level, and water temperature at the first tailrace record date. We included date and time of first tailrace record in additional models. We used a P < 0.15 criteria for inclusion in all models. No variable met the 0.15 selection criteria for entry into the model for Rocky Reach Dam.

At Bonneville Dam, we found environmental conditions when sockeye salmon passed tailrace sites accounted for a small proportion of the variability in passage times. Spill was the first variable selected by the stepwise model, with an r^2 value of 0.02; water temperature and depth were added to the model, increasing r^2 to 0.06 (Table 11). Limiting the model to fish that passed the dam in < 5 d produced a model r^2 of 0.04, with spill, temperature, and flow selected. In similar multiple regression analyses for passage of sockeye salmon at The Dalles Dam, flow was the only variable selected (r^2 = 0.03). Limiting the model to fish that passed the dam in < 5 d also produced a model r^2 of 0.03, with flow selected first. Models that included tailrace date and time were produced a model r^2 of 0.06 with date replacing water temperature as the first variable selected. No stepwise models for sockeye salmon produced r^2 values > 0.06.

For John Day Dam, spill and dissolved gas were the only variables selected with an overall model r^2 of 0.13 (Table 11). When we only included fish with passage time < 5 d, water temperature was the only variable selected, but model r^2 was only 0.09. The addition of passage date and time to models resulted in a similar model with minimally

Table 10. Summary of univariate regression analyses relating flow and spill to time for sockeye salmon to pass dams in 1997, based on weighted models that grouped data by 10 kcfs blocks. Arrows indicate median passage times increased with flow or spill (↑), or decreased with flow or spill (↓).

	n	r^2	↑↓
Models using mean daily flow at time fish passed tailrace receivers			
Bonneville	552	*0.21	↑
The Dalles	414	0.01	↑
John Day	340	*0.20	↑
McNary[1]	166	0.00	↓
Priest Rapids	170	0.12	↓
Rock Island	371	0.05	↑
Rocky Reach	206	0.00	↑
Models using mean daily spill at time fish passed tailrace receivers			
Bonneville	552	0.39	↑
The Dalles	414	0.03	↑
John Day	340	*0.33	↑
McNary[1]	166	0.01	↓
Priest Rapids	170	0.23	↑
Rock Island	371	0.20	↑
Rocky Reach	206	0.15	↑

[1] does not include estimated passage times
* $P < 0.05$, ** $P < 0.005$

improved fit. For sockeye salmon at Rock Island dam water temperature was selected first ($r^2 = 0.09$) and Secchi depth was added for a model r^2 of 0.13.

Effects of Injury on Passage Times

We examined all sockeye salmon outfitted with transmitters in 1997 for injuries, including fresh scrapes and bites from marine mammals, descaling, gill net marks, sores, cuts, and fungal infections. Of 577 sockeye salmon outfitted with transmitters, 346 (60%) had no marine mammal marks, 181 (31%) had fresh scrapes, and 50 (9%) had fresh marine mammal bites. About 67% of 577 salmon had no descaling, 30% had less than 10%, 3% and were 10-25% descaled. None of the sockeye salmon had gill net marks. Approximately 96% had no head or mouth injuries, about 3% had scrapes, cuts, or skinned areas on the head or mouth, < 1% had sores or hook marks, eye injuries, and head or jaw deformities.

We used analysis of variance (ANOVA), nonparametric tests, and X^2 tests to determine whether marine mammal marks, descaling, or head injuries affected migration success or passage times past individual or multiple dams. We first tested whether proportions of sockeye salmon known to have passed Columbia River dams

Table 11. Stepwise multiple regression model outputs for the first passage of sockeye salmon at Bonneville, The Dalles, John Day dams, and Rock Island dams in 1997, including models run, variables retained, and standard procedure outputs.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
			Bonneville			
Model 1, Flow spill, Secchi depth, dissolved gas, water temperature						
	a. Spill		0.0214	0.0214	12.01	0.001
	b. Water temperature		0.0381	0.0167	9.55	0.002
	c. Secchi depth		0.0561	0.0142	8.22	0.004
			The Dalles Dam			
Model 1, Flow, spill, Secchi depth, dissolved gas, water temperature						
	a. Flow		0.0279	0.0279	11.82	0.0006
	b. Temperature		0.0342	0.0063	2.69	0.1018
	c. Temperature		0.0279	0.0063	8.29	0.1018
			John Day Dam			
Model 1, Flow, spill, Secchi depth, dissolved gas, temperature						
	a. Spill		0.1070	0.1070	40.50	0.0001
	b. Dissolved gas		0.1268	0.0198	7.62	0.0061
			Rock Island			
Model 1, Flow, spill, Secchi depth, dissolved gas, temperature						
	a. Temperature		0.0918	0.0918	29.80	0.0001
	b. Secchi depth		0.1275	0.0357	11.65	0.0007

with and without fresh marine mammal marks, descaling, or head injuries differed from the proportion in each category when fish were outfitted with transmitters. Compared to initial proportions, we found a significantly more with no marine mammal marks (X^2 P = 0.02) passed Wanapum Dam. Differences between initial proportions and proportions that passed the other dams were not significant.

We found few significant relationships between incidence of fresh marine mammal marks and passage times from tailrace to top-of-ladder receivers at individual dams (comparisons only made for dams in Table 12). Using 3-category (no marks, fresh scrape, fresh bite) and 2-category (no marks vs. fresh scrapes or bites) ANOVA and nonparametric tests, we found no significant differences (P > 0.10) in passage time comparisons for sockeye at Bonneville, The Dalles, McNary, Priest Rapids, Wanapum, Rock Island, and Rocky Reach dams (Table 12). At John Day Dam, sockeye salmon with fresh marine mammal scrapes had the highest median passage times (P = 0.05, K-W X^2 test). Fish with passage times > 10 d were excluded from the above comparisons to reduce variance; including those fish did not substantively affect results.

Table 12. Median passage times past dams by sockeye salmon with or without fresh marine mammal scrapes or bites, descaling, or head injuries at time of tagging at Bonneville Dam in 1997. Sockeye salmon with passage times > 10 d not included.

	Marine mammal marks			Descaling			Head injuries	
	none	scrape	bite	none	<10%	>10%	none	injury
Bonneville Dam								
Number	331	169	46	369	162	15	526	20
Median time (d)	0.63	0.59	0.74	0.64	0.60	0.47	0.63	0.60
The Dalles Dam								
Number	249	138	27	275	128	11	400	14
Median time (d)	0.33	0.32	0.35	0.34	0.30	0.52	0.32	0.61
John Day Dam								
Number	196	117	25	212	116	10	322	16
Median time (d)	0.59†	0.72†	0.56†	0.58	0.55	0.55	0.57	0.48
McNary Dam								
Number	99	57	10	106	56	4	161	5
Median time (d)	0.50	0.64	0.57	0.62	0.46	0.48	0.53	1.06
Priest Rapids Dam								
Number	99	54	12	113	50	3	160	5
Median time (d)	1.18	1.08	1.64	1.17	1.27	1.07	1.16	1.43
Wanapum Dam								
Number	219	160	26	253	119	7	365	14
Median time (d)	1.23	1.22	1.05	1.26†	1.18†	0.76†	1.24	0.99
Rock Island Dam								
Number	209	131	30	242	120	8	357	13
Median time (d)	0.73	0.75	0.60	0.73	0.71	0.54	0.72	0.67
Rocky Reach Dam								
Number	115	75	15	139	62	4	196	9
Median time (d)	1.39	1.48	1.26	1.37	1.40	1.71	1.37*	3.00*

† $P < 0.10$; * $P < 0.05$, K-W X^2 test

Relatively few (1% to 3%) sockeye salmon with transmitters that passed dams had > 10% descaling (Table 12). Differences in median passage times were only significant at Wanapum Dam ($P = 0.06$, K-W X^2 test) where fish with >10% descaling had higher median passage times. Head injuries (described previously) did not appear to affect individual dam passage times. Differences in median passage times for sockeye salmon with head injuries were only significant at Rocky Reach Dam ($P = 0.03$, K-W X^2 test: Table 12).

We found little evidence that fresh marine mammal scrapes or bites delayed sockeye salmon migrations past multiple dams. Median passage times from the Bonneville Dam tailrace to the top of McNary and Priest Rapids dams were not significantly different for sockeye salmon with or without fresh marine mammal marks (*P*

> 0.10, 2- and 3-category ANOVAs and nonparametric tests) (Table 13). Sockeye salmon with marine mammal marks had significantly longer median passage times from the Bonneville Dam tailrace to Rock Island and Rocky Reach tailraces ($P < 0.10$, K-W X^2 test). Sockeye salmon with descaling had significantly longer median times to pass from the Bonneville Dam tailrace to McNary Dam ($P = < 0.06$, K-W X^2 test) than fish without descaling; we found no significant differences in median times from Bonneville to the top of Priest Rapids, Rock Island and Rocky Reach dams (Table 13). We found no significant differences in median passage times for fish with and without head injuries (Table 13).

Table 13. Median passage times past multiple dams by sockeye salmon with or without fresh marine mammal scrapes or bites, descaling, or head injuries at time of tagging at Bonneville Dam in 1997.

	Marine mammal marks			Descaling			Head injuries	
	none	scrape	bite	none	<10%	>10%	none	injury
Bonneville Dam tailrace to top of McNary Dam								
Number	113	64	14	121	65	4	184	7
Median time (d)	6.83	6.92	8.35	7.22†	6.67†	5.86†	6.85	8.67
Bonneville Dam tailrace to top of Priest Rapids Dam								
Number	101	55	12	113	52	3	161	7
Median time (d)	13.0	12.61	12.71	12.91	13.22	10.96	12.91	14.12
Bonneville Dam tailrace to top of Rock Island Dam								
Number	223	139	30	260	124	8	377	15
Median time (d)	16.87	17.88	17.15	17.18	17.46	18.01	17.26	19.00
Bonneville Dam tailrace to top of Rocky Reach Dam								
Number	118	75	16	145	60	4	200	9
Median time (d)	18.94†	19.57†	17.01†	19.06	18.80	16.39	19.00	18.75

† $P < 0.10$; * $P < 0.05$, ** $P < 0.005$ K-W X^2 test

Passage Through Reservoirs

Most sockeye salmon with transmitters migrated through individual Columbia River reservoirs at rates between 38 km/d and 64 km/d (Figure 16). Within the hydrosystem, median passage rates were lowest from McNary Dam to the downstream end of the Hanford Reach (59.0 km/d), Priest Rapids (38.8 km/d), and Rock Island (37.9 km/d) pools for sockeye salmon from the last record at top-of-ladder receivers to the first record at tailrace receivers at the next upriver dam. Median rates were highest (> 57 km/d) through the John Day, The Dalles, and Bonneville pools. Sockeye salmon took a median of 1.22 d to pass through the Bonneville pool, 0.59 d through The Dalles pool, 1.86 d through the John Day pool, 4.61 d through the McNary pool to the Priest Rapids

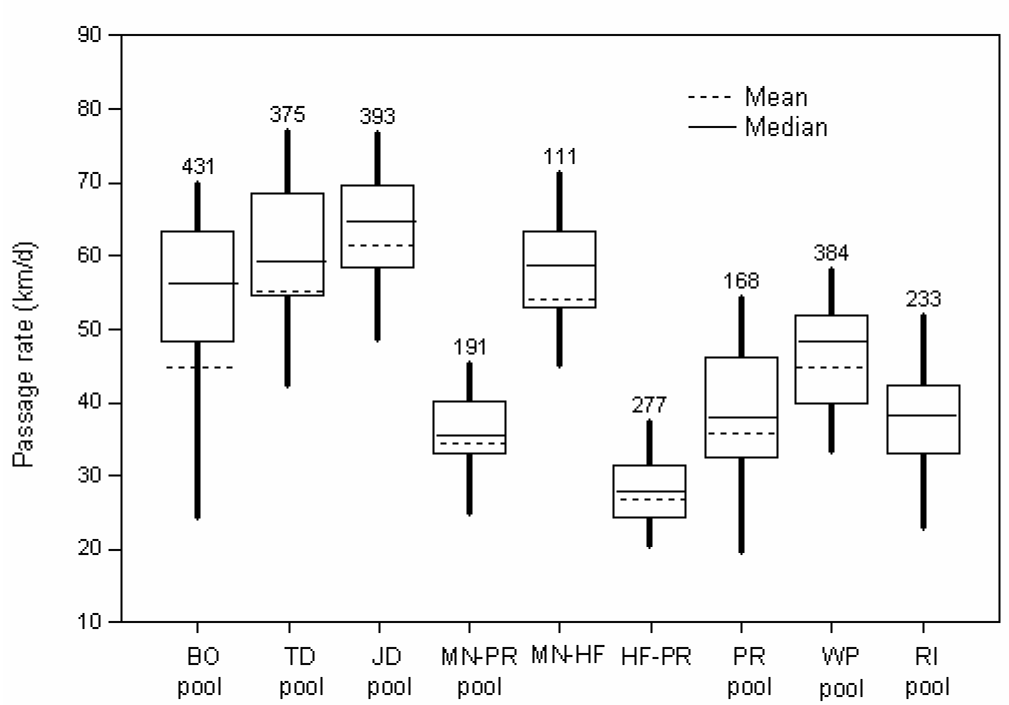


Figure 16. Median, 5% and 95% percentiles, and quartile passage rates for sockeye salmon through reservoirs in the 1997. Times are from last record at the top a ladder to first record at upstream tailrace and do not include fallback time.

tailrace; median passage rates were < 1 d through the Priest Rapids and Rock Island pools and > 1 d through the Wanapum pool (Table 14). Mean passage times were higher than medians through all reservoirs because some fish took several days or weeks to pass. We included time that sockeye salmon temporarily strayed into tributaries in total pool passage time, but did not include time fish spent downstream from the downstream dam after fallback events.

Table 14. Median passage times and rates for sockeye salmon to pass each reservoir from the last record at tops of ladders to the first record at tailrace receivers in 1997. Times do not include downstream fallback time.

	Bonn.	The Dalles	John Day	McNary	Priest Rapids	Wan.	Rock Island
Number of fish							
All fish	431	375	393	191	168	384	233
Median days to pass through reservoirs							
All fish	1.22	0.59	1.86	4.61	0.78	1.28	0.86
Median passage rates (km/d) through reservoirs							
All fish	57.1	62.2	64.7	36.4	38.7	47.4	37.8

We also calculated passage times from the top of McNary Dam to a receiver (rkm 553) near the transition between the McNary reservoir and the unimpounded portion of the Hanford Reach of the Columbia River and from the Hanford receiver to the tailrace of Priest Rapids Dam. Median passage rates were 59.0 km/d through the impounded reach from McNary to the Hanford receiver and 28.2 km/d through the unimpounded reach to the tailrace at Priest Rapids Dam (Figure 16).

Passage Past Multiple Dams

We calculated median passage times past multiple dams for sockeye salmon with transmitters that were recorded at top-of-ladder sites at McNary, Priest Rapids, Rock Island, and Rocky Reach dams and at tailrace receivers downstream from Bonneville Dam. Passage times for 192 sockeye salmon from the Bonneville Dam tailrace to the top of a ladder at McNary Dam ranged from 4.0 d to more than 29 d with median time of 6.9 d (Figure 17).

Passage times for 178 sockeye salmon from the Bonneville Dam tailrace to the top of a ladder at Priest Rapids Dam ranged from 8.5 d to more than 30 d with median time of 12.9 d (Figure 17). Median passage times for 397 sockeye salmon from the Bonneville Dam tailrace to the top of a ladder at Rock Island Dam were 17.3 d (Figure 17). Median passage times from the Bonneville Dam tailrace to the top of Rocky Reach Dam were 19.0 d for 212 fish with records at both sites.

Passage times past multiple upriver projects were negatively correlated with the date that radio-tagged fish passed the Bonneville Dam tailrace. A linear regression for 192 sockeye salmon recorded on their first passage of the Bonneville Dam tailrace and at the top of McNary Dam had an $r^2 = 0.20$ using passage time as the dependent variable and date at the Bonneville tailrace site as the independent variable (Figure 18). Passage times from the Bonneville Dam tailrace to the top of Rock Island and Rocky Reach dams were also negatively correlated with date at the Bonneville Dam tailrace, with r^2 values of 0.15 and 0.26 (Figure 18). The regression value was lower for fish that passed Priest Rapids Dam with an r^2 value of 0.02 (Figure 18).

To examine sockeye salmon passage rates past multiple dams with less influence by delays that may have been associated with the Bonneville and The Dalles pools, we calculated passage times from the first record in the McNary Dam tailrace to the first passage of top-of-ladder receivers at Priest Rapids, Rock Island, and Rocky Reach dams. The 162 sockeye salmon with records at both the McNary tailrace and the top of a ladder at Priest Rapids Dam had a median passage time of 6.3 d. Median passage times from the McNary Dam tailrace were 10.9 d for 371 sockeye salmon to the top of Rock Island Dam and 12.6 d for 197 salmon to the top of Rocky Reach Dam (Figure 19).

On average, sockeye salmon with transmitters spent about one-third of their total upstream migration time passing dams (Figure 20). We summed passage times from first records at tailrace sites until fish passed over each dam (additional passages after fallback not included) and calculated the percentage of total passage time from the Bonneville Dam tailrace that was spent passing dams. Initially, we only included fish

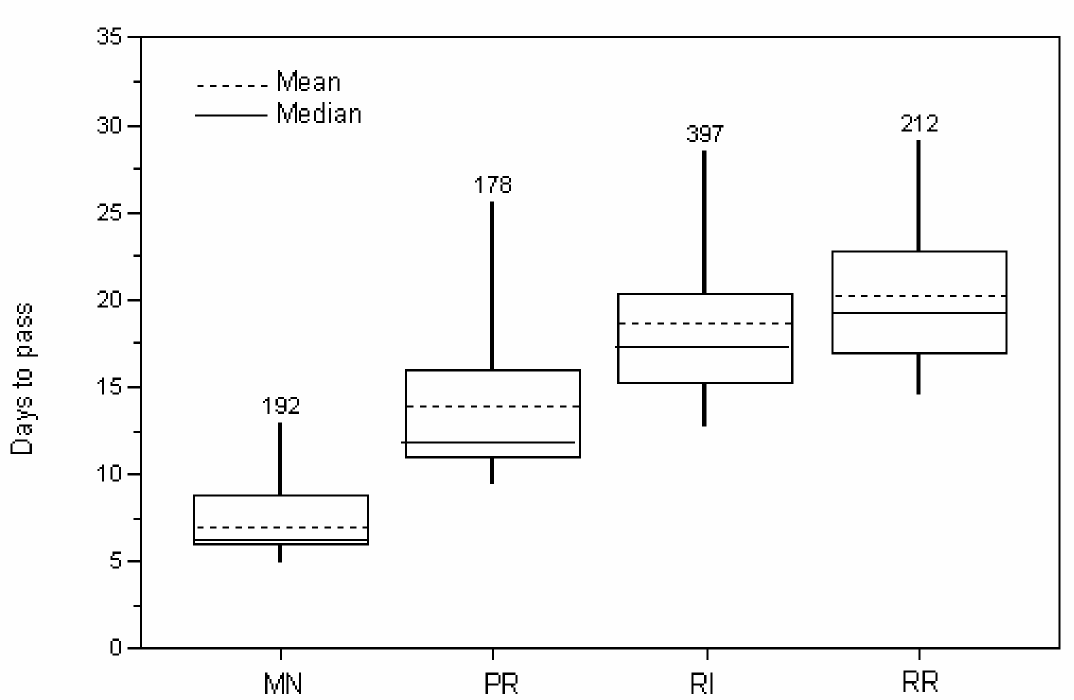


Figure 17. Mean, median, 5% and 95% percentiles, and quartile days sockeye salmon with transmitters took to pass from the Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Priest Rapids, Rock Island, and Rocky Reach dams in 1997.

recorded at the tailrace and top-of-ladder receivers at each monitored dam. When we did not include estimated passage times at McNary Dam, fish spent a median of 43% of the total passage time from the Bonneville Dam tailrace to the top of McNary Dam passing dams, 28% to the top of Priest Rapids Dam, 37% to the top of Rock Island Dam, and 38% to the top of Rocky Reach Dam. Sockeye salmon with longer cumulative time to pass the dams tended to have longer total passage times to migrate from the Bonneville Dam tailrace to upriver dams. For each segment of the migration analyzed, total migration times increased with cumulative dam passage times. Time fish spent passing dams explained 75% to 92% of the variability in total upstream passage time (Figure 21).

Fallback at Dams

Higher-than-average flows in 1997 resulted in nearly continuous spill at all study dams on the Columbia and Snake rivers during the sockeye salmon migration. In previous years, high levels of spill increased fallback rates (Bjornn and Peery 1992), and we found similar patterns in 1997. (Complete analyses of fallback behavior at Bonneville, The Dalles, and John Day dams were reported in Bjornn et al. 2000a, 2000b, and 2000c).

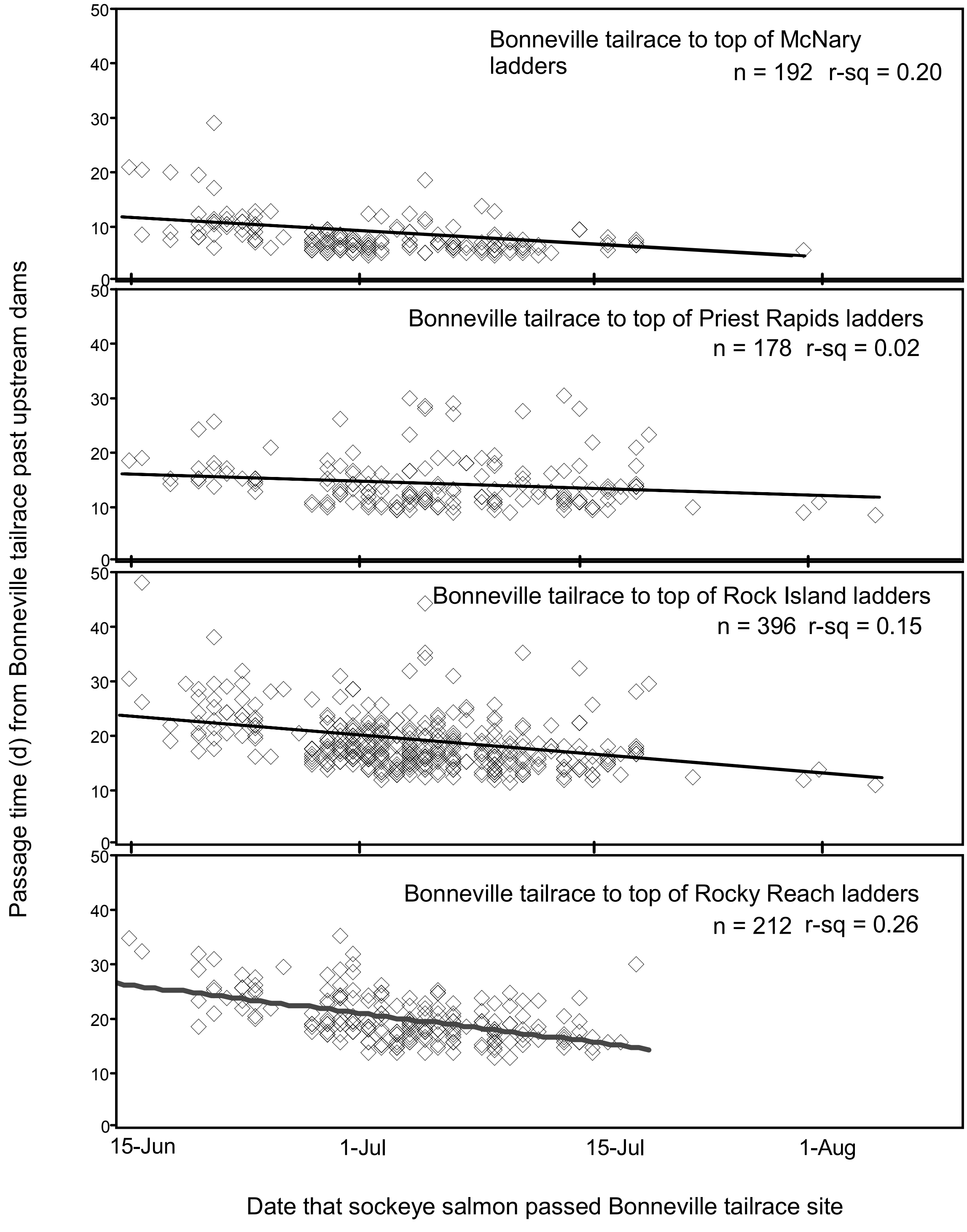


Figure 18. Days to pass from the Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Priest Rapids, Rock Island, and Rocky Reach dams for sockeye salmon with transmitters in 1997.

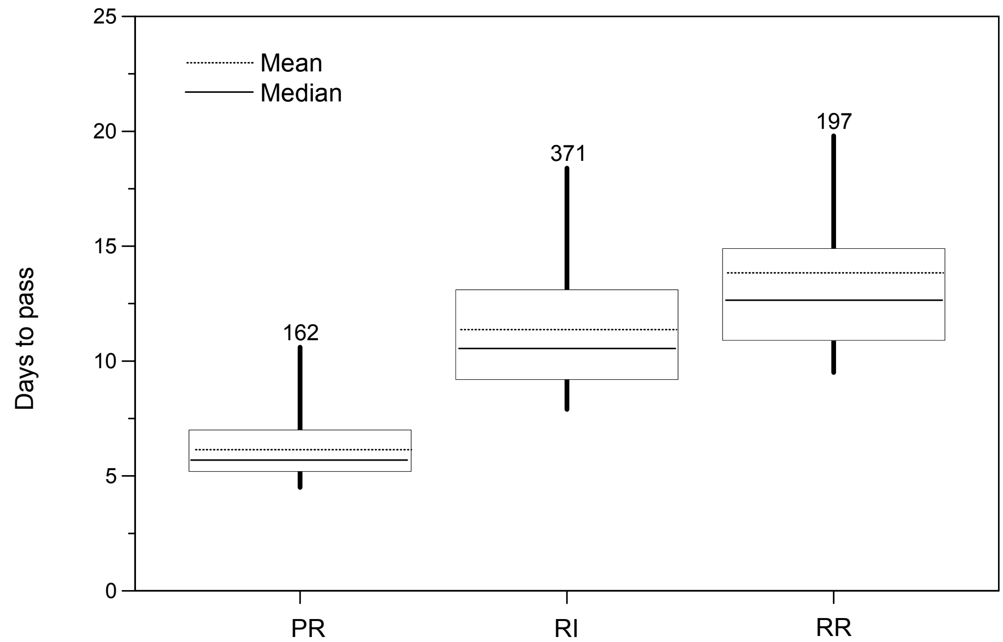


Figure 19. Mean, median, 5% and 95% percentiles, and quartile days sockeye salmon with transmitters took to pass from the McNary Dam tailrace receivers to top-of-ladder receivers at Priest Rapids, Rock Island and Rocky Reach dams in 1997. Estimated times included for Priest Rapids dam during top-of-ladder receiver outages.

At least 164 sockeye salmon with transmitters fell back at least once at one or more of the 8 monitored Columbia River dams. We believe most fell back over spillways, but a few fell back through powerhouses, navigation locks, juvenile bypass systems, or ice and trash sluiceways in 1997. Of the 562 sockeye salmon known to have passed Bonneville Dam, 29.2% eventually fell back at a monitored dam. The 164 fish had 181 recorded fallback events, of which 77 (43%) were at Bonneville Dam. Of 562 sockeye salmon known to have passed Bonneville Dam, 76.3% did not fall back at any dam, 22.1% fell back once, 2.9% fell back twice, 1.3% fell back 3 times, and 0.2% fell back 4 times. The percentages of unique fish with transmitters that fell back over a dam ranged from 0.67% at McNary Dam to 11.4% at Bonneville Dam based on the number of unique fish with transmitters that fell back divided by the number of unique salmon with transmitters known to have passed the dam, regardless of route (Table 15).

Percentages of unique fish that fell back did not incorporate multiple fallbacks by individual fish or multiple passages of the dam and should not be used to adjust counts of fish passing through fishways. Percentages of sockeye salmon with radio transmitters that fell back are a reasonably good estimate of the proportion of sockeye salmon in the run that fell back at dams.

Fallback rates, the total number of fallback events divided by the number of unique fish with transmitters known to have passed a dam ranged from 0.7% at McNary Dam to 13.7% at Bonneville Dam (Table 16). Fallback rates based only on fish that passed

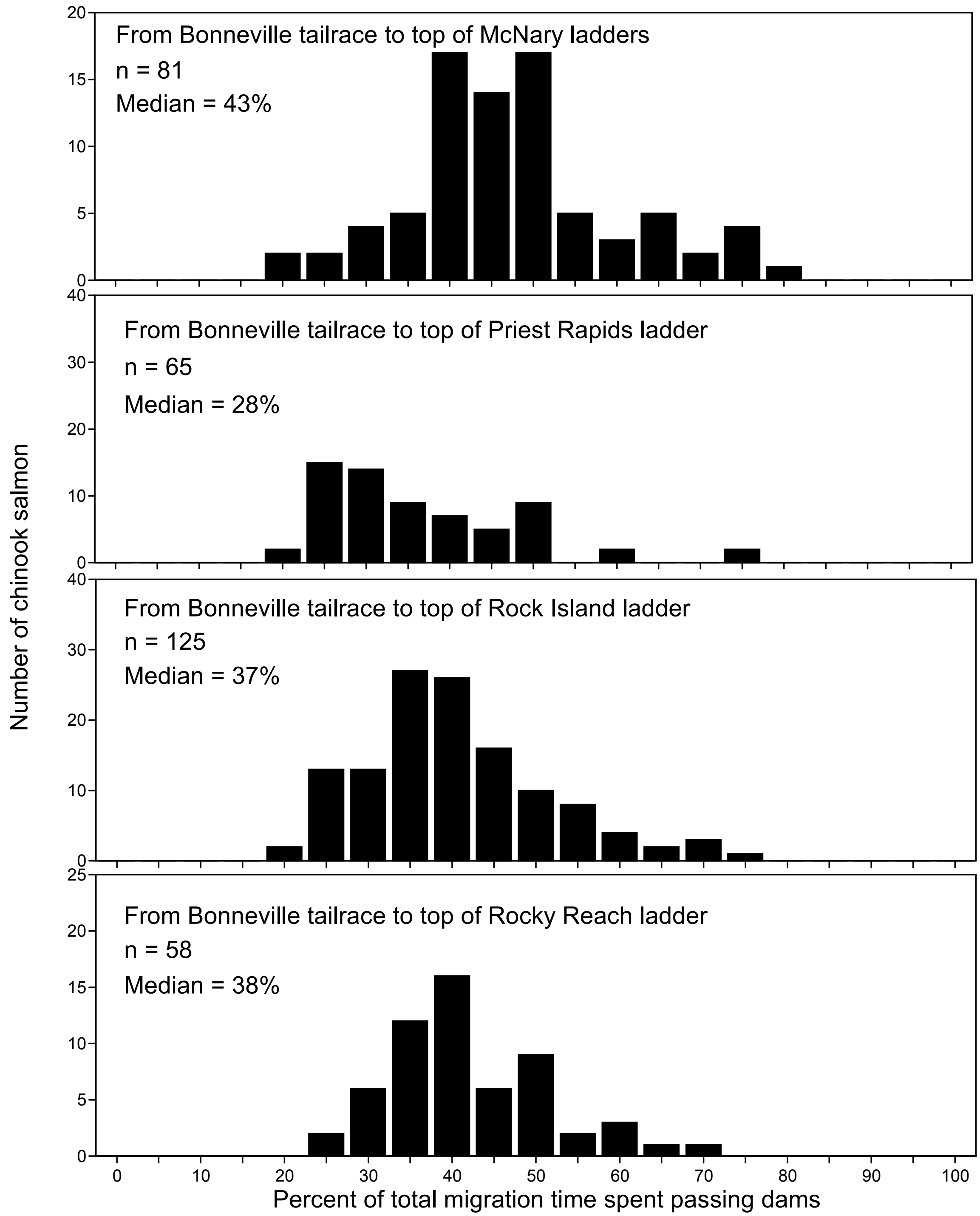


Figure 20. Number of sockeye salmon and the percent of total passage time spent on first passage of dams (dam passage times after fallback not included) from Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Priest Rapids, Rock Island, and Rocky Reach dams for sockeye salmon in 1997.

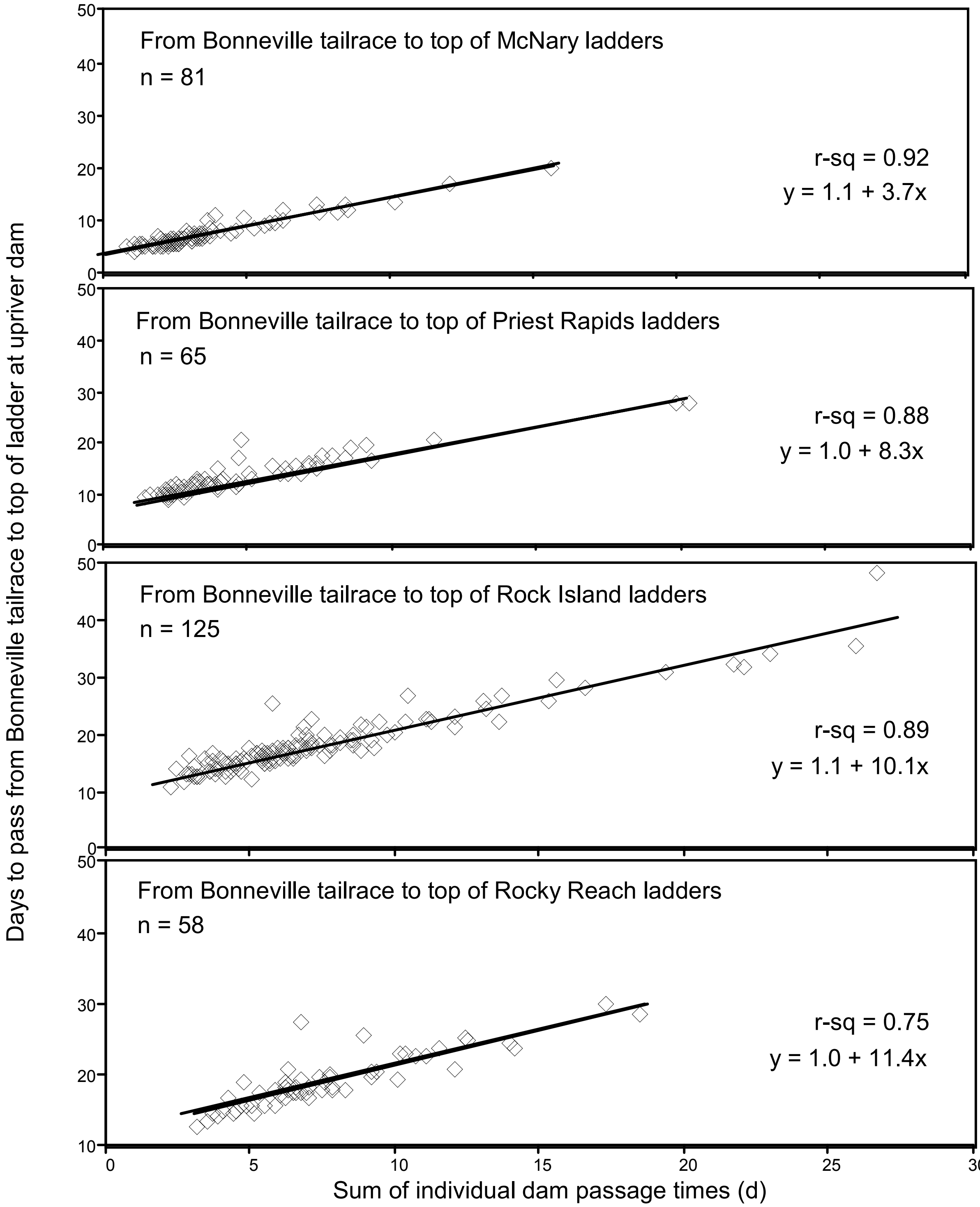


Figure 21. Sum of individual dam passage times and total time for sockeye salmon to pass from the Bonneville Dam tailrace receivers to top-of-ladder receivers at McNary, Priest Rapids, Rock Island, and Rocky Reach dams in 1997.

Table 15. Number of unique sockeye salmon with transmitters that fell back (FB) at dams, number known to have passed dams, number that passed the dam via fishways at each dam and the percentage of fish that fell back at each dam in 1997. Confidence intervals (0.95) based on normal binomial approximation in parenthesis.

Dam	Fish that fell back at dam	Number known to pass dam	Passed dam via fishways	FB as percent of fish known to pass dam	FB as percent of fish that passed via fishways
Bonneville	64	562	501	11.4 (8.8-14.0)	12.8 (9.9-15.7)
The Dalles	24	492	414	4.9 (3.0-6.8)	5.8 (3.5-8.0)
John Day	17	468	340	3.6 (1.9-5.3)	5.0 (2.7-7.3)
McNary[1]	3	457	142	0.7 (0.0-0.4)	2.1(0.0-4.5)
Priest Rapids[1]	15	433	170	3.5 (1.7-5.2)	8.8 (4.6-13.1)
Wanapum	17	427	382	4.0 (2.1-5.8)	4.5 (2.4-6.5)
Rock Island[1]	8	417	371	1.9 (0.6-3.2)	2.2 (0.7-3.6)
Rocky Reach[1]	16	240	206	6.6 (3.5-9.8)	7.8 (4.1-11.4)

[1] fishway passage estimate not available due to receiver outages or limited antenna coverage

Table 16. Number of fallback (FB) events by sockeye salmon with transmitters at dams, number known to have passed dams, number that passed dams via fishways at each dam, and the fallback rates for 1997. Confidence intervals (0.95) based on normal binomial approximation in parenthesis.

Dam	Total FB events at dam	Number known to pass dam	Passed dam via fishways	FB rate of fish known to pass dam	FB rate of fish that passed via fishways
Bonneville	77	562	501	13.7 (10.9-16.5)	15.4 (12.2-18.5)
The Dalles	25	492	414	5.1 (3.1-7.0)	6.0 (3.7-8.3)
John Day	18	468	340	3.8 (2.1-5.6)	5.3 (2.9-7.7)
McNary	3	457	142	0.7 (0.0-1.4)	2.1 (0.0-4.5)
Priest Rapids	15	433	170	3.5 (1.5-5.2)	8.8 (4.6-13.1)
Wanapum	17	427	382	4.0 (2.1-5.8)	4.5 (2.4-6.5)
Rock Island	8	417	371	1.9 (0.6-3.2)	2.2 (0.7-3.6)
Rocky Reach	18	241	206	7.5 (4.1-10.8)	8.7 (4.9-12.6)

the dam via the ladders (no navigation lock or undetected passages) were similar except at McNary and Priest Rapids dams where there were a substantial number of top-of-the-ladder outages.

Fallback rates, as defined here, offered a more comprehensive view of fallback behavior by sockeye salmon than percentages of fish that fell back because multiple fallbacks by individual fish were included. However, neither percent of unique salmon that fell back, nor fallback rates should be used to correct fishway count inflation caused by multiple passages of salmon that fell back. Fallback rates accounted for multiple fallbacks, but not multiple reascensions after fallback nor overestimates of escapement due to fish that fell back and did not reascend. Multiple passages over dams by individual fish add a positive bias to counts of fish passing through fishways, as do fish that fall back and do not reascend and thus fallbacks and reascensions must be used to correct dam fish counts.

The 95% confidence intervals assuming normally distributed errors and a normal binomial approximation for sockeye salmon fallback rates were about +/- 5.0%. Confidence intervals in Table 16 were based on pooled data for all radio-tagged fish in each year and did not address variability in tagged/untagged fish ratios during the course of the run.

Multiple fallbacks by individual sockeye salmon occurred most frequently at Bonneville Dam, where 64 fish fell back 77 times: 7 fell back twice and 3 fell back three times. At The Dalles Dam, 23 fish fell back once and 1 fish fell back twice. At John Day Dam, 16 fell back once and 1 fell back twice. At McNary Dam, 3 sockeye salmon fell back once. The number of fallbacks per unique fallback fish was 1.20 at Bonneville, 1.04 at The Dalles, 1.06 at John Day, and 1.13 at Rocky Reach dams. No fish fell back more than once at all other monitored dams.

Sockeye salmon with transmitters that fell back over dams in 1997 did so after a variety of movements upstream from dams. Although we could not monitor the exact time fish fell back we could usually estimate fallback times to within a few hours of the event using forebay, tailrace or fishway telemetry records. We estimated from 67 to 100% of all fallback events at Bonneville, The Dalles, John Day, and McNary dams occurred within 24 h of the fish passing over those dams (Table 17). Less than 40% fell back within 24 h at Rock Island and > 80% fell back within 24 h at Priest Rapids, Wanapum and Rock Reach dams. Between 6% and 33% of the fallback events at all dams except John Day dam occurred after fish were recorded upriver (Table 17). The remaining fallback events at dams occurred more than 24 h after fish passed dams, but the fish were not recorded at receivers upriver from the dams.

Table 17. Number of fallback (FB) events by sockeye salmon with transmitters at dams in 1997, the number and percent that fell back within 24 h of passing dams, the percent recorded upriver before they fell back and the percent that fell back more than 24 h after passing but were not recorded upstream.

			Percent of all FB events		
				Fish FB in > 24 h	
	Total FB events at dam	Number that FB in <24 h	Fish FB in <24 h	Recorded upriver	Not recorded upriver
Bonneville	77	66	86	10	4
The Dalles	25	18	72	28	0
John Day	18	18	100	0	0
McNary	3	2	67	33	0
Priest Rapids	15	12	80	20	0
Wanapum	17	15	88	6	6
Rock Island	8	3	38	25	38
Rocky Reach	18	17	94	6	0

Fallback percentages varied considerably for different ladders and dams. Higher percentages fell back after passing south-shore ladders at Bonneville and McNary dams and after passing north-shore ladders at The Dalles and John Day dams (Table 18). At mid-Columbia River dams, a higher percentage fell back after passing the east- shore ladder at Priest Rapids Dam and Rock Island dams and after passing the west-shore ladder at Wanapum Dam and Rocky Reach dams. Between-ladder comparisons were only significant at Bonneville Dam, where 18.8% fell back after passing via the south-shore (Bradford) ladder and no fish fell back after passing the north-shore ladder, and at McNary Dam where 2.7% fell back after passing the south-shore ladder and no fish fell back after passing the north-shore ladder. At The Dalles Dam, 2.0% fell back after passing the south-shore ladder and 9.2% fell back after passing the north-shore ladder, adjacent to the spillway. At John Day Dam, 3.4% of fish that passed via the south-shore ladder and 5.1% of those that passed via the north-shore ladder, adjacent to the spillway, fell back. We also calculated the percentage of fallback events by sockeye salmon with transmitters based solely on the ladder passed, without regard for the disproportionate numbers of fish that passed via south- or north-shore ladders at individual dams.

Table 18. Number of unique sockeye salmon with transmitters recorded at the tops of south-shore[1] and north-shore[2] ladders at each dam, the number of unique fish that fell back (FB), and the percentage of fish that passed each ladder and fell back at each dam in 1997.

	South-shore ladder			North-shore ladder		
	Unique fish at top of ladder	Unique fish that fell back	% past ladder that FB	Unique fish at top of ladder	Unique fish that fell back	% past ladder that FB
Bonneville	335	63	18.8	187	0	0.0
The Dalles	301	6	2.0	195	18	9.2
John Day	264	9	3.4	177	9	5.1
McNary	110	3	2.7	58	0	0
Priest Rapids	114	10	8.8	66	5	7.6
Wanapum	368	5	1.4	56	12	21.4
Rock Island	129	7	5.4	244	9	3.7
Rocky Reach	284	17	6.0	212	18	8.5

[1] 'South' ladders at mid-Columbia River dams are on east side of Columbia River.
[2] 'North' ladders at mid-Columbia River dams are on west side of Columbia River.

Sockeye salmon passed via south-shore ladders prior to 28% to 100% of all fallback events at lower Columbia River dams (Table 19). When we only considered fallbacks that occurred within 24 h of passing dams, 100% of sockeye salmon at Bonneville Dam and McNary Dams passed via south-shore ladders; 50% at John Day and 17% at The Dalles dams. At mid-Columbia River dams, 33% passed east-shore ladders at Rock Island Dam and 17% at Priest Rapids dams and 27% passed the west-shore ladder at

Table 19. Number of total fallback (FB) events and fallback events within 24 h of passing each dam by sockeye salmon with transmitters, and the percentage of fallback events by fish using the south-shore[1] or north-shore[2] ladders at each dam in 1997.

	All fallback events			Fallback events within 24 h		
	Number of events	Percent south ladder[1]	Percent north ladder[2]	Number of events	Percent south ladder	Percent north ladder
Bonneville	77	99	1	65	100	0
The Dalles	25	28	72	18	17	83
John Day	18	50	50	18	50	50
McNary	3	100	0	2	100	0
Priest Rapids	15	33	67	12	17	83
Wanapum	17	29	71	15	27	83
Rock Island	8	50	50	3	33	67
Rocky Reach	18	0	100	17	0	100

[1] 'South' ladders at mid-Columbia River dams are on east side of Columbia River.
[2] 'North' ladders at mid-Columbia River dams are on west side of Columbia River.

Wanapum Dam. No radio-tagged sockeye salmon were recorded passing the east-shore ladder at Rocky Reach Dam (Table 19).

Percentages of fish that passed via south-shore ladders prior to falling back were higher or similar for all events than for events within 24 h (Table 19). Fish that passed over Bonneville Dam via the Bradford Island ladder fell back at a higher rate than for all other dams and ladders monitored in 1997. The ladder was unique among all dams in that the top of the ladder was on an island. Based on mobile-tracking of chinook and sockeye salmon with transmitters in 1997 and 1998, we observed that many fish that exit the Bradford Island ladder follow the Bradford Island shoreline into the forebay of the spillway and subsequently fall back over the dam (Reischel and Bjornn 2003).

Effect of Injury on Fallback

About 40% of the sockeye salmon outfitted with transmitters in 1997 had fresh marine mammal scrapes or bites, 33% had some descaling, and 4% had head injuries of some type. To evaluate the effects of these injuries on fallback, we compared fallback behavior by sockeye salmon with injuries to those without injuries. Of 562 sockeye salmon that passed Bonneville Dam with transmitters, 27.2 % of the fish with no fresh mammal marks fell back at one or more dams, 29.4% with fresh scrapes fell back, and 23.4% with fresh bites fell back (Figure 22). Differences in fallback proportions were not significant (P = 0.70, X^2 test). The fallback proportion for fish with no mammal marks (27.2%) was not significantly different than for fish with either fresh scrapes or bites (40.6%) (P = 0.81, X^2 test).

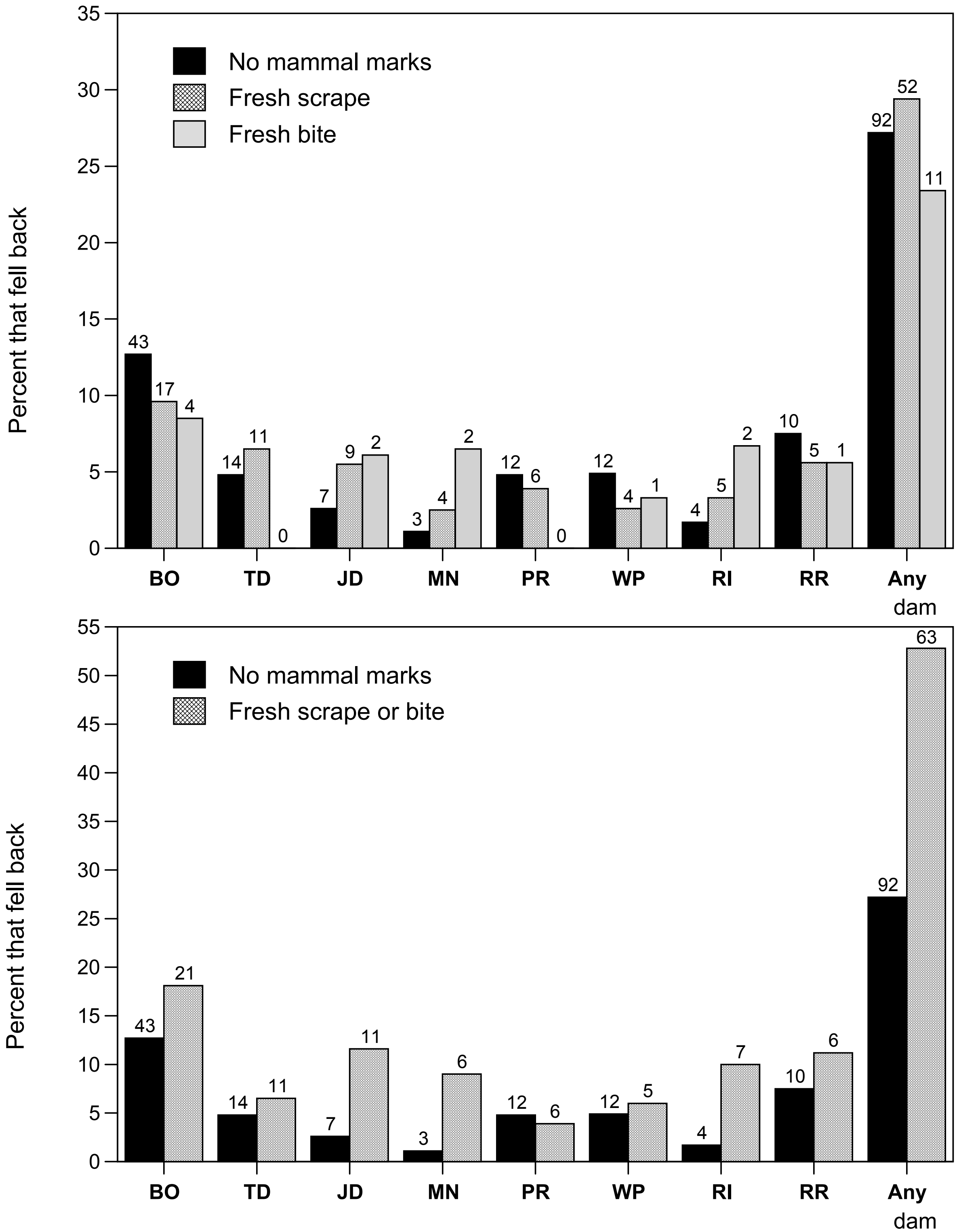


Figure 22. Proportion of sockeye salmon that fell back at dams monitored in 1997, and did or did not have fresh marine mammal scrapes or bites at the time fish were outfitted with transmitters.

We found little evidence that fish with fresh mammal marks had higher fallback percentages at individual dams. Fallback percentages for fish with no mammal marks were lower than percentages for fish with fresh scrapes or bites at John Day, McNary and Rock Island dams, while fish with no mammal marks had an intermediate fallback percentage at The Dalles Dam (Figure 22). Differences among the three categories were not significant at any of the lower Columbia River dams ($P > 0.25$, X^2 test); we did find a significant difference in fallback percentage between fish with no marks and fish with either fresh scrapes or bites (P = 0.09) at John Day Dam, but sample sizes were small (<10 fish in each category). We found no differences in fallback percentages at Priest Rapids, Wanapum Dam, Rock Island, and Rocky Reach dams ($P > 0.16$ in 2- and 3-category tests).

Descaling at the time sockeye salmon were outfitted with transmitters also had little detectable affect on fallback. Among 562 fish that passed Bonneville Dam with transmitters, 14.4% with no descaling fell back at one or more dams, 15.8% with < 10% descaling fell back, and 12.0% of fish with > 10% descaling fell back. Differences in 3-category tests were not significant (P = 0.27, X^2 test), nor were differences in 2-category comparisons ($P = 0.32$; Figure 23). We also found no significant differences in fallback percentages at individual dams using 2-category (no descaling, any descaling) or 3-category (no descaling, < 10% descaling, > 10% descaling) tests ($P > 0.16$).

A significantly higher proportion of fish with head injuries (8.4%) at the time they were outfitted with transmitters fell back at one or more dams during their migration than fish that did not have head injuries (Figure 24) (2.3%; $P = 0.04$, X^2 test). Significantly higher percentages of fish with head injuries also fell back at Bonneville and Priest Rapids dams ($P < 0.01$). At least 28 sockeye salmon fell back multiple times during their upstream migration. Of these fish, 61% had no fresh mammal marks, 36% had fresh scrapes, and 4% had fresh bites, a distribution that was not significantly different ($P = 0.61$, X^2 test) from proportions for all sockeye salmon outfitted with transmitters (60% no marks, 31.4% fresh scrapes, 8.7% fresh bites). Of the 28 sockeye salmon with multiple fallbacks, 71% had no descaling, 25% had < 10% descaling, and 4% had > 10% descaling, a distribution not significantly different ($P = 0.39$) from overall proportions (67% no descaling, 30% < 10% descaling, 3% > 10% descaling). Sockeye salmon that fell back multiple times did not have a higher incidence of head injuries (7.1%) than all fish outfitted with transmitters (3.8%; $P = 0.38$).

Effect of Fallbacks on Passage Time

Sockeye salmon that fell back at any lower Columbia River dam in 1997 had significantly longer passage times past multiple dams than fish that did not fall back. Median passage times from release after tagging to the most upriver dam passed were longest for sockeye salmon that fell back once, and were longer than fish that did not fall back (Figure 25). Multiple (>1) fallbacks by sockeye salmon were recorded at Bonneville, The Dalles, John Day, and Rocky Reach dams. Ten fish that fell back more than once at Bonneville Dam had significantly longer passage times than fish that fell back once or did not fallback. Only one each fish fell back more than once at The

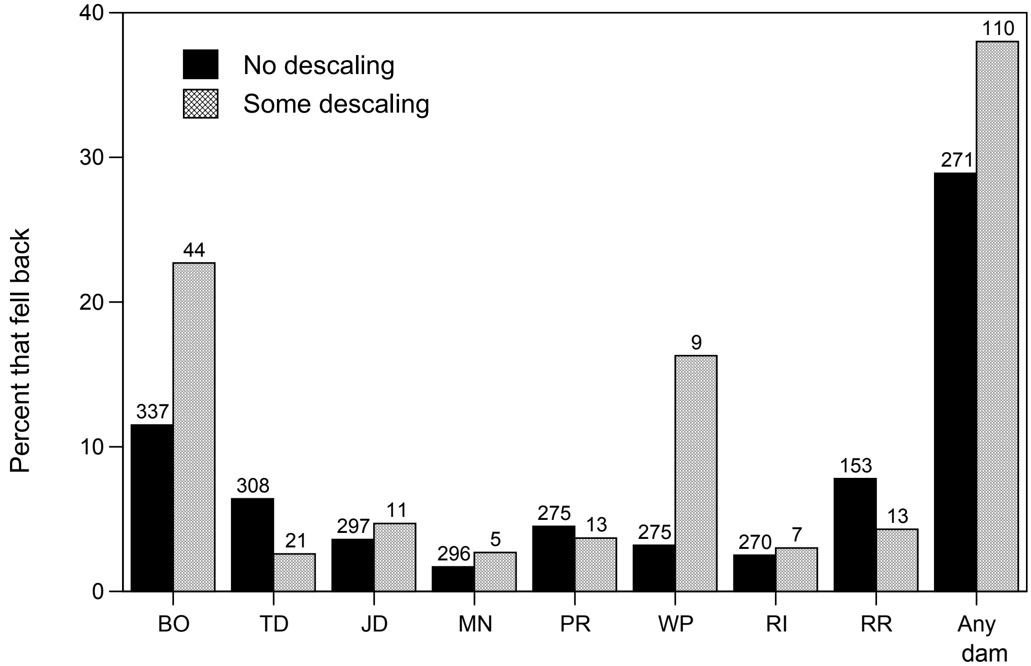


Figure 23. Proportion of sockeye salmon that fell back at dams monitored in 1997, and did or did not have descaling at the time fish were outfitted with transmitters.

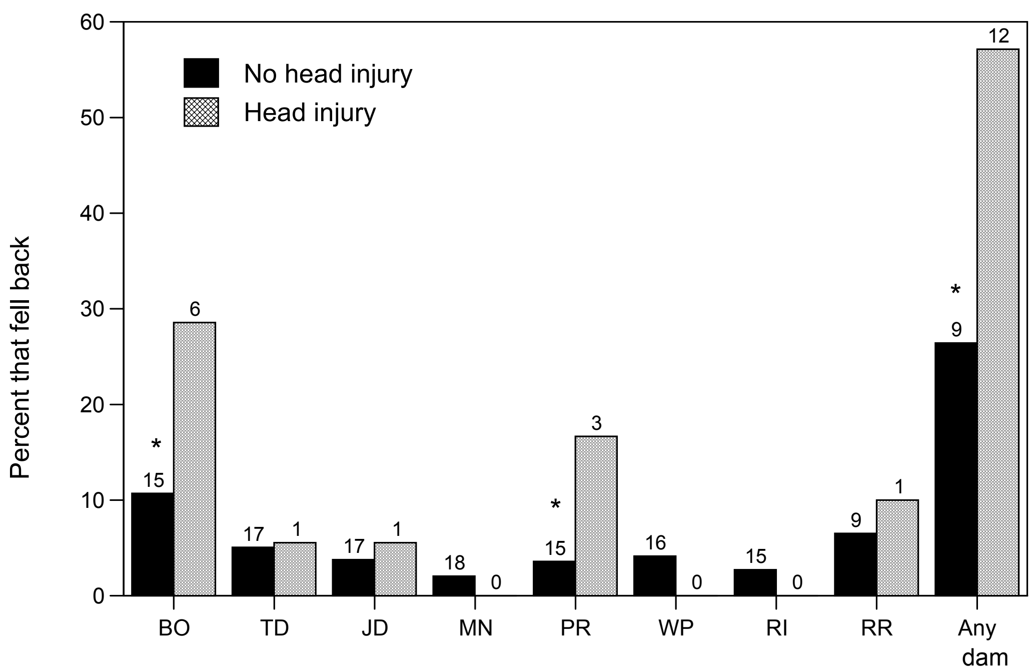


Figure 24. Proportion of sockeye salmon that fell back at dams monitored in 1997, and did or did not have head injuries at the time fish were outfitted with transmitters.

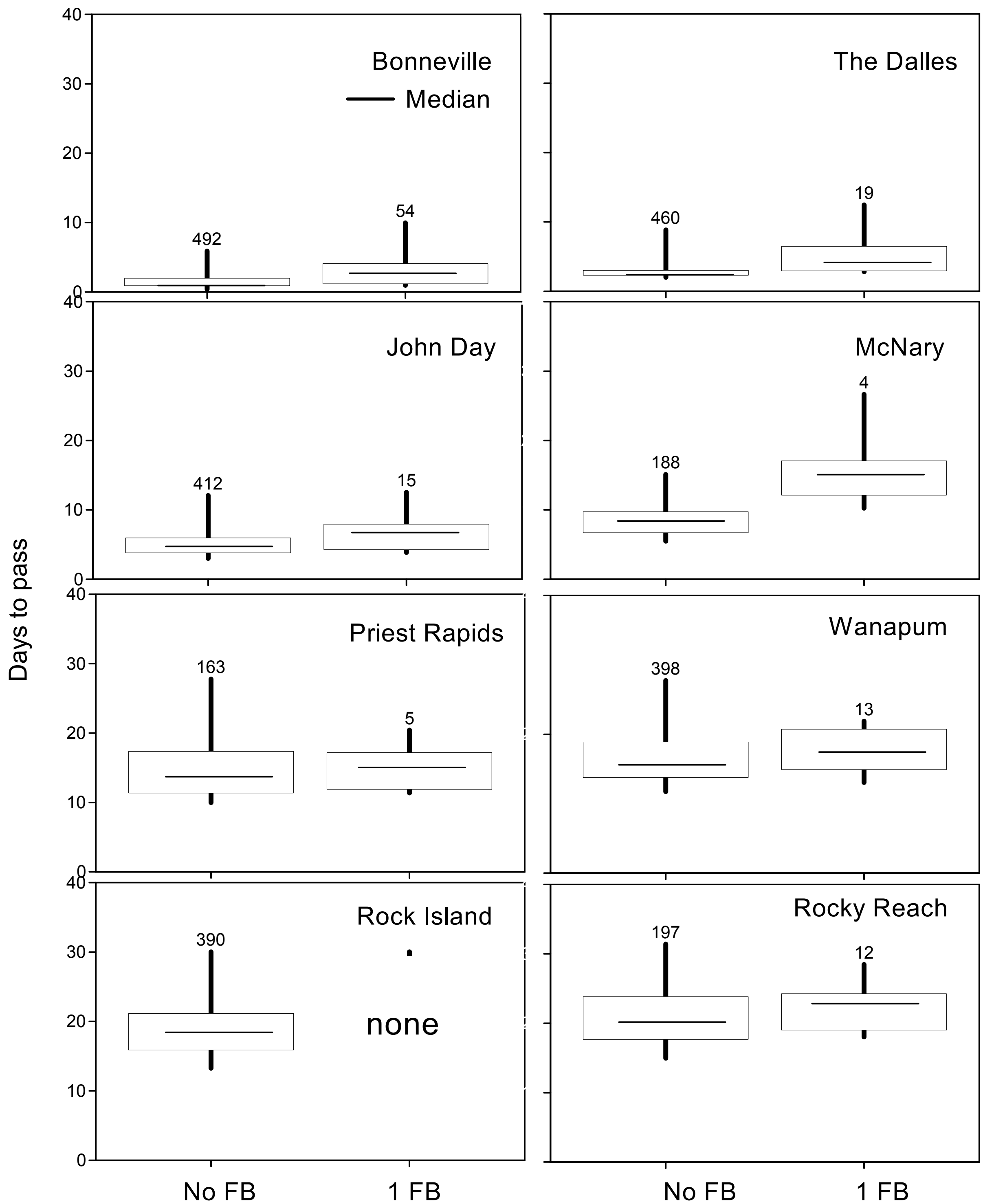


Figure 25. Median, 5% and 95% percentiles, and quartile passage times from release after tagging to pass dams for sockeye salmon that did not fall back, fell back one time, or fell back > 1 time. Number of fish above bars. Estimated times included for McNary and Priest Rapids dams during top-of-ladder receiver outages.

Dalles, John Day and Rocky Reach dams. It is important to note that sockeye salmon that fell back but did not survive to reascend the dams were not included in our analyses. While delayed passage may impact survival, direct and indirect mortality due to fallback was not addressed in this section. Median passage times, from release to the time that sockeye salmon last exited from the top of a ladder at a dam, were 1.1 to 6.7 days longer for fish that fell back once versus for those that did not fall back (Figure 25). Median passage times from release to the top of Bonneville, The Dalles, John Day, and McNary dams were significantly ($P < 0.01$, K-W X^2 test) longer for sockeye salmon that fell back one or more times than for those that did not fall back. Passage time differences were similar past Priest Rapids, Wanapum, Rock Island, and Rocky Reach dams. Passage time distributions for fish that did or did not fall back during their migration showed that fallbacks delayed most fish, however, the significant differences we report above for The Dalles, John Day, and McNary dams may be due to a few fish with greatly delayed passage.

Reascension Over Dams, Escapement and Final Distribution after Fallbacks

At least 142 (87%) of the 164 sockeye salmon with transmitters that fell back one or more times in 1997 reascended all dams at which they fell back, based on fixed receiver, mobile-tracking and recapture records. Of the remaining 22 fish, some reascended dams after falling back, but did not reascend all dams at which they fell back (Table 20). About 27% of sockeye salmon that did not reascend the most upriver dam they passed were subsequently recorded in tributaries downstream from the fallback location and potentially reached spawning sites.

Fallbacks by fish that subsequently entered tributaries downstream from the dam where they fell back were likely caused by fish migrating upstream past their natal stream and then having to return downstream. But, they may also have been fish that were destined for other streams and permanently strayed into the tributary where they were last located. Most (n = 5) of the fish only migrated past the dam immediately upriver from the tributary they eventually entered, but one fish passed multiple dams upriver from the tributary they subsequently entered (Table 20).

Tributaries downstream from Bonneville Dam were not monitored with fixed antennas in 1997, and none of 5 sockeye salmon that fell back at Bonneville Dam and did not reascend were recaptured in downstream tributaries (Table 20). Of 5 fish that fell back at The Dalles Dam and did not reascend, two fish entered the Klickitat River downstream from The Dalles Dam. Two of 17 (12%) fish that fell back at John Day Dam entered downstream tributaries (Table 20). None of the four fish that fell back and did not reascend at Priest Rapids Dam entered a downstream tributary. Two of the sockeye salmon that fell back at Rocky Reach Dam and did not reascend entered the Wenatchee River.

Escapement to tributaries by fallback fish was based primarily on telemetry or recapture records indicating a fish had entered and remained in a tributary long enough to spawn or be recaptured. It is likely that some sockeye salmon with last records in tributaries did not spawn or were recaptured before spawning occurred. It was also possible that a few fish that were last recorded at dams or at main stem sites and were

Table 20. Number of sockeye salmon that did not reascend dams where they fell back, and did or did not enter downstream tributaries after falling back in 1997.

	Fell back and did not reascend	Did not enter tributary	Entered downstream tributary	Final distribution (river entered)
Fish that fell back and did not reascend at one or more dams				
	22	16	6	White Salmon (2)[2], Klickitat (2)[2], Wenatchee (2)
Bonneville[1]	5	5	--	
The Dalles	6	2	4	Klickitat (2), White Salmon (2)
John Day	2	2	--	
McNary	0	--	--	
Priest Rapids	4	4	--	
Wanapum	1	1	--	
Rock Island	3	3	--	
Rocky Reach	1	--	2	Wenatchee (2)

[1] limited or no coverage of tributaries downstream from Bonneville Dam in 1997
[2] fish last recorded in the White Salmon and Klickitat rivers were considered strays

classified as not escaping eventually reached tributaries or spawning areas undetected (most likely if they lost their transmitter). Escapement was unknown for 9 sockeye salmon that we believe regurgitated their transmitters after passing Bonneville Dam. When we removed those fish, escapement was 69.9% for fish that fell back versus 70.2% for fish that did not fall back at any dam (P = 0.94; Table 21).

Sockeye salmon that passed individual dams and did not fall back escaped at higher rates than fish that passed dams and fell back at Bonneville, The Dalles and John Day dams; rates were 12.2% higher at Bonneville (P = 0.04), 20.2% higher at The Dalles (P = 0.02), and 9.1% higher at John Day dams. Escapement rates were 14.3% lower for fish that did not fall back versus fish that fell back at McNary dam (Table 22). Escapement rates were higher for fish that did not fall back by 5.6% to 56.4% at Priest Rapids and Rock Island dams. Escapement rates were lower for fish that did not fall back by 3.4% at Wanapum and 4.5% at Rocky Reach dams.

Of 64 fish that fell back at Bonneville Dam, 37 (59%) were later recorded in tributaries upstream from Rock Island Dam and one was recorded in the Klickitat River (Table 23). Last records for the 24 sockeye salmon that fell back at Bonneville Dam and did not reach tributary sites were mostly (46%) at or downstream from Bonneville Dam, in the Bonneville pool or at The Dalles Dam. Of 24 sockeye salmon that fell back at The Dalles Dam, 16 (67%) were later recorded in tributaries upstream from Rock Island Dam and two fish were later recorded in the Klickitat River (Table 23). Last

Table 21. Escapement to tributaries[1] for 553 sockeye salmon that we believe retained transmitters for their entire migration and passed Bonneville Dam.

	Did not fall back		Fell back one or more times	
	Number	Percent	Number	Percent
Survived	288	70.2	100	69.9
Did not survive	122	29.8	43	30.1
Total	416		143	

[1] Escapement to 'major tributaries' included all fish that were recorded in tributaries with fixed receivers at their mouths or by mobile tracking. Only fish that remained in tributaries long enough to potentially spawn, or that were recaptured were considered to have escaped.

Table 22. Escapement to major tributaries by sockeye salmon with transmitters that did or did not fall back at individual dams in 1997. Only includes fish that we believe retained transmitters for their entire migration.

	Total	Did not fall back at dam		Fell back one or more times	
Dam	Number	Number	Escaped (%)	Number	Escaped (%)
Bonneville	490	351	*71.6	63	58.7
The Dalles	461	374	*81.1	23	60.9
John Day	447	376	84.1	16	75.0
McNary	449	385	85.7	3	100.0
Priest Rapids	418	377	90.2	13	84.6
Wanapum	410	372	90.7	17	94.1
Rock Island	410	385	*93.9	8	37.5
Rocky Reach	225	201	89.3	16	93.8

* $P < 0.05$; ** $P < 0.005$, K-W X^2 test

records for the 6 sockeye salmon that fell back at the dam and did not reach tributary sites were all at dams or in reservoirs in the lower and middle Columbia River. Of 17 salmon that fell back at John Day Dam, 12 (67%) were last recorded in tributaries upstream from Rock Island Dam and 1 was recorded in the Klickitat River. Last records for 2 (22%) sockeye salmon that fell back at the dam and did not reach tributary sites were at dams or in reservoirs in the lower and middle Columbia River.

Of 3 sockeye salmon that fell back at McNary Dam, all were recorded in tributaries upstream from Rock Island Dam. Between 73% and 94% of sockeye salmon that fell back at Priest Rapids, Wanapum, or Rock Reach dams were last recorded in tributaries (Table 23). Thirty-eight percent of the fallback fish at Rock Island Dam were last recorded in the Wenatchee River and 62% were last recorded at Rock Island or Rocky Reach dams. Nine of 10 fish that fell back at mid-Columbia River dams and did not return to tributaries were last recorded at mid-Columbia River dams and one was last recorded at Ice Harbor Dam.

Table 23. Final location of sockeye salmon with transmitters that fell back (FB) over monitored dams in 1997 and percent that reached tributaries, based on last records for fish and/or evidence that fish reached spawning areas before returning to main stem sites. (Note: totals do not add up because some fish fell back at more than one dam.)

	All FB fish	Fallback location							
		BO	TD	JD	MN	PR	WP	RI	RR
Number of FB fish	**143**	64	24	17	3	15	17	8	16
Final location									
White Salmon River	**2**	0	2	0	0	0	0	0	0
Klickitat River	**4**	1	2	1	0	0	0	0	0
Wenatchee River	**42**	12	8	7	1	4	10	3	2
White River	**3**	1	2	1	0	1	0	0	0
Methow River	**2**	1	0	1	0	0	0	0	1
Okanogan River	**53**	23	6	3	2	6	6	0	12
Number recaptured at Wells Dam or recorded upstream from Wells Dam	**3**	2	0	0	0	0	0	0	1
Number at tributary sites	**117**	37	18	13	3	11	16	3	15
Number with last record at a dam or main stem site	**44**	24	6	4	0	4	1	5	0
Percent with records at tributaries	**71**	58	75	76	100	73	94	38	94

Timing of Migration Past Dams and into Tributaries

Adult sockeye salmon with transmitters started migrating into tributaries in early-July and continued through August. Because we did not monitor some mid-Columbia River tributaries with fixed receivers, 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 17 July; the median first date at Wells Dam was 20 July for Methow and Okanogan river stocks, including those fish last recorded at Wells Dam (Figure 26).

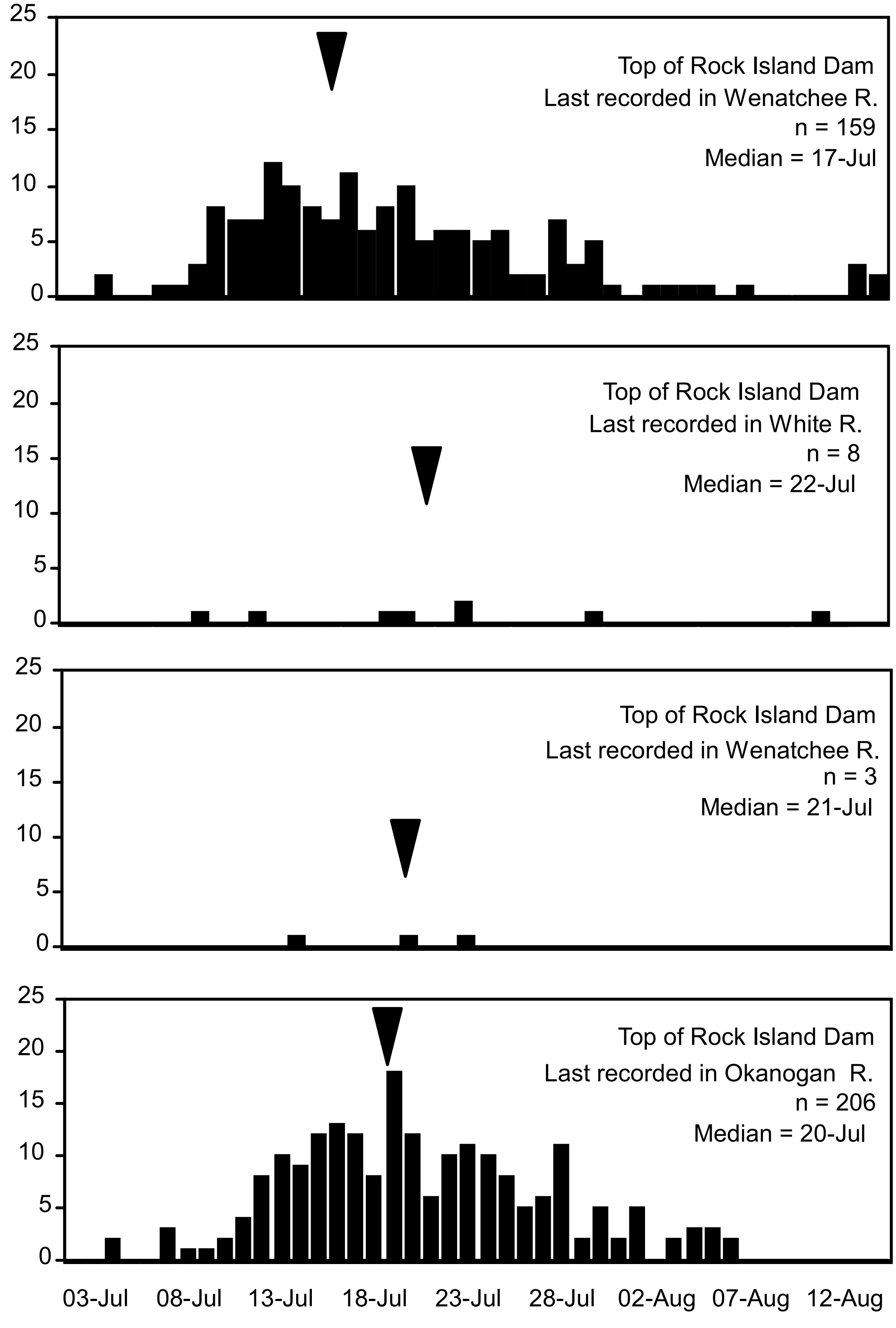


Figure 26. Number of sockeye salmon and date of first record at Rock Island Dam for fish last recorded in the Wenatchee and White rivers, and date of first record at Wells Dam for fish last recorded in the Methow or Okanogan rivers in 1997.

Tag Dates for Specific Stocks of Sockeye Salmon with Transmitters

Identifying distinct adult salmon and steelhead stocks at lower Columbia River dams during annual runs has been a management challenge. In 1997, we used tag dates and final distribution records for radio-tagged sockeye salmon to identify when stocks returning to the Wenatchee and Okanogan river drainages passed Bonneville Dam. Sockeye salmon that returned to the Wenatchee River drainage were outfitted with transmitters at Bonneville Dam mostly from mid-June to mid-July with median tag date of 29 June (Figure 27). The median tagging date for sockeye salmon last recorded in the White River was 3 July. Fish that returned to the Okanogan River drainage were tagged from mid-June to mid-July with a median date of 29 June. Comparisons of median and quartile tag dates for specific stocks indicated that late June passage at Bonneville Dam was primarily fish bound for the Wenatchee and Okanogon River drainages. Although the sample size was small (n = 10), stocks bound for the White River passed from late June through mid-July (Figure 28). Length frequencies of sockeye salmon with transmitters were similar between Wenatchee and Okanogan river stocks. Median fork length was 49.5 cm for Wenatchee River fish and 49.0 cm for Okanogan River stocks (Figure 29).

Reach Escapement Estimates

In addition to overall estimates of escapement to tributaries, we calculated reach escapement estimates through each hydrosystem segment to partition the loss of fish not accounted for by recapture or entry into tributaries. We calculated reach escapement (E_R) with the formula:

$$E_R = (UD_P + POOL_R + POOL_T + DS_R + DS_T)/ DD_P$$

where:

UD_P was the number of fish known to have passed the upstream dam,

$POOL_R$ was the number of fish reported recaptured in the reach reservoir,

$POOL_T$ was the number of fish that entered monitored tributaries in the reach,

DS_R was the number of fish reported recaptured downstream from the downstream dam,

DS_T was the number of fish that entered tributaries downstream from the downstream dam, and

DD_P was the number of fish known to have passed the downstream dam.

All fish recaptured in fisheries or at hatcheries were considered to have escaped. Fish that passed the dam at the upstream end of a reach were considered to have escaped through the reach regardless of subsequent fallback. The small number of transmitters found at main stem sites and returned were considered non-survivors

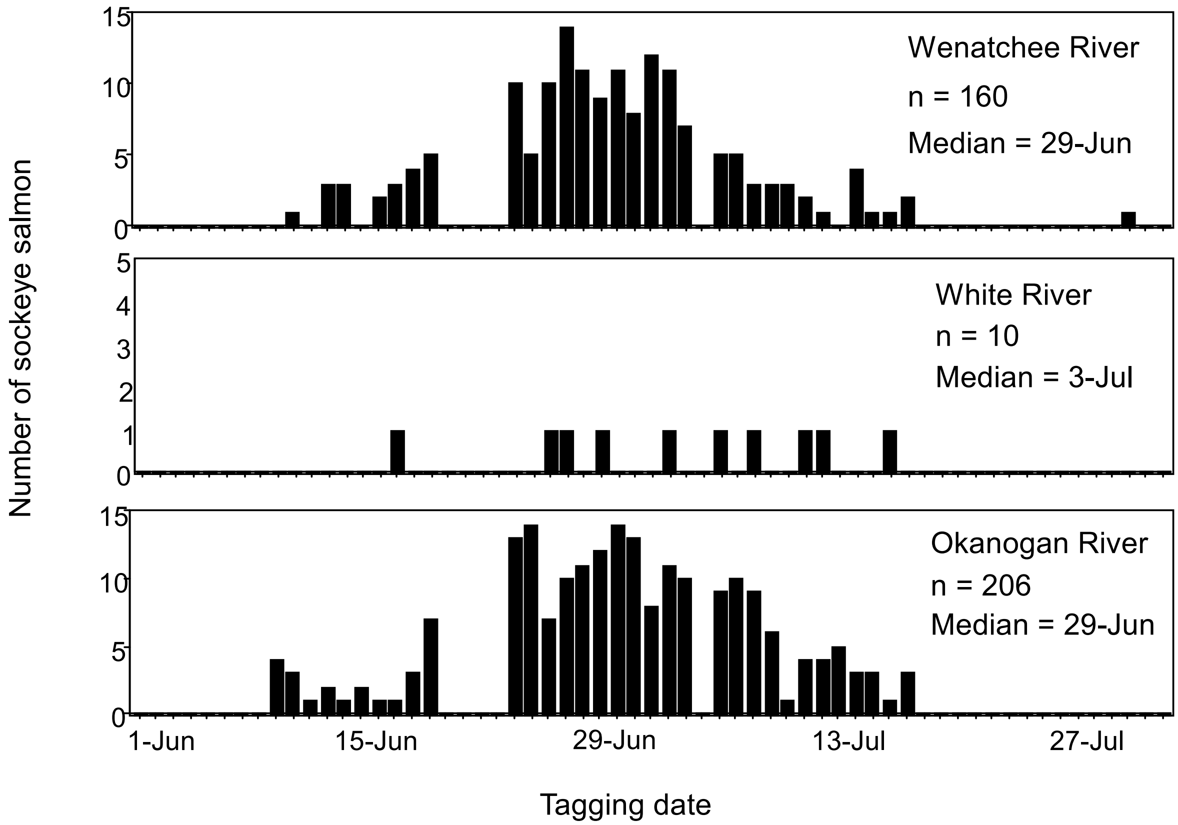


Figure 27. Tagging dates for sockeye salmon with last records in the Wenatchee, White, and Okanogan rivers in 1997.

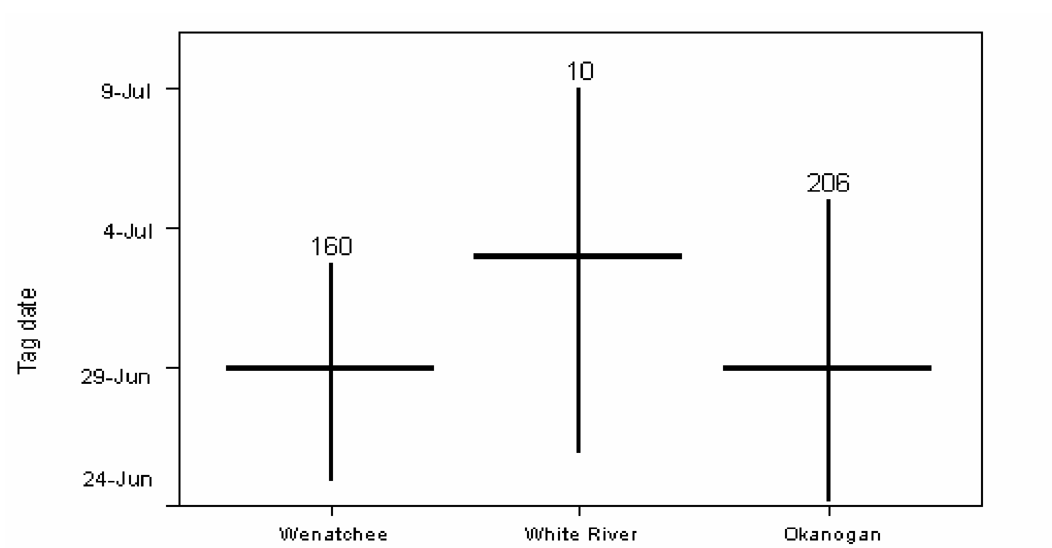


Figure 28. Median and quartile dates sockeye salmon were outfitted with transmitters at Bonneville Dam for selected stocks in 1997.

Figure 29. Median, minimum, maximum, and quartile fork lengths for sockeye salmon at time of tagging for fish that returned to individual tributaries. Number of fish above bar.

(unaccounted for). Other fish unaccounted for in tributaries or by recaptures were last recorded primarily at dams or in reservoirs. Some unaccounted-for fish may have been recaptured but not reported, entered tributaries undetected, or entered unmonitored tributaries, but we believe most likely did not survive. Reach escapement estimates in 1997 ranged from 0.961 to 0.988 (Table 24). Escapement estimates were lowest from The Dalles to John Day dams (0.961) and between McNary and Priest Rapids dams (0.965). Escapement estimates through the mid-Columbia River reaches were lowest from Wanapum to Rock Island dams (0.979) and highest between Rock Island to Rocky Reach dams (0.988).

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 (Figure 30), concomitant with the onset of what we considered to be stressful river temperatures. In comparison, 61.3% of salmon tagged during the period 5-16 July were successful migrants (n = 155).

Last Recorded Distribution of Sockeye Salmon with Transmitters

This summary of the final distribution of sockeye salmon was based on our last telemetry or recapture record for each fish (telemetry records after likely spawning were disregarded.) Of 559 sockeye salmon that we believe retained transmitters throughout their migration in 1997, 9 (1.6 %) had last records downstream from Bonneville Dam and 2 were last recorded at the top of the dam (Figure 31, Table 25). Seven percent of the tagged fish had last records in the Columbia River between the top of Bonneville Dam and The Dalles Dam. Two percent (10 fish) last recorded at tributary sites were

Table 24. Number of sockeye salmon known to have passed downstream dam (DD_P), number that passed upstream dam (UD_P), number recaptured in reach reservoir ($POOL_R$), number that entered monitored tributary in reach ($POOL_T$), number recaptured downstream from the downstream dam (DS_R), number that entered tributaries downstream from the downstream dam (DS_T), and reach escapement estimates (S) for radio-tagged sockeye salmon in 1997.

Reach DS dam (E)	Reach US dam	DD_P	UD_P	$POOL_R$	$POOL_T$	DS_R	DS_T	Escapement
Bonneville	The Dalles	562	492	53	0	0	0	**0.970**
The Dalles	John Day	492	468	4	0	1	0	**0.961**
John Day	McNary	468	457	1	0	0	0	**0.979**
McNary	PR	457	433	8	0	0	0	**0.965**
Priest Rapids	Wanapum	433	427	0	0	0	0	**0.986**
Wanapum	Rock Island	427	418	0	0	0	0	**0.979**
Rock Island	Rocky Reach	418	240	0	173	0	0	**0.988**
Rocky Reach	Wells	240	236	0	1	0	1	**0.986**

considered strays; 4 each in the White Salmon and Klickitat rivers and 1 fish each in the Little White Salmon and Yakima rivers. Five percent (29 fish) of the sockeye salmon had last records in the Columbia River or its tributaries between the top of The Dalles Dam and McNary Dam (Table 25).

Twenty-one fish (4%) were last recorded between the top of McNary Dam and either Priest Rapids or Ice Harbor Dam. Ten fish were in the Hanford Reach, 9 fish at Priest Rapids dam, 1 fish in the Yakima River, and one fish was last recorded downstream from Ice Harbor Dam (Table 25). Thirteen fish were last recorded between Wanapum Dam and the top of Rock Island Dam. Some 181 fish (32%) were last recorded upstream from Rock Island Dam, of which 168 (30%) were in the Wenatchee River, 9 (2%) in the White River and 1 in the Napeequa River and 2 at non-tributary sites downstream from Rocky Reach Dam. Another 234 fish (42%) were last recorded upstream from Rocky Reach Dam; 206 (37%) were in the Okanogan River basin, 3 were in the Methow River, 1 was in the Entiat River, and 4 were at or upstream of Rocky Reach Dam. Seventeen fish (3%) were at or upstream of Wells Dam and 3 fish were last recorded at Chief Joseph Dam.

Recaptures of Sockeye Salmon with Transmitters

A minimum of 17% of sockeye salmon outfitted with transmitters in 1997 were ultimately recaptured in fisheries, at hatcheries, traps or weirs, recovered at spawning grounds, or recovered from dead fish or transmitters found by people along rivers

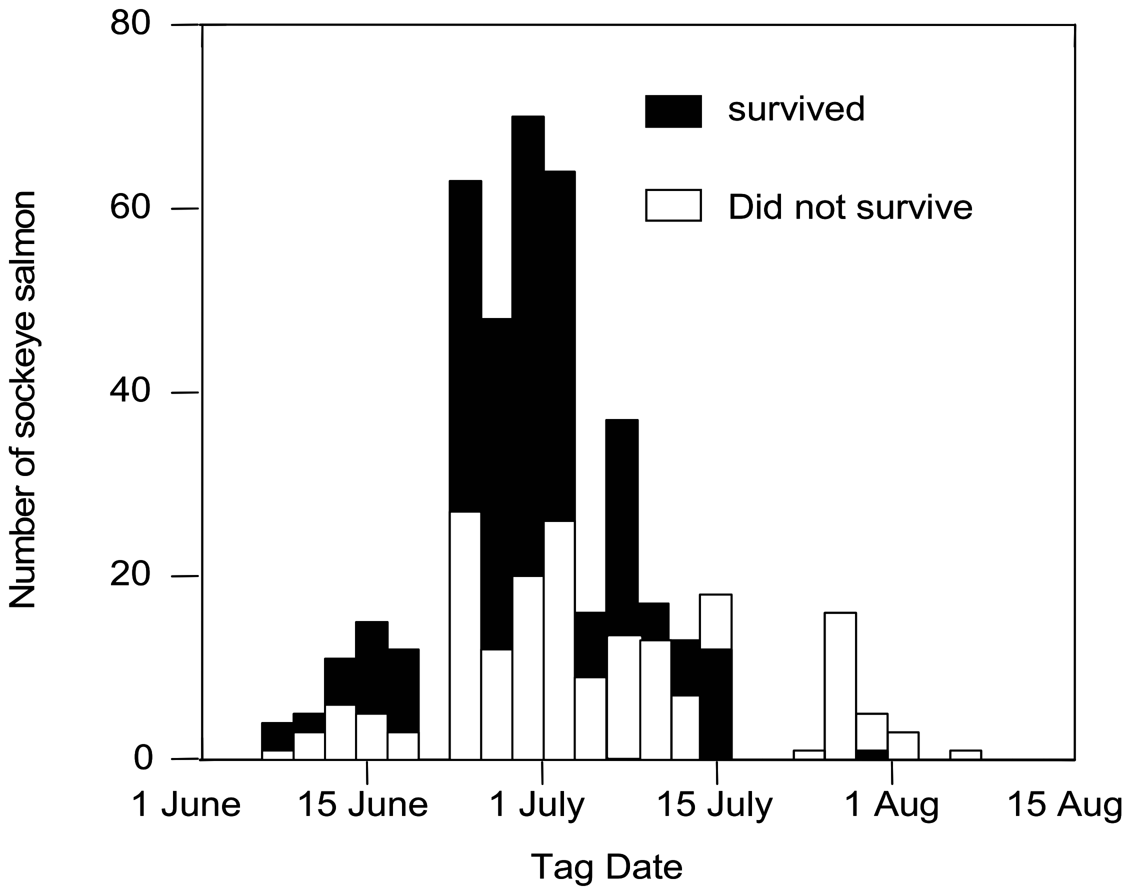
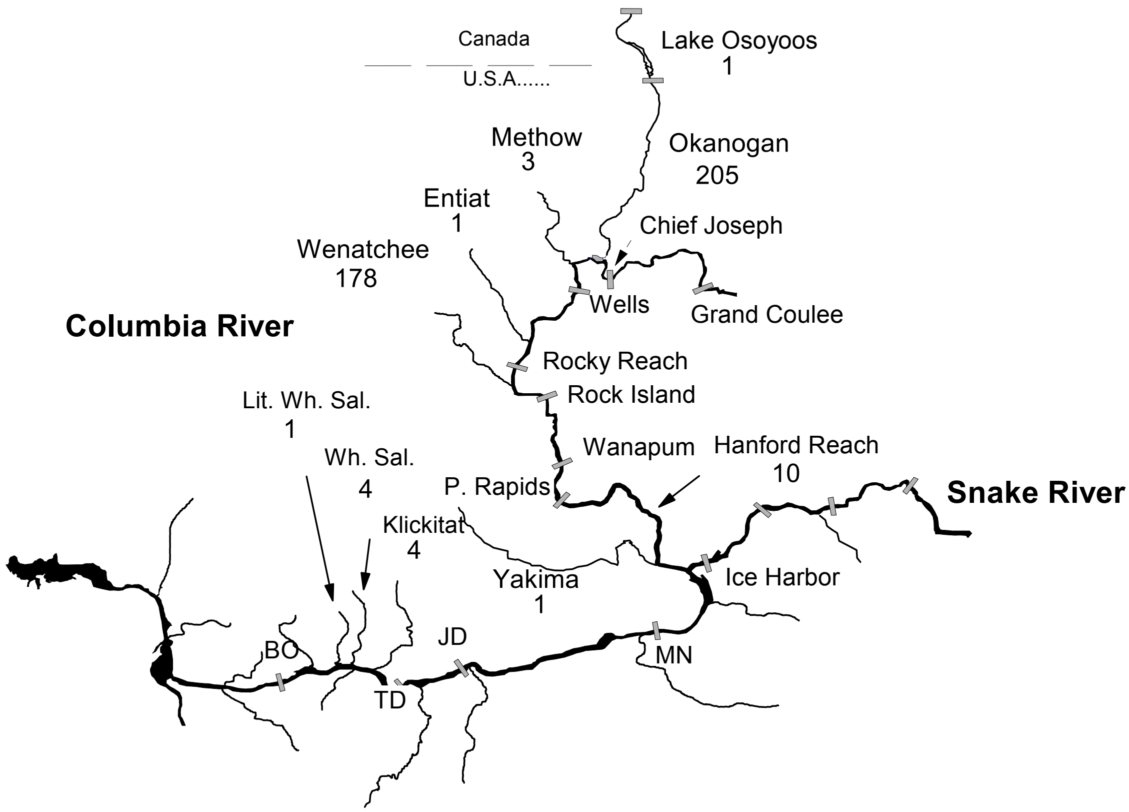


Figure 30. Histogram representing the number of sockeye salmon (*Oncorhynchus nerka*) tagged by date for successful (dark bar) and unsuccessful migrants (open bars).

(Table 26). Seventeen percent is a minimum recapture rate because not all recaptured fish may have been reported to us. Of the 100 sockeye salmon recaptured, 3 were from sport fisheries, 68 from tribal fisheries, 7 at hatchery traps and weirs, and 22 at spawning grounds, in dead fish or transmitters found along river corridors (Table 26). Most recaptures (69 of 100 fish) were in the Lower Columbia River with fifty-two of the sockeye salmon were recaptured by tribal fisheries in the Bonneville pool. Six fish were recaptured at the Bonneville trap and three were recaptured in The Dalles and John Day pools. At least thirty-one (31% of 100) of sockeye salmon were recaptured in the Mid-Columbia River and tributaries (Table 26). Nine fish were recaptured in the White River and 8 were recaptured in the Priest Rapids pool and Okanogan River.

We also summarized recapture information by three major basin subsections: downstream from Bonneville Dam, from the top of Bonneville Dam to the McNary Dam tailrace, from the top of McNary Dam upriver through the mid-Columbia River. Of 100 recaptured sockeye salmon recaptured, 9 (9%) were recaptured downstream from Bonneville Dam, 60 (60%) between Bonneville and McNary dams, and 31 (31%) in the mid Columbia River (Table 27).



151 Sockeye Salmon in Columbia and Snake river mainstem dams
9 at BO; 2 top of BO; 38 in BO pool
24 at The Dalles; 2 top of TD; 4 in TD pool
10 at John Day; 2 top of JD; 1 in JD pool
8 at McNary; 2 top of MN
9 at Priest Rapids
1 at Wanapum; 4 top of Wanapum
7 at Rock Island; 1 top of RI
2 at Rocky Reach; 3 top of RR; 1 in RR pool
12 at Wells; 5 in WL pool
3 at Chief Joseph
1 at Ice Harbor

Figure 31. Final distribution of 559 sockeye salmon outfitted with transmitters at Bonneville Dam in 1997 using last known records of each fish; fish that regurgitated transmitters not included.

Of nine fish recaptured downstream of Bonneville Dam, six were recaptured in the Bonneville Dam trap, two were recaptured in non-spawning areas and one was recaptured in a tribal fishery (Table 27). In the Lower Columbia River and its tributaries between Bonneville and McNary dams, 56 (9.7%) sockeye salmon were recaptured in tribal fisheries. Two fish were recaptured in sport fisheries, one in a trap or weir and one was found in a non-spawning area (Table 27). In the mid-Columbia River section

Table 25. Final distribution by location based on last records of all sockeye salmon that we believe retained transmitters in 1997. Records after potential spawning in tributaries were disregarded. See Table 7 for fish that regurgitated transmitters

All Fish	**559**
Lower Columbia River and Lower Columbia River Tributaries	
At Bonneville Dam	9
Top of Bonneville Dam	2
Bonneville Pool	38
Little White Salmon R.	1
White Salmon River	9
Klickitat River	4
At The Dalles Dam	24
Top of The Dalles Dam	2
The Dalles Pool	4
At John Day Dam	10
Top of John Day Dam	2
John Day Pool	1
At McNary Dam	8
Top of McNary Dam	2
Mid-Columbia River and Mid-Columbia River Tributaries	
Yakima River	1
Hanford Reach	10
At Priest Rapids Dam	9
At Wanapum Dam	1
Top Wanapum Dam	4
At Rock Island Dam	7
Top Rock Island Dam	1
Wenatchee River	168
White River	9
Napeequa River	1
At Rocky Reach Dam	2
Top Rocky Reach Dam	3
Entiat River/hatchery	1
Downstream Wells Dam	1
At Wells Dam	1
Wells Trap - released	11
Above Wells Dam	5
Methow River	3
Okanogan River	206
At Chief Joseph Dam	3
Snake River	
At Ice Harbor Dam	1

Table 26. Number and percent of sockeye salmon released with transmitters downstream from Bonneville Dam in 1997 with recaptures at all sites, recaptured and reported in sport and tribal fisheries, at hatcheries, weirs and other traps, and those recaptured in spawning areas, or found along rivers.

	All recaps	Sport fisheries	Tribal fisheries	Hatcheries weirs, traps	Other[1]
Unique Fish	100				
Percent of 577	17.3	0.5	11.8	1.2	3.8
Lower Columbia River					
Downstream from Bonn. Dam	2		1		1
At/near release site	1				1
Bonneville Trap, released	6			6	
Bonneville Pool	54	1	52	1	
The Dalles Pool	3		2		1
John Day Pool	3	1	2		
Mid-Columbia River and Mid-Columbia Tributaries					
Priest Rapids Pool	8		8		
Stemlit Creek	1				1
Wenatchee River	1				1
Icicle River	1				1
White River	9				9
Napeequa River	1				1
Wells Dam Hatchery/Trap	1				1
Okanogan River	8		3		5
Lake Osoyoos	1	1			

[1] Other includes recaptures at spawning grounds, found transmitters or found dead fish

from McNary Dam, 17 of 100 recaptures were from spawning ground surveys. Eleven fish (2%) were recaptured in tribal fisheries, one was recaptured in a sport fishery and two transmitters were found in non-spawning areas.

Fate of Sockeye Salmon with Transmitters

In addition to summaries of last recorded location, and type and location of recapture, we made best estimates of the fate of each radio-tagged sockeye salmon. In best-estimate summaries of fate, we calculated total escapement to tributaries and hatcheries (not including fisheries harvest in tributaries), total reported harvest, and total unaccounted for fish. We also summarized the approximate last recorded distribution of

Table 27. Number of sockeye salmon released in 1997 downstream from Bonneville Dam with transmitters that were recaptured or the transmitter was found somewhere in the basin and was returned to us, and the number recaptured and percent of total recaptures in various locations. Does not include fish recaptured at the Bonneville adult trap.

	Number	Percent
Number released and % returned	577	17.3
Transmitter returned[1] from:		
Downstream from Bonneville	**9**	**1.6**
Weirs/traps in tributaries[2]	6	1.0
Found in non-spawning area	2	0.4
Tribal Fishery	1	0.2
Bonneville to McNary dams	**60**	**10.4**
Sport fishery	2	0.4
Tribal fishery	56	9.7
Found in non-spawning area	1	0.2
Weirs/traps in tributaries	1	0.2
Mid Columbia River	**31**	**5.4**
Sport fishery	1	0.2
Tribal fishery	11	1.9
Spawning ground	17	3.0
Found in non-spawning area	2	0.4

[1] some fish recaptured at traps released with transmitters

[2] six fish recaptured at the Bonneville trap

unaccounted for fish, and similar summaries for known or presumed regurgitated transmitters. Fish that regurgitated transmitters and those unaccounted for may have returned to spawning areas or to areas other than those reported. In particular, fish that we designated presumed regurgitated because they were not recorded after release downstream from Bonneville Dam may have entered unmonitored downstream tributaries.

The final distribution for all radio-tagged sockeye salmon based on our best estimate of the fate of each fish 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 (Table 28, Figure 31). Escapement was 69% in tributaries and 12.3% were reported recaptured in mainstem or tributary tribal and sport fisheries. Known regurgitated transmitters in non-spawning areas made up 0.5% of the fish, and 2.6% were presumed regurgitated based on telemetry records and circumstances of the transmitter (3.1% total estimated).regurgitation rate). Another 16.1% were unaccounted for throughout the study area (Table 28).

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 (Table 29). Another 14 (15.1%) were last recorded between the top of McNary Dam and either the Priest

Table 28. Our best estimate of the fate of 577 sockeye salmon released in 1997 downstream from Bonneville Dam with transmitters with the numbers released, numbers and percents of total that ended up in the various sections of the Columbia River basin.

	Number	Percent
Number released	**577**	**100**
Downstream from Bonneville	**17**	**2.9**
Known regurgitated trans.	2	0.2
Presumed regurgitated trans.[1]	7	1.2
Unaccounted for	8	1.4
Bonneville to McNary dams	**105**	**18.2**
Entered a tributary	9	1.6
Sport fishery	2	0.4
Tribal fishery	57	9.8
Known regurgitated trans.	1	0.4
Presumed regurgitated trans.	3	0.5
Unaccounted for	33	5.7
McNary to Priest Rapids dams	**28**	**4.9**
Unaccounted for	14	2.4
Tribal fishery	8	1.4
Presumed regurgitated trans	5	0.9
Entered a tributary	1	0.2
Priest Rapids to Wells dams	**210**	**36.4**
Entered a tributary	179	31.4
Unaccounted for	30	5.2
Upstream from Wells Dam	**217**	**37.6**
Entered a tributary	205	35.5
Sport Fishery	1	0.2
Tribal Fishery	3	0.5
Unaccounted for	8	1.4
Basin-wide summary		
Recorded in tributaries	**395**	**68.5**
Recaptured in tribal or sport fishery	**71**	**12.3**
Known regurgitated trans.	**3**	**0.5**
Presumed regurgitated trans.[1]	**15**	**2.6**
Transmitters unaccounted for	**93**	**16.1**

[1] includes fish not recorded at any location after release

Rapids and Ice Harbor dam tailraces. Twelve fish (12.9%) were last recorded between the top of The Dalles Dam and the John Day Dam tailrace. Eleven fish (11.8%) were last recorded between the top of Bonneville Dam and the tailrace of The Dalles Dam.

Table 29. Last known locations for 93 sockeye salmon unaccounted for by records in tributaries, at hatcheries, in fisheries, or recovery of transmitters in any other way[1] throughout the monitored reach of the main stem Columbia and Snake rivers in 1997. Unaccounted for fish in each section and as a percentage of all fish in section, and percent of all unaccounted for fish and all fish released.

River section Last record location	Fish unaccounted for	All fish in section	Percent unaccounted for	Percent of 93 fish	Percent of 577 fish
Downstream from Bonneville	**8**	**8**	**100**	**8.6**	**1.4**
At Bonneville Dam	22		100	8.6	1.4
Top of Bonneville to The Dalles	**11**	**74**	**14.9**	**11.8**	**1.9**
Top of Bonneville Dam	3		4.1	3.2	0.5
Bonneville pool	7		9.5	7.5	1.2
At The Dalles Dam	1		1.4	1.1	0.2
Top of The Dalles to John Day	**12**	**16**	**75.0**	**12.9**	**2.1**
Top of The Dalles Dam	2		2.6	1.2	0.2
The Dalles pool	6		7.7	3.5	0.6
At John Day Dam	11		14.1	6.4	1.1
Top of John Day to McNary	**10**	**11**	**90.9**	**10.8**	**1.7**
Top of John Day Dam	2		18.2	2.2	0.3
At McNary Dam	8		72.7	8.6	1.4
Top of McNary to Ice Harbor or Priest Rapids dams	**14**	**23**	**60.9**	**15.1**	**2.4**
Top of McNary Dam	2		8.7	2.2	0.3
Hanford reach	9		39.1	9.7	1.6
At Ice Harbor Dam	1		4.3	1.1	0.2
At Priest Rapids Dam	2		8.7	2.2	0.3
Top of Priest Rapids to Wanapum 1	**1**	**100**	**1.1**	**0.2**	
At Wanapum Dam	1		100	1.1	0.2
Top of Wanapum to Rock Island 11	**11**	**100**	**11.8**	**1.9**	
Top of Wanapum Dam	4		36.4	4.3	0.7
At Rock Island Dam	7		63.6	7.5	1.2
Top of Rock Island to Rocky Reach3	**181**	**1.7**	**3.2**	**0.5**	
Top of Rock Island Dam	1		0.6	1.1	0.2
At Rocky Reach Dam	2		1.1	2.2	0.3
Top of Rocky Reach to Wells	**15**	**17**	**88.2**	**16.1**	**2.6**
Top of Rocky Reach Dam	3		17.6	3.2	0.5
Rocky Reach pool	1		5.9	1.1	0.2
At Wells Dam	11		64.7	11.8	1.9
Wells to Chief Joseph	**8**	**217**	**3.7**	**8.6**	**1.4**
Wells Pool	3		1.4	3.2	0.5
At Chief Joseph	5		2.3	5.4	0.9
Total	**93**		**100**	**100**	**16.1**[2]

[1] fish known or presumed to have regurgitated transmitters based on circumstances associated with the transmitter were considered accounted for

[2] 93 of 577 fish (16.1%) outfitted with transmitters were unaccounted for

Another 11 fish were last recorded between the top of Wanapum Dam and the tailrace of Rock Island Dam. We also calculated the proportion unaccounted for in each section of the hydrosystem. Downstream from Bonneville Dam, where we estimate 8 fish ended up (including fish not recorded after release) 100% were unaccounted for (Table 29). Between Bonneville and The Dalles dams 11 of 74 sockeye salmon (14.9%) were unaccounted for, and 12 of 16 (75.0%) were unaccounted for between The Dalles and John Day dams. Some 10 of 11 (90.9%) were unaccounted for between John Day and McNary dams, and 14 of 23 (60.9%) were unaccounted for from McNary to Priest Rapids and Ice Harbor dams. One-hundred percent of the fish (n=11) last recorded between Wanapum and Rock Island dams were unaccounted for, and 15 of 17 (88.2%) were unaccounted for between Rocky Reach and Wells dams. The highest proportion of unaccounted for sockeye salmon (41%) was from Priest Rapids to Wells dams (Figure 32). Only 8 of 217 (3.7%) were unaccounted for between Wells and Chief Joseph dams (Table 29).

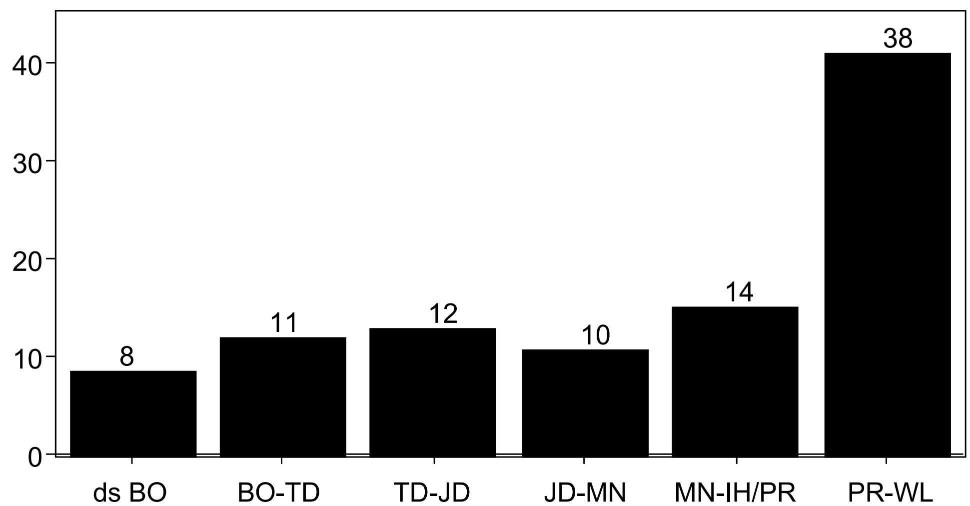


Figure 32. Proportion of sockeye salmon with radio transmitters that were unaccounted for, by section of the Columbia River hydrosystem in 1997.

Discussion

In 1997 we were able to successfully use radio telemetry on a large scale to assess and evaluate the passage of adult sockeye as they migrated past dams and through reservoirs in the Columbia River on their way to spawning grounds and hatcheries. We examined passage rates, fallback behavior, recaptures in fisheries, survival to tributaries, and final fate from release downstream from Bonneville Dam into the middle Columbia River. Compared to the previous 10-year average, the 1997 sockeye salmon run was about 80% of average at Bonneville and McNary dams, about 90% of average at Priest Rapids and Rock Island dams, and greater than 110% of average at Rocky Reach and Wells dams. Peak sockeye salmon counts at Bonneville and The Dalles dams were similar than average, but was about a week later at the other dams, perhaps because flow and spill in 1997 were nearly double the prior 10-year average, turbidity was higher than average, and water temperatures were consistently one to two degrees colder than average. Spill was nearly continuous at all dams during most of the 1997 sockeye salmon migration. Spill at Bonneville and McNary dams was about 45% of total flow, spill at The Dalles Dam was about 64% of total flow, and at John Day Dam spill was about 20% of total flow during the migration period. Spill at Priest Rapids Dam was about 40% of total flow and at Rock Island and Rocky Reach dams spill was about 20% of total flow.

Of the 577 sockeye salmon we released with transmitters in 1997, we could account for 484 (83.9%) of the fish or their transmitters, in that we were able to discern their final fates. Of 577, 68.5% of the fish ended up in tributaries, 12.3% were reported as harvested in sport or tribal fisheries, and 3.1% had regurgitated their transmitters near the release site or their transmitters were found in non-spawning areas. The remaining 16.1% were classified as being unaccounted for because they were last recorded at dams or in reservoirs, although we do not know if they died before spawning, were harvested but not reported to us, or entered tributaries undetected (perhaps because transmitters were regurgitated).

Transmitter retention was quite good overall: 7 (38.9%) salmon were known or presumed to have regurgitated tags near the release site, 4 (22.2%) regurgitated transmitters were found after passing one or more fixed sites and 7 were repeatedly mobile tracked in the same location. Overall, the known regurgitation rate was 0.5% (3 of 577). Some of the 93 (16.1%) transmitters we could not account for may have been regurgitated in reservoirs where we were unable to relocate them.

Of the 570 salmon released that did not regurgitate their transmitters at the release sites, 99.5% were recorded back at Bonneville Dam and 98.6% were known to have passed the dam. Eighty-six percent proceeded upriver and passed The Dalles Dam, 82% John Day Dam, 80% McNary Dam, 76% Priest Rapids Dam, 75% Wanapum Dam, 73% Rock Island Dam and 42% Rocky Reach. A small proportion of the tagged salmon passed each dam without being recorded at tailrace or top-of-ladder receivers, but were usually recorded in the fishways at the dam and at upstream receiver sites. Receiver efficiency averaged 94% for tailrace sites at lower Columbia River dams and 88% at Priest Rapids and Wanapum dams, 96% for top-of-ladder sites and lower Columbia River dams and 84% at Priest Rapids and Wanapum dams, and 95% for tributary sites.

Median times for salmon to pass individual dams in 1996 were less than 1.4 d, and were less than one day at Bonneville, The Dalles, John Day, McNary and Rock Island dams. At each dam, however, <1% to 8% of the radio-tagged fish took more than 5 d to pass, and all time-to-pass distributions were right-skewed, with mean times higher than medians.

Higher than average flows and nearly continuous spill during the sockeye salmon migration period in 1997 did not appear to have significant adverse effects on the passage of most sockeye salmon. In general, passage times tended to be longer under higher flow and spill conditions, but correlations of passage time and flow and spill were weak despite a large range of in-river conditions. Lack of comparison with other study years limits our ability to sufficiently evaluate these types of relationships.

Because all environmental conditions varied continuously, it was difficult to separate the effects of high flow, spill, and turbidity on passage times of salmon. Stepwise multiple regression models of passage times at individual dams tended to select spill, flow and temperature as the best predictor of passage times at lower Columbia River dams. However, no model had an r-square value greater than 0.12. Sockeye salmon migrated through the four lower Columbia River reservoirs relatively quickly in 1997.

Passage through the unimpounded section of the Columbia River (Hanford Reach) was about half through the impounded reservoirs. The significance of this is that passage through reservoirs may compensate in part for delay incurred passing dams.

Median passage times from the Bonneville Dam tailrace over several dams and through reservoirs were 6.9 d to the top of McNary Dam 11.9 d to the top of Priest Rapids Dam, 17.3 d to the top of Rock Island Dam, and 19.0 d to the top of Rocky Reach dam. Of the total migration time from Bonneville Dam tailrace to McNary Dam, approximately 43% of the median time was spent passing dams and 57% was spent passing through reservoirs. For the total migration time from Bonneville to past Rock Island and Rocky Reach dams, about 40% of the median time was spent passing dams. In multiple regression models, the best predictors of upstream passage times past multiple dams and reservoirs was the date fish passed the Bonneville Dam tailrace, however, the relationship was weak. In general, fish migrated faster the closer they came to spawning time, which may have been a response to warming temperatures.

A significant number of sockeye salmon with transmitters fell back over one or more of the four lower Columbia River dams in 1997. Twenty-nine percent (164 fish) of the sockeye salmon that passed Bonneville Dam fell back at one or more dams 181 times in 1997. Forty-three percent of all fall back event occurred at Bonneville Dam. Fallback rates for Chinook salmon and steelhead were also highest at Bonneville Dam in 1997 (Boggs et al. 2004). The Bradford Island fishway seemed to be important in the percentage of fish that fell back at Bonneville Dam. The Bradford Island ladder, which exits into the forebay on Bradford Island at Bonneville Dam, had the highest fallback rates for all ladders and dams. Many sockeye salmon exited the Bradford Island fishway and followed the shoreline around the island into the spillway forebay at the dam, where a relatively high proportion fell back. Full analyses of sockeye salmon fallback behavior and circumstances contributing to fallback at Bonneville, The Dalles, and John Day dams were reported in Bjornn et al. (2000b; 2000c; 2000d).

About 87% of sockeye salmon with transmitters that fell back at the Columbia River dams eventually reascended the fishways and passed upstream. Overall, about 26% of the fish that fell back and did not reascend entered tributaries downstream from the fallback location. We could not identify if such behavior was due to straying or temporary errors in homing (overshoot fallback).

Sockeye salmon bound for upriver sites that experienced direct or delayed mortality because of a fallback could not be included in passage time comparisons. Some of the fish that fell back over dams and did not reascend could not be accounted for and may have died as a result of falling back at a dam. However, we believe that direct mortalities from fallbacks must be relatively infrequent given that some fish fell back several times and still succeeded in migrating to upriver tributaries. In some cases a fish may have fallen back over a dam because it was sick or injured.

Fish that fell back at any location survived to major tributaries at similar rates (70.2%) as those fish that did not fall back (69.9%). However, sockeye salmon that fell back at Bonneville Dam survived at a significantly ($P < 0.10$) lower rate (58.7%) than fish that did not fall back at Bonneville Dam (71.6%). Routes of fallback at Bonneville Dam may be more deleterious to sockeye salmon than at other dams. Sockeye salmon that fell back at any dam were eventually recorded at tributary and main stem sites in the middle Columbia River basin, roughly in proportion to overall distributions. Fish last recorded in the Okanogan River drainage comprised a higher proportion of fallback fish at Bonneville Dam than fish last recorded in the Wenatchee River drainage, potentially indicative of a differential homing ability of the two stocks.

Sockeye salmon with transmitters that entered the middle Columbia River tributaries passed Bonneville Dam throughout the June-July migration season. Fish destined for the Wenatchee and Okanogan river drainages made up the majority of returns to middle Columbia River tributaries. The median date sockeye salmon passed Rock Island Dam was 19-July for Wenatchee River sockeye salmon. The median first date at Wells Dam was 20-July for Methow and Okanogan river stocks, including those fish last recorded at Wells Dam. Passage distributions for radio-tagged sockeye salmon was similar to that of all sockeye salmon passing lower and middle Columbia River dams.

About 70% of the 570 sockeye salmon that retained transmitters at time of release in 1997 survived to enter middle Columbia River tributaries. In 1997, our monitoring of radio-tagged salmon in the mid Columbia basin was not as extensive as in previous Snake River studies. We classified fish as having survived to tributaries if they were recorded in tributaries upstream from Rock Island and Rocky Reach dams (data provided by Chelan and Douglas counties PUDs). 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, concomitant with the onset of stressful river temperatures. In comparison, 61.3% of salmon tagged during the period 5-16 July were successful migrants (n = 155).

About 17% of all sockeye salmon outfitted with transmitters in 1997 were reported recaptured in fisheries, at hatcheries, weirs or traps (not including the Bonneville trap), at spawning grounds, or their transmitters were found along river corridors. Sixty-eight percent of recaptures were in tribal fisheries, 3% in sport fisheries, 7% at hatcheries, weirs or traps and 22% at spawning grounds or through found transmitters. Fifty-four percent of all recaptures were from tribal fisheries in the Bonneville pool. Our best final-distribution estimate for all fish with transmitters was 3% downstream from Bonneville Dam, 18% between Bonneville Dam and the McNary Dam tailrace, 4% in the from McNary Dam to Priest Rapids Dam, 36% from Priest Rapids to Wells Dam, and 37% upstream from Wells Dam. Maximum escapement to tributaries for spawning was 66.7%. About 1.7% of the fish were last recorded in lower Columbia River tributaries and were considered strays, 3.1% of transmitters were found in non-spawning areas, and 16.1% were unaccounted for.

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