Technical Report 2014-12

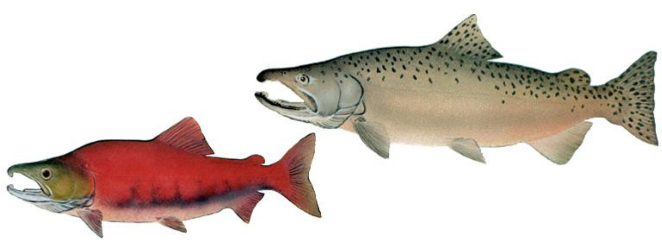
REACH CONVERSION RATES OF RADIO-TAGGED CHINOOK AND SOCKEYE SALMON IN THE LOWER COLUMBIA RIVER, 2013

A Report for Study Code ADS-P-13-2

by

M. L. Keefer, M. A. Jepson, T. S. Clabough, E. L. Johnson, C. C. Caudill
Department of Fish and Wildlife Sciences
University of Idaho, Moscow, ID 83844-1136

B. J. Burke, and K. E. Frick
National Marine Fisheries Service, National Oceanic and Atmospheric Administration,
Northwest Fisheries Science Center, Fish Ecology Division
Seattle, WA 98112



For

U.S. Army Corps of Engineers
Portland District, Portland, OR

2014

Technical Report 2014-12

REACH CONVERSION RATES OF RADIO-TAGGED CHINOOK AND SOCKEYE SALMON IN THE LOWER COLUMBIA RIVER, 2013

A Report for Study Code ADS-P-13-2

by

M. L. Keefer, M. A. Jepson, T. S. Clabough, E. L. Johnson, and C. C. Caudill
Department of Fish and Wildlife Sciences
University of Idaho, Moscow, ID 83844-1136

B. J. Burke, and K. E. Frick
National Marine Fisheries Service, National Oceanic and Atmospheric Administration,
Northwest Fisheries Science Center, Fish Ecology Division
Seattle, WA 98112

For

U.S. Army Corps of Engineers
Portland District, Portland, OR

2014

Acknowledgements

This study was funded by the U.S. Army Corps of Engineers, Portland District. We are grateful for the assistance from Portland District and Bonneville project biologists. They include: Brian Bissell, Ben Hausmann, Tammy Mackey, Jon Rerecich, Ida Royer, Sean Tackley, and Andrew Traylor. Others at the Bonneville Lock and Dam and at The Dalles and John Day dams and at McNary and the lower Snake River dams that supported the project include the electrical and crane crews as well as the project biologists. Successful completion of this work was also made possible with the help from University of Idaho staff members Inga Aprans, Charles Erdman, Noah Hubbard, Karen Johnson, Dan Joosten, Mark Kirk, Luis Martinez-Rocha, Chris Noyes, Kaan Oral, Joe Renner, Theresa Tillson, Michael Turner, Leslie Layng and Jeff Garnett who assisted with fish collection and tagging, fish transport, and radio telemetry set-up, downloading, and coding. We are grateful to John Whiteaker and the Columbia River Inter-tribal Fish Commission (CRITFC) tagging crew as they helped with daily trap operations and maintenance. We would also like to extend our thanks to Ann Stephenson and the tagging crew at the Washington Department of Fish and Wildlife who provided the lifting assembly for the bridge crane and assisted with trapping and transport of radio-tagged fish. This study was conducted under Cooperative Ecosystems Study Unit (CESU) agreement CESU W912HZ-12-2-0004 funded by the U.S. Army, Corps of Engineers (USACE), Portland District, with the assistance of Jon Rerecich, Sean Tackley, Glen Rhett, and Deberay Carmichael.

Table of Contents

Executive Summary

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

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

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

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

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

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

Introduction

The overarching objective of this study was to estimate upstream passage success (i.e., 'conversion rates') by adult salmon and steelhead through the lower Columbia River. Recent conversion rate estimates between Bonneville Dam and McNary have been below performance standards established by the Federal Columbia River Power System (FCRPS) Biological Opinion ('BiOp') for three Evolutionarily Significant Units (ESUs). These include Snake River and Upper Columbia River spring–summer Chinook salmon (*Oncorhynchus tshawytscha*) and Snake River steelhead (*O. mykiss*). Standards are currently being developed for the endangered Snake River sockeye salmon (*O. nerka*).

Understanding where and why migrants from the listed ESUs fail to pass through the lower FCRPS is critically important for managers responsible for maintaining the native fish runs and for achieving the recovery goals outlined by NOAA Fisheries (NOAA) and the Northwest Power Planning Council (NWPPC). Adequate upstream passage and high survival through the FCRPS for adult salmonids are primary requirements of the 2008 BiOp, the 2010 Supplemental BiOp, and the recently-released 2014 BiOp.

Conversion estimates lower than the Bonneville-McNary performance standards have primarily been calculated using PIT-tag detections of adults that were tagged as juveniles at sites upstream from McNary Dam (e.g., Tuomikoski et al. 2013). While the PIT-tagged samples provide good estimates of Bonneville-to-McNary conversion rates, they do not provide much information on the behaviors or fates of the fish that fail to pass or on potential causative factors. The pre-2013 PIT-based estimates also could not partition loss rates among dam-to-dam reaches because The Dalles and John Day dams had no PIT detection antennas (antennas were installed at The Dalles Dam in 2013).

There are several potential sources of mortality and unaccounted-for loss in the lower FCRPS study area. These include legal and illegal harvest (Dauble and Mueller 2000), natural mortality (e.g., from sea lion *Zalophus californianus* and *Eumetopias jubatus* predation; Stansell et al. 2010; Keefer et al. 2012), mortality associated with fallback at dams (Boggs et al. 2004; Keefer et al. 2005), failure to pass dams (Caudill et al. 2007), straying into non-natal tributaries associated with natural processes or as a result of juvenile transportation (e.g., Keefer et al. 2008a; Marsh et al. 2012; Keefer and Caudill 2014), and environmental effects such as exposure to high water temperature (Naughton et al. 2005; Goniea et al. 2006; Keefer et al. 2009).

Efforts to partition adult loss in the lower FCRPS have included harvest monitoring, estimation of stray rates using tagged fish, and radiotelemetry studies with transmitter reward programs (e.g., Keefer et al. 2005; Naughton et al. 2005; Caudill et al. 2007). In 2013, we collected and radio-tagged adult salmon and steelhead at Bonneville Dam to address the conversion rate objectives described above as well as several dam-specific behavioral objectives (see companion reports: Burke et al. 2014 and Johnson et al. 2014). The radiotelemetry study groups included adult sockeye salmon, adult and jack spring–summer Chinook salmon, and adult summer steelhead. This report summarizes data from Year 1 of a two-year study, with tagging for Year 2 underway as of this writing. Note that data for summer steelhead were not fully processed in spring 2013 because overwintering steelhead were actively migrating. Steelhead data collected in 2013-2014 was processed in summer 2014. Reach conversion summaries for steelhead will be included in the final project report.

This report addresses the following specific objectives for samples of adult salmon radio-tagged at Bonneville Dam in 2013:

1) *estimate conversion rates of spring-summer Chinook salmon and sockeye salmon between Bonneville and McNary dams to identify reaches where loss is occurring*;

2) *estimate tributary turnoff rates of spring-summer Chinook salmon and sockeye salmon*;

3) *evaluate fallback, re-ascension, and Bonneville to McNary conversion rates of spring Chinook salmon in relation to sea lion presence in the Bonneville tailrace*;

4) *evaluate fallback, re-ascension, and Bonneville to McNary conversion rates of spring-summer Chinook and sockeye salmon passing FCRPS dams*; and

5) *evaluate the influence of environmental and operational variables on Objectives 1-4*.

Methods

Salmon collection and tagging at Bonneville Dam

We collected and intragastrically radio-tagged jack and adult spring–summer Chinook salmon and adult sockeye salmon at the Adult Fish Facility (AFF), located adjacent to the Washington-shore ladder. Chinook salmon were collected and tagged starting 2 May (i.e., none were tagged in April) and were tagged in approximate proportion to the run thereafter. Sockeye salmon were collected throughout the run. Fish were selected in the order that they entered the trap each day. We did not select for any particular group but we did select against fish that had PIT tags from juvenile tagging projects due to concerns about handling effects on research outcomes (i.e., all known-origin fish were excluded from radio tagging). Selection against previously PIT-tagged fish meant that the samples were not fully representative of the runs at large. It also made it impossible to identify fish that strayed into lower Columbia River tributaries, a behavior that can reduce reach conversion for upriver populations (Keefer et al. 2008; Keefer and Caudill 2014).

Protocols for collecting and outfitting salmon with transmitters at Bonneville Dam, coding of the data, and data analysis were similar to those used in prior years (e.g., Keefer et al. 2004a; 2005; Jepson et al. 2011). Fish receiving a radio transmitter were anesthetized in a ~18 mL/L solution of AQUI-S-20E (Aquatactics, Kirkland, WA). We used four types of digitally-encoded radio transmitters developed by Lotek Wireless Inc. (Newmarket, Ontario). The transmitter models used to tag adult Chinook salmon were 7-volt MCFT-7F (16mm × 88mm; 31g in air) and the MCFT-7A (16mm × 83mm; 29 g in air). Jack Chinook salmon, defined as having a fork length < 60 cm, were tagged with a nano transmitter (NTC-4-2L; 8mm × 18mm; 2 g in air) and adult sockeye were tagged with a 3-volt MCFT2-3BM transmitter (11mm × 43mm; 7.7 g in air).

All adults were also tagged with a full duplex PIT-tag inserted to the abdominal cavity as a secondary tag that allowed estimation of tag loss rates, detection efficiencies and conversion rates using both radio- and PIT-detections.

Fish that were radio-tagged were weighed (nearest 10 g), measured for fork length (nearest 0.5 cm), and were assessed for lipid content using a Distell Fatmeter (Distell Industries Ltd., West Lothian, Scotland). All fish were inspected for fin clips, injuries, and other marks. We also collected scale samples from each fish to determine fish age and caudal fin punches for DNA analyses (these data will be reported separately once processed). After recovery from anesthesia, radio-tagged fish were transported by truck in river water and released ~ 8 km downstream from Bonneville Dam from sites on both sides of the Columbia River. Fish were supplied with continuous oxygen until release.

Radiotelemetry and PIT monitoring

We used an array of fixed-site radio receivers with digital spectrum processors (DSPs) at dams, in reservoirs, and in major tributaries to monitor tagged salmon (Table 1, Figure 1). Radio receivers with Yagi aerial antennas were used to monitor dam tailraces, reservoirs, and tributaries. At dams, most antennas were underwater coaxial cable antennas, though a few sites also had aerial Yagis. Underwater antennas at dams were used to monitor fishway openings, collection channels, transition areas, ladders, and top-of-ladder exit areas. Fish detection efficiencies on these arrays have historically been >95% at most sites, and antenna redundancy in most fishways increased dam-wide detection efficiency to near 100%. We used top-of-ladder sites and upstream detections to determine whether fish passed dams and to estimate dam-to-dam reach conversion rates (see methods below). Missed radio detections at top-of-ladder antennas mostly occurred during power outages.

The raw radiotelemetry data were screened for likely ‘noise’ records using filters that identified signal collisions (i.e., two or more codes at the same receiver at the same time). A detection history for each radio-tagged fish was generated using an automated coding program that assigned activity codes (e.g., tailrace entry and exit, fishway entry and exit, ladder passage, tributary entry, etc.) to the time-stamped detections at each antenna using a set of coding rules followed with review by experienced technicians who identified records that did not have corroborating support from detections at nearby antennas.

Each fish received a full-duplex PIT tag as a secondary marker, and we supplemented the radiotelemetry histories using PIT detections inside dam fishways (Bonneville, The Dalles, McNary, Ice Harbor, Lower Granite, and upper Columbia River dams), inside tributaries, and at fish collection facilities. The PIT detection data were downloaded from the Pacific States Marine Fisheries Commission PIT Tag Information System database (PTAGIS). PIT detections were also used to identify passage by salmon that lost transmitters or that had transmitters that were not working. Both radio and PIT data were used to assign dam passage events and to assign final detection locations.

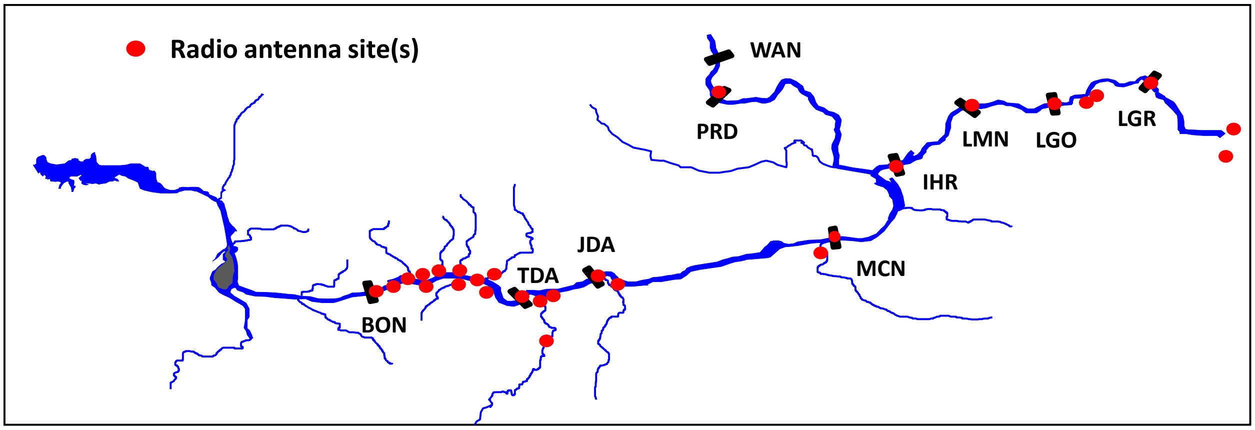


Figure 1. Map of the study area showing the reaches where conversion rates were estimated for radio-tagged adult Chinook and sockeye salmon in 2013: Bonneville Dam to The Dalles Dam, The Dalles Dam to John Day Dam, and John Day Dam to McNary Dam. Detection probabilities (ρ) were estimated at the three dams using radio- and PIT-tag interrogation records from upstream sites. Note that no tributaries were monitored downstream from Bonneville Dam.

Conversion rate estimation

We estimated reach-specific conversion rates using Cormack-Jolly-Seber (CJS) survival models (Lebreton et al. 1992; Perry et al. 2012). This method has frequently been used to estimate reach survival for juvenile salmonids in the Columbia River system (e.g., Muir et al. 2001; Sandford and Smith 2002) and to estimate adult salmon reach survival and escapement to tributaries (e.g., Keefer et al. 2005, 2010). CJS models allow simultaneous estimation of detection probabilities (ρ, accounting for undetected fish) and survival probabilities (φ). The generally high detection efficiency of both radio- and PIT-tagged fish in the adult fishways at Columbia River dams allows calculation of precise, unbiased estimates of adult reach conversion.

The salmon in the 2013 study were double-tagged with radio transmitters and PIT tags. We used radiotelemetry detections at dams to calculate detection efficiency estimates (ρ) at the tops of dams. Fish that passed top-of-ladder radio antennas undetected were coded as 'undetected' but were subsequently identified as passing either by PIT detections at the same dam or by upstream detections at radiotelemetry or PIT antennas at dams and in tributaries. These fish were therefore in the 'passed dam' category for conversion estimates but in the 'missed detection' for detection probability estimates. This was a conservative approach to calculating detection efficiency that resulted in slightly wider confidence intervals for the reach conversion estimates than if we had used both radiotelemetry and PIT detections at each dam. Missed radiotelemetry detections occurred primarily during power outages or because fish either lost transmitters or transmitters stopped working.

We used program Mark (White and Burnham 1999) to estimate conversion rates through five lower Columbia River reaches: (1) from release to the top of Bonneville Dam; (2) from the top of Bonneville Dam to the top of the Dalles Dam; (3) from the top of The Dalles Dam to the top

Table 1. Radiotelemetry monitoring sites in the Columbia and Snake rivers in 2013.

Site	Antenna type	# Receivers
Bonneville Dam Tailrace	Aerial	2
Bonneville Dam Fishways	Aerial	6
Bonneville Dam Fishways	Underwater	11
Bonneville Reservoir – Bridge of the Gods	Aerial	1
Bonneville Tributary – Wind River Mouth	Aerial	1
Bonneville Reservoir – Viento State Park	Aerial	1
Bonneville Reservoir – Cook-Underwood Rd	Aerial	1
Bonneville Tributary – Little White Salmon River Mouth	Aerial	1
Bonneville Tributary – White Salmon River	Aerial	2
Bonneville Tributary – Hood River Mouth	Aerial	1
Bonneville Reservoir – Chamberlain Lake Rest Area	Aerial	1
Bonneville Reservoir – Memaloose Rest Area State Park	Aerial	1
Bonneville Reservoir – Chamberlain Lake Rest Area	Aerial	1
Bonneville Tributary – Klickitat River Mouth	Aerial	1
The Dalles Dam Tailrace	Aerial	2
The Dalles Dam Fishways	Underwater	8
The Dalles Reservoir – Celilo Park	Aerial	1
The Dalles Reservoir – Wishram-Celilo	Aerial	1
The Dalles Tributary – Deschutes River Mouth	Aerial	1
The Dalles Tributary – Deschutes River Sherars Falls	Aerial	1
John Day Dam Tailrace	Aerial	2
John Day Dam Fishways	Underwater	6
John Day Tributary – John Day River Mouth	Aerial	1
McNary Dam Tailrace	Aerial	2
McNary Dam Fishways	Underwater	6
Priest Rapids Dam Fishways	Underwater	2
Ice Harbor Dam Tailrace	Aerial	1
Ice Harbor Dam Fishways	Underwater	6
Lower Monumental Dam Tailrace	Aerial	1
Lower Monumental Dam Fishways	Underwater	6
Lower Monumental Reservoir – Lyons Ferry Hatchery	Aerial	1
Lower Monumental Reservoir – Downstream of Tucannon River	Aerial	1
Lower Monumental Tributary – Tucannon River	Aerial	1
Little Goose Dam Tailrace	Aerial	2
Little Goose Dam Fishways	Underwater	6
Lower Granite Dam Tailrace	Aerial	2
Lower Granite Dam Fishways	Underwater	5
Lower Granite Tributary – Clearwater River near Potlatch Mill	Aerial	1
Lower Granite Tributary – Snake River upstream of 3 Mile Island	Aerial	1

of John Day Dam; (4) from the top of John Day Dam to the top of McNary Dam; and (5) from the top of Bonneville Dam to the top of McNary Dam (Figure 1). Within MARK, we used the live recaptures CJS model with a logit link function and allowed detection probabilities (ρ) and survival probabilities (φ) to vary across sites. This type of mark-recapture model uses maximum likelihood estimation to generate the parameter estimates (Perry et al. 2012). We note that – for this application – reach conversion estimates were synonymous with survival rates. 95% profile likelihood confidence intervals were generated for each estimate.

We calculated several reach conversion estimates to differentially account for fish that were self-reported as harvested (known to be minimum estimates) and those that entered tributaries between release below Bonneville Dam and passage of McNary Dam (Table 2). The first estimate (A, Table 2) was a raw minimum survival estimate, unadjusted for self-reported harvest or tributary turnoff and is similar in principle to estimates based solely on adult counts at dams (though without accounting for fallback and reascension; see Boggs et al. 2004). The second estimate (B) treated fish last recorded in a reach tributary as successful if the tributary had a population of the species (i.e., sockeye salmon last recorded in Bonneville reservoir tributaries were treated as unsuccessful because there are no sockeye salmon populations in those rivers). The third estimate (C) treated tributary fish as successful and those self-reported as harvested in the reach were censored (i.e., removed from the sample because their reach survival was independent of FCRPS operations). The final estimate (D) censored both self-reported harvested and tributary fish, leaving only the 'unaccounted for' group in the failed category. This metric was closest to management-based methods that use counts at dams, harvest estimates, and estimates of tributary turnoff and straying to 'adjust' reach conversion estimates (e.g., Dauble and Mueller 2000 and the 2008 and 2014 Biological Opinions).

The above estimates were calculated separately for sockeye salmon, adult Chinook salmon and jack Chinook salmon. Spring- and summer-run Chinook were combined for most analyses to increase inferential power. However, given stakeholder interest in separate estimates for spring- and summer-run Chinook salmon, we also calculated point estimates of Bonneville-McNary reach conversion for these groups using 16 June as the start date for the summer run (date based on the U.S. v Oregon agreement). Point estimates did not substantively differ from CJS estimates.

Table 2. Four metrics used to evaluate adult and jack salmon reach-specific upstream conversion rates in the lower FCRPS. Metrics differ in how reported harvest and tributary turnoff are treated.

Conversion estimate	Passed upstream dam	Entered tributary	Reported harvested	Unaccounted for
A	Success	Fail	Fail	Fail
B	Success	Success[1]	Fail	Fail
C	Success	Success[1]	Censor	Fail
D	Success	Censor	Censor	Fail

[1] sockeye salmon in BON-TDD and JDD-MCN tributaries considered unsuccessful

Effects of covariates on reach conversion

For each sample group, we used logistic regression (Agresti 2012) to evaluate the relationships between reach conversion rate and the following factors: migration date, fish fork length (cm), estimated fish sex (M, F), hatchery versus wild origin (based on fin clips), and fallback history at dams. In these models (separate from the CJS conversion models), fish that entered reach tributaries and those reported harvested were censored (equivalent to conversion rate Metric D). Migration date was either the date of release (release-Bonneville top reach) or the date that fish first passed the downstream dam (all other reaches). Date was a surrogate for water temperature, as later migrants encountered higher temperatures in both the sockeye salmon and Chinook salmon runs. Date was also associated with flow, though more weakly than temperature. Fork length was selected as the measure of fish size; models with fish weight produced similar results, but more fish were missing weight than fork length data. The fallback covariate was binary (yes, no) and indicated whether fish fell back at the downstream dam for the dam-to-dam reaches (BON-TDD, TDD-JDD, JDD-MCN) or at any dam for the BON-MCN reach. We ran a series of logistic regression models to evaluate the effects of each covariate independently and in combination. No interactions were considered. Additional analyses of covariate effects are planned after Year 2 of this study.

Results

Radio-tagged sample summary

We collected and radio-tagged 414 adult spring Chinook salmon (2 May-15 June), 186 adult summer Chinook salmon (16 June-15 July), 208 jack spring Chinook salmon, 92 jack summer Chinook salmon, and 400 adult sockeye salmon (Figure 2). No Chinook salmon were tagged in April due to institutional constraints, including contracting related to transmitter delivery. Total counts at Bonneville Dam during the tagging intervals were: 81,717 adult spring Chinook (2 May-15 June), 40,482 jack spring Chinook, 52,871 adult summer Chinook salmon (16 June-15 July), 15,085 summer jack Chinook, and 172,140 adult sockeye salmon. Radio-tagged salmon represented ~0.4-0.6% of the Chinook salmon and ~0.2% of the sockeye salmon counted at the dam during the tagging periods.

The sockeye salmon sample included 8 (2%) adipose-clipped fish of presumed hatchery origin and 392 (98%) unclipped fish. The adult Chinook salmon sample was 48% clipped and 52% unclipped, and the jack sample was 52% clipped and 48% unclipped.

Last detection sites

Seven radio-tagged salmon were censored from all analyses (Table 3). Two were adult Chinook salmon that died (0.3% of 600 tagged), including one in the AFF prior to transport and one during transport. One jack Chinook salmon was recovered dead in the AFF (0.3% of 300 tagged) after it was released, migrated upstream, entered a Bonneville fishway, and re-entered the AFF. The four other fish had transmitters recovered in the transport tank or near a release site (1 sockeye salmon, 1 jack Chinook salmon, 2 adult Chinook salmon). The telemetry data suggested that additional fish likely lost transmitters upon release, but tags were not recovered and these fish were conservatively treated as unaccounted for in all analyses.

Sockeye salmon. Combined radio- and PIT-tag migration histories indicated that 83.3% of adult sockeye salmon passed McNary Dam, the upper end of the 2013 study reach (Table 3). Relatively few sockeye salmon (2.8%) were reported as harvested and total of 13.5% were unaccounted for downstream from McNary Dam. The group that was not accounted for presumably included unreported harvest and mortality events as well as potential lost transmitters. No sockeye salmon were recorded in the Deschutes River, the only tributary in the study reach with potential for returning adults.

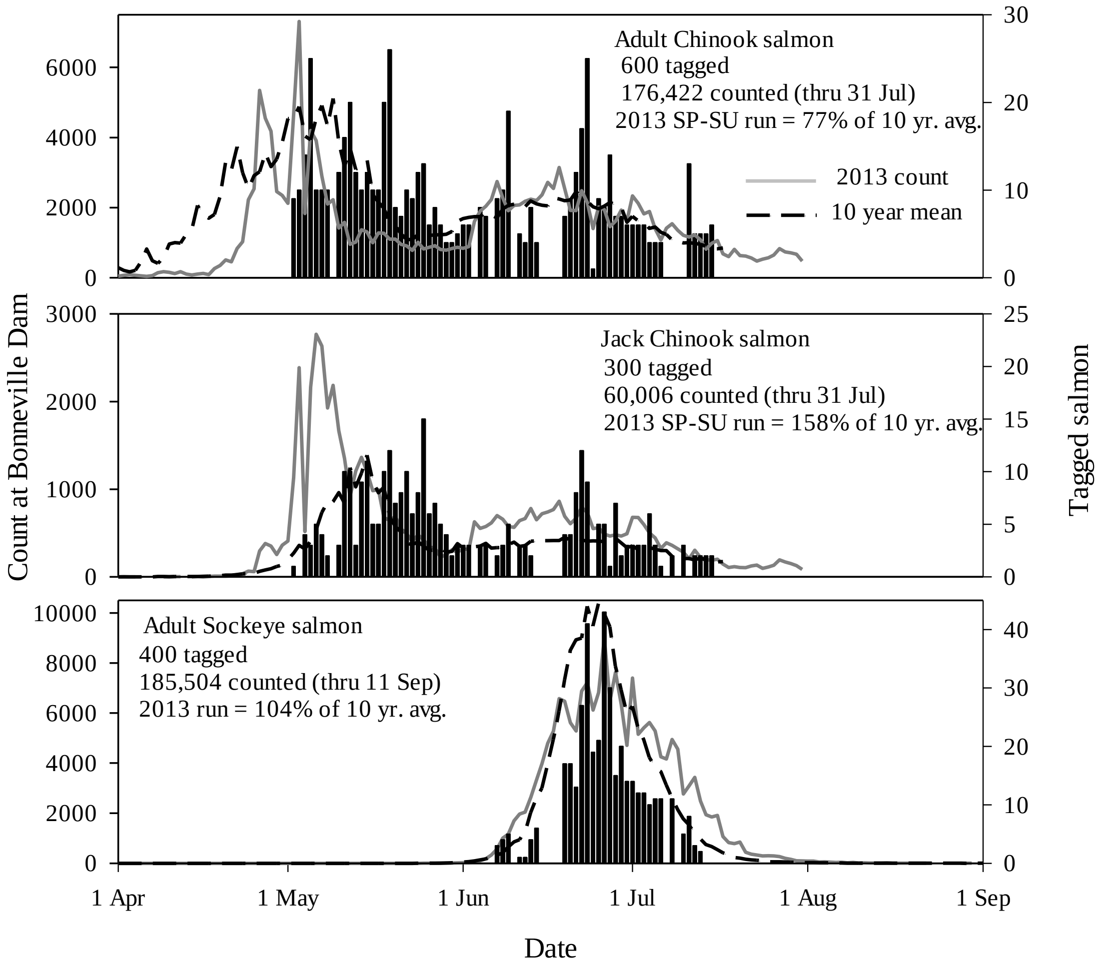


Figure 2. The numbers of adult and jack Chinook salmon and adult sockeye salmon radio-tagged and released downstream from Bonneville Dam in relation to the counts of salmon passing the dam in 2013 and on average from 2003-2012. Note: 16 June was the nominal start of the summer Chinook salmon run at Bonneville Dam.

Table 3. Last recorded locations of radio-tagged sockeye and spring–summer Chinook salmon in 2013 derived from the combination of radiotelemetry and PIT detection histories. Note that some fish were recorded passing dams upstream from their final location (i.e., they fell back downstream) and harvest estimates are likely minimums given low self-reported harvest rates.

	Adult sockeye	%	Adult Chinook	%	Jack Chinook	%
Tagged	400		600		300	
Censored	*1*	*0.3*	*3*	*0.5*	*3*	*1.0*
Below BON (harvest)	-	-	2	*0.3*	-	-
Below BON (unaccount)	12	*3.0*	25	*4.2*	6	*2.0*
BON reservoir (harvest)	10	*2.5*	14	*2.3*	1	*0.3*
BON reservoir (unaccount)	23	*5.8*	41	*6.8*	5	*1.7*
Wind River	-	-	8	*1.3*	-	-
Little White Salmon River	[1]4	*1.0*	3	*0.5*	1	*0.3*
Hood River	-	-	6	*1.0*	2	*0.3*
Klickitat River	[1]1	*0.3*	5	*0.8*	9	*3.0*
TDD reservoir (harvest)	-	-	7	*1.2*	-	-
TDD reservoir (unaccount)	11	*2.8*	25	*4.2*	-	-
Deschutes River	-	-	16	*2.7*	6	*2.0*
JDD reservoir (harvest)	1	*0.3*	4	*.7*	-	-
JDD reservoir (unaccount)	3	*0.8*	15	*2.5*	4	*1.3*
John Day River	-	-	9	*1.5*	4	*1.3*
Umatilla River	-	-	2	*0.3*	9	*3.0*
Top of McNary Dam	25	*6.3*	11	*1.8*	4	*1.3*
Snake River dams	3	*0.8*	20	*3.3*	37	*12.3*
Snake River tributaries	-	-	148	*24.7*	117	*39.0*
Walla Walla River	-	-	1	*0.2*	-	-
Yakima River	1	*0.3*	28	*4.7*	19	*6.3*
Hanford Reach	1	*0.3*	-	-	-	-
Upper COL River dams	173	*43.3*	132	*22.0*	50	*16.7*
Upper COL River tributaries	130	*32.5*	75	*12.5*	23	*7.7*
Release-MCN Harvest	11	*2.8*	27	*4.5*	1	*0.3*
Release-MCN Tributary	-	-	49	*8.2*	31	*10.3*
Release-MCN Unaccount	54	*13.5*	106	*17.7*	15	*5.0*
Passed MCN at least once	333	*83.3*	[2]420	*70.0*	[2]258	*86.0*
Last detection >MCN	333	*83.3*	415	*69.2*	250	*83.3*

[1] Treated as unaccounted for

[2] Most Chinook salmon that passed MCN but were last detected downstream entered the Umatilla River

Chinook salmon. At least 69% of adult spring–summer Chinook salmon and 83% of jack spring–summer Chinook salmon passed McNary Dam (Table 3). Reported main stem harvest downstream from McNary Dam was 4.5% and 0.3%, respectively. Tributary turnoff was 8.2% (adults) and 10.3% (jacks) and unaccounted for rates were 17.7% (adults) and 5.0% (jacks).

Conversion estimates: Sockeye salmon

Release-top of Bonneville. Conversion estimates were 0.975 for all four metrics (Figure 3), because there was no reported harvest or tributary entry downstream from the dam.

Bonneville -The Dalles. Conversion estimates were 0.905 for Metrics A and B (harvest = unsuccessful) and 0.929 for Metrics C and D (harvest = censored). We treated the sockeye salmon last detected in the Little White Salmon and Klickitat rivers (see Table 3) as unsuccessful rather than tributary turnoff because there are no spawning sockeye populations in these rivers.

The Dalles -John Day. Conversion estimates were 0.960 for all four metrics. Neither harvest nor Deschutes River entry was recorded.

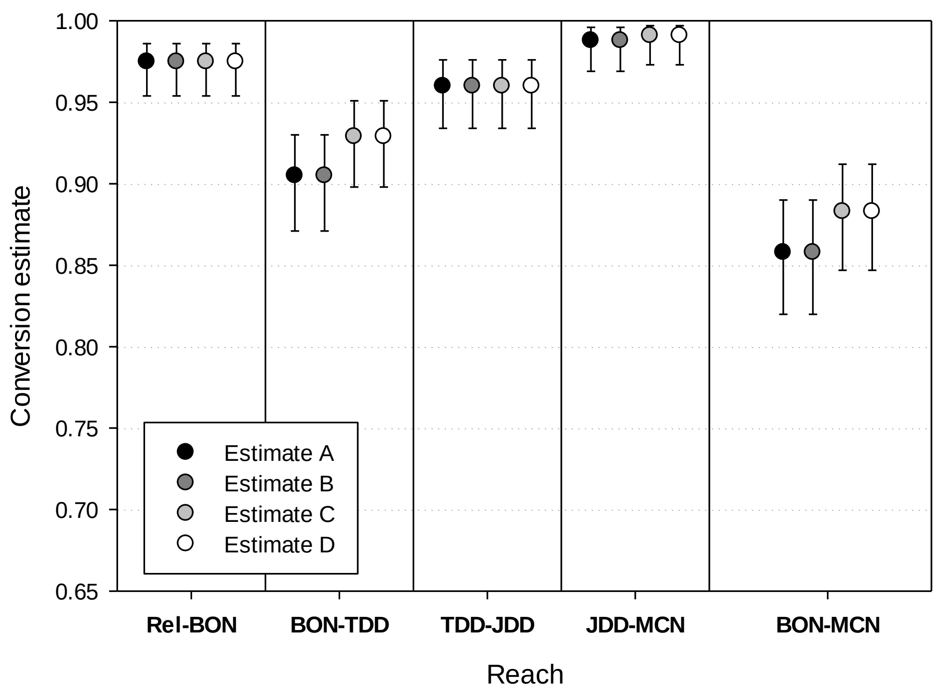


Figure 3. Reach-specific conversion rate estimates (±95% CI's) for radio-tagged adult sockeye salmon in 2013. See Table 2 for details on the estimation methods, which varied according to how harvest and tributary turnoff were handled. Rel = Release site; BON = top of Bonneville Dam; TDD = top of The Dalles Dam; JDD = top of John Day Dam; MCN = top of McNary Dam.

John Day -McNary. Conversion estimates were 0.988 for Metrics A and B and 0.991 for Metrics C and D. A single sockeye salmon was reported harvested in this reach, and no fish were recorded entering the John Day or Umatilla rivers.

Bonneville-McNary. Conversion estimates were 0.858 for Metrics A and B and 0.883 for Metrics C and D. Total harvest in the lower Columbia River downstream from McNary Dam was 11 fish; none entered the Deschutes River, the only potential spawning site.

Conversion estimates: Adult spring-summer Chinook salmon

Release-top of Bonneville. Conversion estimates were 0.966 for Metrics A and B (harvest = unsuccessful) and 0.970 for Metrics C and D (harvest = censored) (Figure 4). Two adults were reported harvested downstream from the dam.

Bonneville-The Dalles. Conversion estimates were 0.884 (Metric A), 0.910 (Metric B), 0.933 (Metric C), and 0.931 (Metric D). Fourteen salmon were reported harvested in the reach and 15 entered tributaries. (Note that these numbers differ slightly from Table 3, which gives final detection locations, which includes post-fallback movements.)

The Dalles-John Day. Conversion estimates were 0.882 (Metric A), 0.922 (Metric B), 0.934 (Metric C), and 0.932 (Metric D). Seven adult Chinook salmon were reported harvested in the reach and 20 entered the Deschutes River.

John Day-McNary. Conversion estimates were 0.933 (Metric A), 0.956 (Metric B), 0.964 (Metric C), and 0.963 (Metric D). Four adult Chinook salmon were reported harvested in the reach and 10 entered tributaries to John Day reservoir.

Bonneville-McNary. Conversion estimates were 0.728 (Metric A), 0.806 (Metric B), 0.842 (Metric C), and 0.828 (Metric D). In total, 25 adult Chinook salmon (10 spring, 15 summer) were reported harvested downstream from McNary Dam and 45 (41 spring, 4 summer) entered tributaries.

Bonneville-McNary (spring only). Point estimates of conversion were 0.737 (Metric A), 0.841 (Metric B), 0.862 (Metric C), and 0.846 (Metric D).

Bonneville-McNary (summer only). Point estimates of conversion were 0.709 (Metric A), 0.731 (Metric B), 0.796 (Metric C), and 0.791 (Metric D).

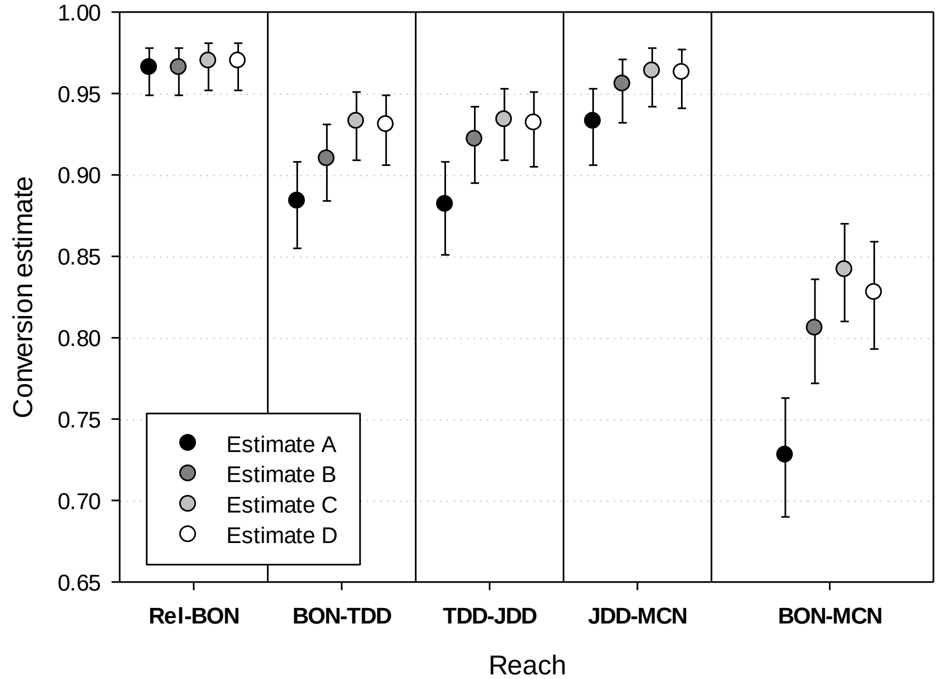


Figure 4. Reach-specific conversion rate estimates (±95% CI's) for radio-tagged adult spring–summer Chinook salmon in 2013. See Table 2 for details on the estimation methods, which varied according to how harvest and tributary turnoff were handled. Rel = Release site; BON = top of Bonneville Dam; TDD = top of The Dalles Dam; JDD = top of John Day Dam; MCN = top of McNary Dam.

Conversion estimates: Jack spring-summer Chinook salmon

Release-top of Bonneville. Conversion estimates were 0.980 for all four metrics (Figure 4), because there was no reported harvest or tributary entry downstream from the dam.

Bonneville-The Dalles. Conversion estimates were 0.948 (Metric A), 0.979 (Metric B), 0.983 (Metric C), and 0.982 (Metric D). One jack Chinook salmon was reported harvested in the reach and 9 entered tributaries.

The Dalles-John Day. Conversion estimates were 0.967 (Metric A) and 1.000 (Metrics B, C and D). Nine jacks entered the Deschutes River and none were reported harvested in the reach.

John Day-McNary. Conversion estimates were 0.966 (Metric A), 0.985 (Metrics B, C and D). Five jacks entered tributaries to John Day reservoir and none were reported harvested.

Bonneville-McNary. Conversion estimates were 0.887 (Metric A), 0.966 (Metric B), 0.969 (Metric C), and 0.966 (Metric D). In total, 1 jack spring Chinook salmon was reported harvested downstream from McNary Dam and 23 (16 spring, 7 summer) entered tributaries.

Bonneville-McNary (spring only). Point estimates of conversion were 0.875 (Metric A), 0.955 (Metric B), 0.960 (Metric C), and 0.956 (Metric D).

Bonneville-McNary (summer only). Point estimates of conversion were 0.912 (Metric A), 0.989 (Metric B), 0.989 (Metric C), and 0.988 (Metric D).

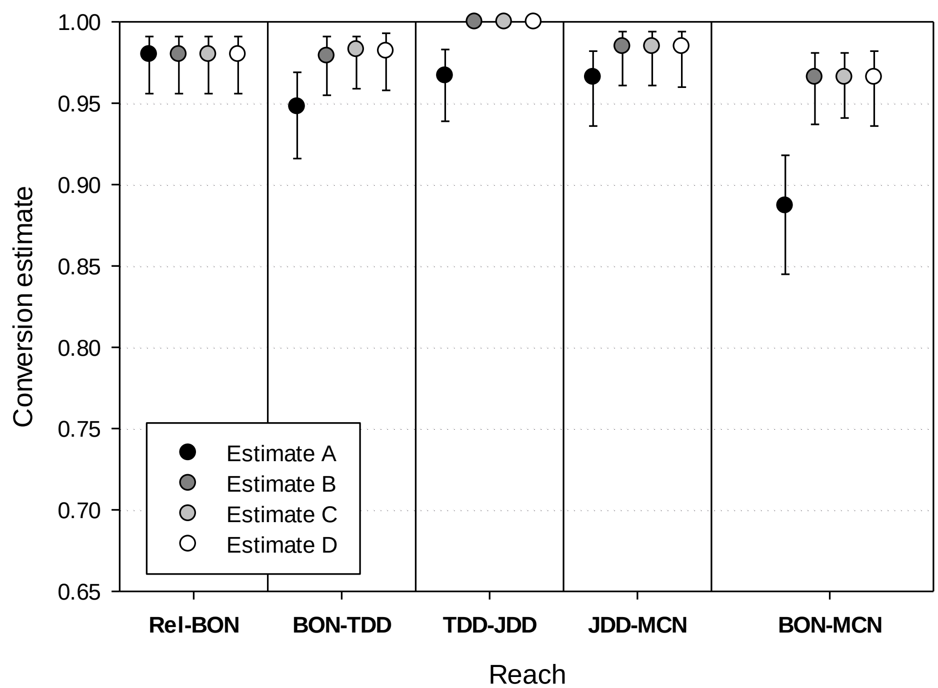


Figure 5. Reach-specific conversion rate estimates (±95% CI's) for radio-tagged jack spring–summer Chinook salmon in 2013. See Table 2 for details on the estimation methods, which varied according to how harvest and tributary turnoff were handled. Rel = Release site; BON = top of Bonneville Dam; TDD = top of The Dalles Dam; JDD = top of John Day Dam; MCN = top of McNary Dam.

Covariate effects on conversion rates

Sockeye salmon. We ran univariate logistic regression models for date, salmon fork length, and sex for each of the five reaches. Origin (clipped, unclipped) was not included due to the small sample (n = 8) of fin-clipped sockeye salmon. Fallback was evaluated in all reaches except the release-Bonneville reach. Multiple logistic regression models included each of the estimable covariates (Tables 5-9). In all models, fish that were reported harvested and that entered tributaries were excluded.

No univariate models were statistically significant ($P < 0.05$) for sockeye salmon in the release-Bonneville, Bonneville -The Dalles, or John Day-McNary reaches. Sockeye salmon that fell back at The Dalles Dam were less likely to survive through the The Dalles-John Day reach than those that did not fall back (Tables 4 and 7). Earlier migrants were more likely than later migrants to survive the full Bonneville-McNary reach (Table 9, Figure 6).

In the multiple regression models, larger sockeye salmon were less likely to survive the Bonneville-The Dalles reach (Table 6). Later migrants and those that fell back at The Dalles Dam were less likely to survive the The Dalles-John Day reach (Tables 4 and 7). Later-timed and larger sockeye salmon were less likely to survive the combined Bonneville-McNary reach (Table 9). No covariates were statistically significant in the release-Bonneville or John Day-McNary models (Tables 5 and 8).

Table 4. Reach conversion estimates by salmon origin and by fallback behavior. Sample size in each group given parenthetically.

		Conversion estimate (*n*)			
		Origin[1]		Fallback	
Run	Reach	Wild	Hatchery	Yes	No
Sockeye	Rel-BON	0.974 (390)	1.000 (8)	-	-
	BON-TDD	0.930 (370)	0.875 (8)	0.875 (16)	0.931 (362)
	TDD-JDD	0.962 (344)	0.857 (7)	**0.800 (10)	**0.965 (341)
	JDD-MCN	0.991 (330)	1.000 (6)	1.000 (16)	0.991 (320)
	BON-MCN	0.886 (369)	0.750 (8)	0.878 (41)	0.884 (336)
Adult Chinook	Rel-BON	*0.984 (308)	*0.955 (286)	-	-
	BON-TDD	**0.959 (294)	**0.897 (253)	**0.710 (31)	**0.944 (517)
	TDD-JDD	0.934 (272)	0.929 (210)	**0.697 (33)	**0.949 (450)
	JDD-MCN	0.967 (243)	0.958 (192)	*0.857 (14)	*0.967 (422)
	BON-MCN	*0.861 (273)	*0.790 (233)	**0.645 (62)	**0.854 (445)
Jack Chinook	Rel-BON	0.979 (142)	0.981 (155)	-	-
	BON-TDD	0.993 (139)	0.972 (142)	1.000 (7)	0.982 (274)
	TDD-JDD	-	-	-	-
	JDD-MCN	*0.970 (133)	*1.000 (129)	1.000 (4)	0.985 (258)
	BON-MCN	0.963 (134)	0.970 (133)	1.000 (27)	0.963 (240)

[1]Origin effects not tested for sockeye salmon due to low sample size of hatchery origin adults.

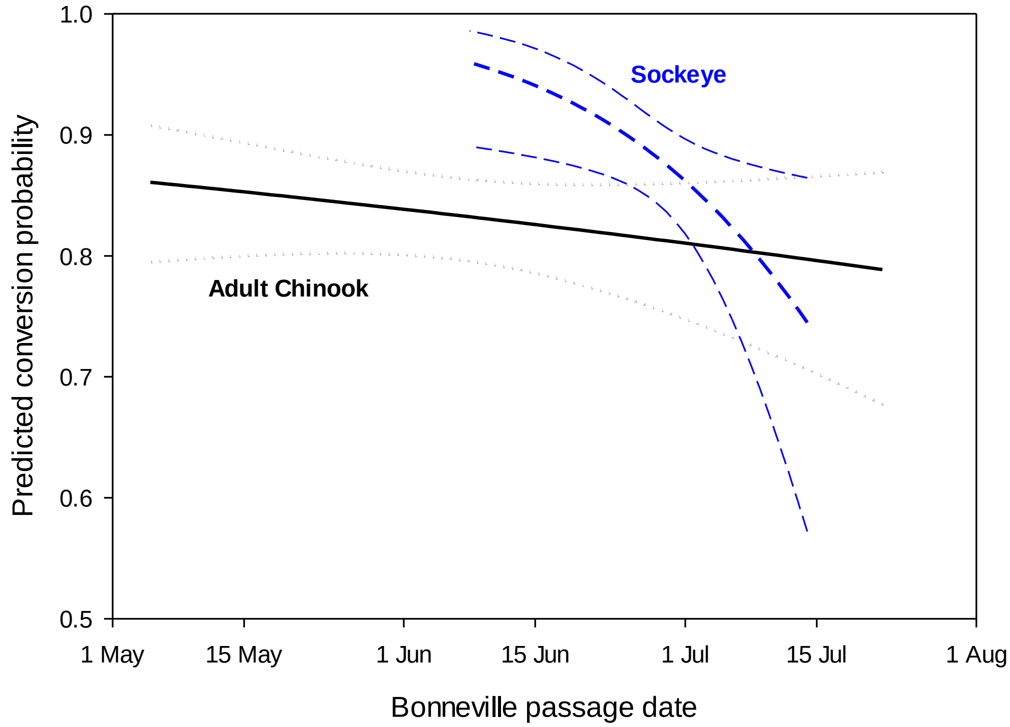


Figure 6. Predicted conversion probabilities (±95% CI) estimated using logistic regression for adult spring–summer Chinook salmon and sockeye salmon from the top of Bonneville Dam past McNary Dam.

Adult spring–summer Chinook salmon. Univariate logistic regression models included the covariates date, salmon fork length, sex, and origin for each of the five reaches. Fallback was evaluated in all reaches except the release-Bonneville reach. Multiple logistic regression models included each of the estimable covariates (Tables 5-9). In all models, fish that were reported harvested and that entered tributaries were excluded.

In univariate models, early-timed and hatchery-origin adults were less likely to survive past Bonneville Dam after release (Tables 4 and 5). Hatchery fish were also less likely than unclipped fish to survive the Bonneville-The Dalles (Tables 4 and 6) and Bonneville-McNary (Tables 4 and 8) reaches. Similarly, fish that fell back at Bonneville Dam (Bonneville-The Dalles reach), at The Dalles Dam (The Dalles-John Day reach), or at any dam (Bonneville-McNary reach) were less likely to survive than those that did not fall back. No covariates were statistically significant at $P < 0.05$ in the John Day-McNary reach (Table 7).

In the multiple regression models, early-timed adult Chinook salmon were less likely to survive the release-Bonneville reach, perhaps indicating a sea lion predation effect or increased tag regurgitation rates earlier in the season. In contrast, late-timed fish were less likely to survive the The Dalles-John Day, John Day-McNary, and Bonneville-McNary reaches (Figure 6). Fish that fell back in any of the reaches were also less likely to survive the reach (Table 4). Hatchery-origin adults had lower conversion estimates than wild fish in the Bonneville-The Dalles and Bonneville-McNary reaches (Table 4).

Jack spring–summer Chinook salmon. None of the covariates in univariate or multiple logistic regression models were statistically significant in any reach for jack Chinook salmon (Tables 5-9). This was likely because of the high jack survival in most reaches and smaller sample sizes relative to adult Chinook salmon. In all models, fish that were reported harvested and that entered tributaries were excluded.

Fallback percentages and rates

Sockeye salmon. Some sockeye salmon fell back at each dam (Table 10). Fallback percentages were about 5% at Bonneville and John Day dams, 2.9% at The Dalles Dam, and 1.2% at McNary Dam. A large majority of the fallback fish fell back only one time at most sites. However, two sockeye salmon fell back at Bonneville Dam 9 and 12 times, respectively. The first was an ad-clipped fish last detected at Wells Dam; the second was unclipped and last detected at the Little White Salmon River (fate = unaccounted for). These multiple-fallback fish resulted in a much higher fallback rate (10.4%) at Bonneville Dam than at other sites (1.2-5.1%).

Adult spring–summer Chinook salmon. Fallback percentages were 6.1% (Bonneville), 7.9% (The Dalles), 3.6% (John Day), and 2.5% (McNary). The maximum numbers of fallback events were 2-3 at each dam, resulting in fallback rates that were only slightly higher than fallback percentages (Table 10).

Jack spring–summer Chinook salmon. Fallback percentages and rates were lower for jack than adult Chinook at Bonneville, The Dalles, and John Day dams (Table 10). Percentages ranged from 2.0-5.5% and rates ranged from 2.5-6.3%. Notably, 7 of the 10 jacks that fell back at McNary Dam were last detected at the PIT antennas at the Umatilla River weir.

Monthly spring–summer Chinook fallback at Bonneville. Thirty fallback events were recorded for adult and jack Chinook at Bonneville Dam in May. Of these, 24 (80%) were followed by passage at Bonneville Dam (i.e., the fish reascended a ladder). Of the six that did not reascend, one was reported harvested downstream and five had unknown fate. By comparison, 19 fallback events were recorded in June and and 5 were in July; 71% of June-July events were followed by reascension. Fates were unknown for the seven salmon that did not reascend. Though sample sizes were small for this comparison, there was little evidence to suggest that fallback fish were being predated by sea lions in May (when sea lions were present) at higher rates than in June-July.

Table 5. Univariate and multiple logistic regression models of radio-tagged adult sockeye salmon, adult Chinook salmon, and jack Chinook salmon conversion from release downstream from Bonneville Dam to exit from the top of a Bonneville fishway. Odds ratios are for successful passage of the upstream site. Fish reported harvested downstream from Bonneville Dam were excluded.

Run	*n*	Model covariate(s)	Wald χ^2	*P*	Odds ratio (CI)
Sockeye salmon	398	Date	1.30	0.254	0.947 (0.864-1.040)
	391	Length	0.03	0.865	1.014 (0.860-1.197)
	398	Sex (F vs M)	Not estimable	-	-
	391	Date	3.59	0.058	0.906 (0.818-1.003)
		Length	0.08	0.782	0.976 (0.819-1.162)
Adult Chinook salmon	595	Date	10.46	**0.001**	1.071 (1.027-1.117)
	595	Length	1.35	0.246	1.037 (0.975-1.102)
	594	Sex (F vs M)	0.24	0.623	1.267 (0.493-3.257)
	594	Origin (W vs H)	3.96	**0.047**	2.886 (1.016-8.199)
	593	Date	8.32	**0.004**	1.066 (1.021-1.113)
		Length	0.01	0.914	1.004 (0.932-1.082)
		Sex (F vs M)	0.08	0.782	1.152 (0.423-3.141)
		Origin (W vs H)	1.06	0.303	1.766 (0.599-5.206)
Jack Chinook salmon	297	Date	0.43	0.510	1.015 (0.970-1.062)
	297	Length	0.01	0.921	1.010 (0.835-1.220)
	296	Sex (F vs M)	Not estimable	-	-
	297	Origin (W vs H)	0.01	0.914	0.914 (0.182-4.606)
	296	Date	0.48	0.487	1.108 (0.969-1.069)
		Length	0.03	0.869	0.982 (0.791-1.219)
		Origin (W vs H)	0.08	0.779	0.786 (0.146-4.218)

Table 6. Univariate and multiple logistic regression models of radio-tagged adult sockeye salmon, adult Chinook salmon, and jack Chinook salmon conversion from the top of a Bonneville fishway to the top of a fishway at The Dalles Dam. Odds ratios are for successful passage of the upstream site. Fish reported harvested and those that entered tributaries in the BON-TDD reach were excluded.

Run	*n*	Model covariate(s)	Wald χ^2	*P*	Odds ratio (CI)
Sockeye salmon	366	Date	1.36	0.244	0.965 (0.910-1.024)
	372	Length	1.53	0.216	0.935 (0.840-1.040)
	378	Sex (F vs M)	0.03	0.856	0.928 (0.417-2.066)
	378	Fallback (Y vs N)	0.70	0.403	0.519 (0.112-2.413)
	351	Date	3.38	0.066	0.939 (0.878-1.004)
		Length	4.71	**0.030**	0.872 (0.770-0.987)
		Sex (F vs M)	0.21	0.647	0.822 (0.354-1.906)
		Fallback (Y vs N)	0.87	0.352	0.475 (0.099-2.278)
Adult Chinook salmon	510	Date	0.92	0.338	1.009 (0.991-1.027)
	548	Length	0.33	0.568	0.988 (0.950-1.029)
	547	Sex (F vs M)	0.04	0.838	1.072 (0.550-2.090)
	547	Origin (W vs H)	7.56	**0.006**	2.692 (1.329-5.453)
	548	Fallback (Y vs N)	19.28	**<0.001**	0.145 (0.061-0.344)
	508	Date	0.03	0.861	0.998 (0.979-1.108)
		Length	0.35	0.553	0.986 (0.942-1.032)
		Sex (F vs M)	0.31	0.578	1.232 (0.590-2.574)
		Origin (W vs H)	4.73	**0.030**	2.434 (1.092-5.427)
		Fallback (Y vs N)	7.23	**0.007**	0.235 (0.082-0.675)
Jack Chinook salmon	252	Date	0.07	0.790	0.994 (0.950-1.040)
	281	Length	0.37	0.541	0.932 (0.745-1.167)
	280	Sex (F vs M)	Not estimable	-	-
	281	Origin (W vs H)	1.52	0.218	4.000 (0.441-36.244)
	281	Fallback (Y vs N)	Not estimable	-	-
	252	Date	0.18	0.673	0.990 (0.942-1.039)
		Length	0.20	0.655	0.949 (0.755-1.193)
		Origin (W vs H)	1.62	0.203	4.324 (0.455-41.119)

Table 7. Univariate and multiple logistic regression models of radio-tagged adult sockeye salmon, adult Chinook salmon, and jack Chinook salmon conversion from the top of a fishway at The Dalles to the top of a fishway at John Day Dam. Odds ratios are for successful passage of the upstream site. Fish reported harvested and those that entered tributaries the Deschutes River were excluded.

Run	*n*	Model covariate(s)	Wald χ^2	*P*	Odds ratio (CI)
Sockeye salmon	342	Date	3.02	0.082	0.931 (0.858-1.009)
	346	Length	0.37	0.545	0.957 (0.830-1.103)
	343	Sex (F vs M)	0.01	0.911	1.064 (0.361-3.134)
	351	Fallback (Y vs N)	5.21	**0.023**	0.146 (0.028-0.762)
	329	Date	4.00	**0.046**	0.913 (0.836-0.998)
		Length	1.15	0.283	0.921 (0.793-1.070)
		Sex (F vs M)	0.12	0.729	1.216 (0.402-3.672)
		Fallback (Y vs N)	4.41	**0.036**	0.165 (0.031-0.887)
Adult Chinook salmon	476	Date	2.59	0.107	0.986 (0.968-1.003)
	483	Length	2.05	0.153	1.032 (0.988-1.079)
	483	Sex (F vs M)	0.49	0.484	1.288 (0.634-2.620)
	482	Origin (W vs H)	0.05	0.821	1.085 (0.534-2.208)
	483	Fallback (Y vs N)	23.04	**<0.001**	0.124 (0.053-0.291)
	475	Date	6.13	**0.013**	0.976 (0.957-0.995)
		Length	2.59	0.108	1.039 (0.992-1.089)
		Sex (F vs M)	1.06	0.303	1.497 (0.695-3.225)
		Origin (W vs H)	0.31	0.577	1.251 (0.570-2.746)
		Fallback (Y vs N)	25.44	**<0.001**	0.093 (0.037-0.234)
Jack Chinook salmon			**No models: Conversion = 1.00**		

Table 8. Univariate and multiple logistic regression models of radio-tagged adult sockeye salmon, adult Chinook salmon, and jack Chinook salmon conversion from the top of a fishway at John Day to the top of a fishway at McNary Dam. Odds ratios are for successful passage of the upstream site. Fish reported harvested and those that entered the John Day or Umatilla rivers were excluded.

Run	*n*	Model covariate(s)	Wald χ^2	*P*	Odds ratio (CI)
Sockeye salmon	318	Date	3.06	0.080	0.855 (0.718-1.019)
	331	Length	0.04	0.835	0.962 (0.666-1.390)
	328	Sex (F vs M)	0.14	0.706	1.591 (0.143-17.723)
	336	Fallback (Y vs N)	Not estimable	-	-
	306	Date	0.24	0.626	0.946 (0.757-1.182)
		Length	0.10	0.754	0.939 (0.634-1.392)
		Sex (F vs M)	0.01	0.920	0.866 (0.053-14.094)
Adult Chinook salmon	424	Date	3.76	0.053	0.975 (0.921-1.000)
	436	Length	1.93	0.165	0.960 (0.906-1.107)
	436	Sex (F vs M)	0.13	0.719	0.831 (0.304-2.274)
	435	Origin (W vs H)	0.23	0.631	1.277 (0.470-3.468)
	436	Fallback (Y vs N)	3.80	0.051	0.206 (0.042-1.008)
	423	Date	4.54	**0.033**	0.971 (0.946-0.998)
		Length	1.19	0.276	0.968 (0.913-1.026)
		Sex (F vs M)	0.28	0.595	1.326 (0.469-3.747)
		Origin (W vs H)	0.01	0.915	1.059 (0.370-3.033)
		Fallback (Y vs N)	4.96	**0.026**	0.131 (0.022-0.784)
Jack Chinook salmon	239	Date	3.72	0.054	1.161 (0.997-1.352)
	262	Length	2.34	0.126	1.195 (0.951-1.502)
		Sex (F vs M)	Not estimable		
		Origin (W vs H)	Not estimable		
		Fallback (Y vs N)	Not estimable		
	239	Date	3.07	0.080	1.146 (0.84-1.334)
		Length	0.72	0.400	1.132 (0.850-1.508)

Table 9. Univariate and multiple logistic regression models of radio-tagged adult sockeye salmon, adult Chinook salmon, and jack Chinook salmon conversion from the top of a Bonneville fishway to the top of a fishway at McNary Dam. Odds ratios are for successful passage of the upstream site. Fish reported harvested and those that entered tributaries in the BON-MCN reach were excluded.

Run	*n*	Model covariate(s)	Wald χ^2	*P*	Odds ratio (CI)
Sockeye salmon	365	Date	5.60	**0.018**	0.943 (0.899-0.990)
	371	Length	1.82	0.177	0.943 (0.866-1.027)
	368	Sex (F vs M)	0.00	0.988	1.005 (0.530-1.907)
	377	Fallback (Y vs N)	0.945	0.912	
	350	Date	7.34	**0.007**	0.929 (0.880-0.980)
		Length	5.69	**0.017**	0.889 (0.807-0.979)
		Sex (F vs M)	0.05	0.825	0.927 (0.473-1.817)
		Fallback (Y vs N)	0.04	0.840	0.901 (0.326-2.490)
Adult Chinook salmon	474	Date	1.15	0.283	0.994 (0.982-1.005)
	507	Length	0.01	0.929	0.999 (0.971-1.027)
	506	Sex (F vs M)	0.23	0.633	1.120 (0.704-1.781)
	506	Origin (W vs H)	4.41	**0.036**	1.647 (1.034-2.623)
	507	Fallback (Y vs N)	15.42	**<0.001**	0.311 (0.174-0.557)
	472	Date	5.28	**0.022**	0.985 (0.973-.998)
		Length	0.07	0.794	1.004 (0.975-1.034)
		Sex (F vs M)	1.40	0.236	1.355 (0.820-2.241)
		Origin (W vs H)	3.99	**0.046**	1.6680 (1.010-2.795)
		Fallback (Y vs N)	12.78	**<0.001**	0.291 (0.148-0.573)
Jack Chinook salmon	240	Date	0.71	0.401	1.018 (0.977-1.061)
	267	Length	0.30	0.583	1.045 (0.892-1.225)
		Sex (F vs M)	Not estimable		
	267	Origin (W vs H)	0.11	0.744	0.800 (0.210-3.047)
		Fallback (Y vs N)	Not estimable		
	240	Date	0.61	0.434	1.107 (0.974-1.063)
		Length	0.03	0.867	1.016 (0.843-1.224)
		Origin (W vs H)	0.02	0.879	0.894 (0.211-3.787)

Table 10. Fallback percentages (unique fish that fell back / unique fish that passed dam) and fallback rates (total fallback events / unique fish that passed dam) of radio-tagged sockeye and Chinook salmon at Bonneville, The Dalles, John Day and McNary dams in 2013.

Run	Dam	Passed dam[1]	Unique FB fish	Total FB events	Fallback %	Fallback rate
Sockeye	Bonneville	383	19	40	5.0%	10.4%
	The Dalles	345	10	10	2.9%	2.9%
	John Day	331	16	17	4.8%	5.1%
	McNary	321	4	4	1.2%	1.2%
Adult Chinook	Bonneville	573	35	42	6.1%	7.3%
	The Dalles	504	40	47	7.9%	9.3%
	John Day	439	16	17	3.6%	3.9%
	McNary	405	10	12	2.5%	3.0%
Jack Chinook	Bonneville	271	7	11	2.6%	4.1%
	The Dalles	253	14	16	5.5%	6.3%
	John Day	244	5	6	2.0%	2.5%
	McNary	229	10	10	4.4%	4.4%

[1] only includes that retained radio transmitters

Discussion

Study constraints

There were two important constraints to this study in 2013: the late start to Chinook salmon tagging and the exclusion of known-origin fish. Due primarily to delays in contracting, no Chinook salmon were tagged in April although nearly 29,000 adults and 2,000 jacks passed in the month. Previous studies of population-specific run timing (e.g., Keefer et al. 2004b; Hess et al. 2014) have shown that Clearwater, Salmon, Icicle, Wind, and John Day River Chinook salmon are among the earliest spring migrants. These populations would therefore have been under-sampled in the 2013 study, resulting in reach conversion and tributary turnoff estimates that differ from the runs at large. No tagging in April also reduced any potential inferences regarding sea lion predation effects on Chinook salmon. With respect to interpreting the telemetry data, we note that any tagged salmon killed by a marine mammal in the Bonneville tailrace would largely be indistinguishable from any tagged salmon that may have migrated downstream to spawn in a lower tributary.

Similarly, other research programs, in particular the Comparative Survival Study, were concerned that radio tagging known-origin (i.e., PIT-tagged) salmon and steelhead could bias the results of on-going research programs such as smolt-to-adult (SAR) survival estimates, and were unable to provide access to these adults for our study. Unfortunately, thousands of jack and adult Chinook salmon and steelhead have PIT tags and represent substantial portions of the runs passing Bonneville Dam. The PIT-tagged Chinook salmon and steelhead disproportionately originate from interior populations in the Snake, mid- and upper-Columbia River basins. Selection against these known-origin groups for radio-tagging – many of which are from the

ESA-listed groups that are the motivation for the conversion rate study – was an unfortunate methodological constraint. In addition to not being able to partition FCRPS loss for these groups, we were unable to directly estimate straying into lower Columbia River tributaries using the origin information; straying by interior populations is a contributing factor for conversion rates below performance standards. Although the forthcoming genetic evaluation may partially address these population-specific information gaps, sample sizes for listed populations will likely be low.

Reach conversion and 'loss' rates

Reach conversion estimates for all three study groups indicated that the highest unaccounted for 'loss' occurred in the Bonneville-The Dalles reach: 59% of unaccounted for sockeye salmon, 44% of unaccounted for adult Chinook salmon, and 55% of unaccounted for jacks were in this reach. This result was unsurprising given the fisheries effort in the Bonneville reservoir and results of previous telemetry studies (e.g., Keefer et al. 2005). Unreported harvest of radio-tagged fish and mortality associated with gillnet dropout and catch and release recreational fisheries are presumed to contribute to the unaccounted for rate in this reach (and others). It is also possible that transmitter loss is a contributing factor, though the installation of a PIT array at The Dalles Dam and inside the Deschutes River mouth substantially reduces the likelihood that unaccounted for fish passed through the The Dalles Dam undetected. Some additional unaccounted for fish may have entered tributaries undetected, though we think the incidence of this was low given redundancy between radiotelemetry, PIT detection sites, and recapture data from tributary hatcheries.

Unadjusted conversion rates in the The Dalles-John Day and John Day-McNary reaches were ≥0.960 for sockeye salmon and jack Chinook salmon. Rates for the jacks were >0.980 after adjusting for reported harvest and tributary turnoff of radio-tagged fish. By comparison, estimates for adult Chinook salmon were consistently lower: unadjusted rates were 0.882 (TDD-JDD) and 0.933 (JDD-MCN) and increased by ~2% in the adjusted estimates. Differences among age classes are not well understood at this time, but could be related to higher unreported harvest of radio-tagged adult Chinook salmon, higher encounter rates with gill nets and higher indirect mortality in adult Chinook salmon escaping gill nets, or other size-selective mortality agents.

Salmon traits that were statistically associated with conversion rates included size for sockeye salmon and origin for adult Chinook salmon. Larger sockeye salmon were less likely than smaller sockeye to survive the Bonneville-The Dalles reach. This may indicate a fishery-related result, with smaller fish less likely to be harvested or less likely to suffer other adverse fishery effects. The lower conversion rates by hatchery- versus presumed wild-origin Chinook salmon may also reflect fisheries impacts, with hatchery fish more likely to be retained in recreational fisheries. The hatchery-conversion relationship also may reflect different source populations, particularly if proportionately more wild fish were from the interior Columbia basin. Known-source information would be required to answer this question definitively, although the GSI evaluation that is underway may add some resolution.

Tributary turnoff

A total of five (1.3%) sockeye salmon were last recorded in lower Columbia River tributaries. As described above, we think these were unlikely to be fish seeking spawning sites as there are no populations in the study reach; it is possible that these were strays. It is also possible that one or more transmitters were from unreported harvest and in-air tags were detected at the tributary receivers.

Tributary entry in the study reach was ~8% for adult Chinook salmon and ~10% for jack Chinook salmon. The 8% adult turnoff rate for adults was lower than most estimates in the radiotelemetry studies from 1996-1998 and 2000-2001 (Keefer et al. 2005), although those earlier years included April samples. Lower than average proportions entered the Wind and Little White Salmon rivers in 2013, again perhaps as a result of the study start date. Tributary distributions for the age classes were generally similar in 2013, with about 3.5% of each entering Bonneville reservoir tributaries, 2-3% in the Deschutes River, and ~1.5% in the John Day River. One notable difference was that 3% of jacks entered the Umatilla River versus 0.3% of adults. The percentages of jacks in spring–summer Chinook salmon populations vary, in part due to hatchery effects, and it is possible that the Umatilla River program produced a cohort with proportionately more jacks than other sites.

Fallback at Bonneville Dam and potential sea lion predation

The target population for this study component was Chinook salmon that fell back at Bonneville Dam in April and May when California and Steller sea lions are actively preying on salmon in the tailrace. There is a reasonable concern that fallback salmon are at greater risk of predation, both because they are exposed to sea lions for longer periods and because they may suffer injuries during fallback that make them more vulnerable.

In previous observation- and telemetry-based predation studies (e.g., Stansell et al. 2010; Keefer et al. 2012), predation rates on Chinook salmon varied widely among weeks, but the highest rates tended to be on the earliest migrants when salmon abundance is low (and per capita risk to salmon is highest). The best opportunity to identify whether there is a double jeopardy predation risk for fallback salmon is likely in April. Fallback percentages in May-July were low (2.6% for jacks and 6.1% for adults), and therefore small samples limited our analysis. That said, there was no evidence that fallback salmon were predated at high rates in the spring. Eighty percent of the spring-time fallback events at Bonneville Dam were followed by ladder reasension events and proportionately more spring than summer fish re-passed the dam after falling back.

It is also possible that sea lions in the Bonneville reservoir may have predated some fish in that reach. At least four sea lions were present in the reservoir in 2013 (Stuart Ellis, CRITFC, *personal communication*). While it is unlikely that these animals had a substantive effect on the Bonneville-The Dalles conversion rate estimates, it is possible that they had a non-zero effect.

Fallback in relation to reach conversion

Fallback percentages for sockeye salmon at the lower Columbia dams (1.2-5.0%) were lower than or similar to those reported for radio-tagged sockeye in 1997 by Reischel and Bjornn (2003) and Naughton et al. (2006). The 1997 migration was characterized by very high flow and spill, which contributed to higher fallback in that year. In 2013, sockeye that fell back had lower reach conversion estimates in three of four comparisons, though only fallback at The Dalles Dam had a statistically significant effect: The Dalles-John Day survival was about 16% lower for those that fell back at The Dalles Dam than those that did not.

There was more evidence that fallback reduced conversion rates for adult Chinook salmon. Reach conversion estimates were ~10-25% lower for fallback fish in each of the four reaches. This is consistent with the reduced survival to tributaries we have reported for much larger radio-tagged samples of spring–summer Chinook salmon in previous study years (Keefer et al. 2005). In contrast to the 2005 summary, Chinook salmon that fell back in 2013 and entered a downstream tributary (i.e., potential 'overshoot' fish; Keefer et al. 2008b) were considered unsuccessful for the conversion estimate in the upstream reach. The 10-25% lower conversion associated with fallback therefore is not equivalent to a 10-25% mortality effect.

The fallback percentages for adult Chinook in 2013 (2.5-7.9%) were generally lower than reported in 1996-2001 by Boggs et al. (2004). In part, this was a consequence of no tagging in April as fallback rates tend to be higher for spring than summer Chinook salmon.

Compared to adults, relatively few jack Chinook salmon fell back at dams and there was no evidence that jack fallback resulted in reduced reach conversion. In fact, all jacks that fell back either passed McNary Dam, entered tributaries between Bonneville and McNary dams, or were harvested (i.e., none were unaccounted for). The apparent difference in fallback effects between jacks and adults is currently unknown, but jacks may be less vulnerable to sea lion predation and harvest (i.e., they may pass through gillnets and may be released by recreational anglers). Jacks also may suffer fewer injuries during fallback than the larger-bodied adults.

Environmental effects on reach conversion

In this first study year, we limited our analysis of environmental effects to migration timing, which is a reasonably good surrogate measure for water temperature and discharge during the Chinook and sockeye salmon runs. There were several timing effects identified in the logistic regression models. In the sockeye salmon, conversion through the full Bonneville-McNary reach substantially declined over the migration season. This was consistent with results from the 1997 radiotelemetry study, when much lower survival was observed for late migrants that encountered warm water temperatures (Naughton et al. 2005). It was also consistent with a late-timing, warm water effect on survival reported for Snake River sockeye salmon in a 2000 radiotelemetry study (Keefer et al. 2008c) and in recent evaluations using PIT-tagged sockeye over multiple years (Keefer et al. 2014; Crozier et al. *in review*). Other regional sockeye salmon studies also support a strong relationship between high water temperature and adult mortality (e.g., Hyatt et al. 2003; *review* by Hinch et al. 2012).

Early-timed adult Chinook salmon were less likely than later-timed migrants to pass Bonneville Dam after release. This may be indirect evidence of sea lion predation early in the run, though that could not be confirmed. In contrast, adult Chinook salmon conversion from the top of Bonneville Dam past McNary Dam decreased through the season. This may indicate a temperature effect like the one suspected for sockeye salmon. Alternately, there may have been population effects, tributary overshoot behaviors, different fisheries impacts, or other seasonal factors that reduced survival for later migrants. Notably, the timing effect persisted after accounting for salmon origin, size, and fallback behaviors. There was little evidence for timing effects on jack Chinook salmon conversion. We will expand upon these analyses in Year 2.

References

Agresti, A. 2012. Categorical data analysis. 3rd edition. John Wiley and Sons, Hoboken, New Jersey.

Boggs, C. T., M. L. Keefer, C. A. Peery, T. C. Bjornn, and L. C. Stuehrenberg. 2004. Fallback, reascension and adjusted fishway escapement estimates for adult chinook salmon and steelhead at Columbia and Snake River dams. Transactions of the American Fisheries Society 133:932-949.

Burke, B. J., K. E. Frick, J. Garnett, M. A. Jepson, M. L. Keefer, and C. C. Caudill. 2014. Behavior of radio-tagged Chinook and sockeye salmon at The Dalles Dam in relation to spill volume and the presence of the Bay 8/9 spill wall, and at John Day Dam in relation to north shore fishway modifications. Technical report 2014-DRAFT of Northwest Fisheries Science Center and University of Idaho to U.S. Army Corps of Engineers, Portland District.

Caudill, C. C., W. R. Daigle, M. L. Keefer, C. T. Boggs, M. A. Jepson, B. J. Burke, R. W. Zabel, T. C. Bjornn, and C. A. Peery. 2007. Slow dam passage in Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality? Canadian Journal of Fisheries and Aquatic Sciences 64:979-995.

Crozier, L. G., B. J. Burke, B. P. Sandford, G. A. Axel, and B. L. Sanderson. *In review*. Adult Snake River sockeye salmon passage and survival within and upstream of the FCRPS. DRAFT Research Report, Northwest Fisheries Science Center, NOAA Fisheries, Seattle.

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

Goniea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. H. Bennett, and L. C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society 135:408-419.

Hess, J. E., J. M. Whiteaker, J. K. Fryer, and S. R. Narum. 2014. Monitoring stock-specific abundance, run timing, and straying of Chinook salmon in the Columbia River using genetic stock identification (GSI). North American Journal of Fisheries Management 34:184-201.

Hinch, S. G., S. J. Cooke, A. P. Farrell, K. M. Miller, M. Lapointe, and D. A. Patterson. 2012. Dead fish swimming: a review of research on the early migration and high premature mortality in adult Fraser River sockeye salmon *Oncorhynchus nerka*. Journal of Fish Biology 81:576-599.

Jepson, M. A., M. L. Keefer, C. C. Caudill, and B. J. Burke. 2011. Passage behavior of adult spring Chinook salmon at Bonneville Dam including evaluations of passage at the modified Cascades Island fishway, 2010. Technical Report 2011-1 of University of Idaho to U.S. Army Corps of Engineers, Portland District.

Johnson, E. L. and 10 coauthors. 2014. Evaluation of adult salmon passage behavior in relation to fishway modifications at Bonneville Dam – 2013. Technical Report 2014-10 of University of Idaho to U.S. Army Corps of Engineers, Portland District.

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

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

Keefer, M. L., C. A. Peery, W. R. Daigle, M. A. Jepson, S. R. Lee, C. T. Boggs, K. R. Tolotti, and B. J. Burke. 2005. Escapement, harvest, and unknown loss of radio-tagged adult salmonids in the Columbia River - Snake River hydrosystem. Canadian Journal of Fisheries and Aquatic Sciences 62:930-949.

Keefer, M. L., C. C. Caudill, C. A. Peery, and S. R. Lee. 2008a. Transporting juvenile salmonids around dams impairs adult migration. Ecological Applications 18(8):1888-1900.

Keefer, M. L., C. C. Caudill, C. A. Peery, and C. T. Boggs. 2008b. Non-direct homing behaviours by adult Chinook salmon in a large, multi-stock river system. Journal of Fish Biology 72:27-44.

Keefer, M. L., C. A. Peery, and M. J. Heinrich. 2008c. Temperature-mediated en route migration mortality and travel rates of endangered Snake River sockeye salmon. Ecology of Freshwater Fish 17:136-145.

Keefer, M. L., C. A. Peery, and B. High. 2009. Behavioral thermoregulation and associated mortality trade-offs in migrating adult steelhead (*Oncorhynchus mykiss*): variability among sympatric populations. Canadian Journal of Fisheries and Aquatic Sciences 66:1734-1747.

Keefer, M. L., G. A. Taylor, D. F. Garletts, G. A. Gauthier, T. M. Pierce, and C. C. Caudill. 2010. Prespawn mortality in adult spring Chinook salmon outplanted above barrier dams. Ecology of Freshwater Fish 19:361-372.

Keefer, M. L., R. J. Stansell, S. C. Tackley, W. T. Nagy, K. M. Gibbons, C. A. Peery, and C. C. Caudill. 2012. Use of radiotelemetry and direct observations to evaluate sea lion predation on adult Pacific salmonids at Bonneville Dam. Transactions of the American Fisheries Society 141:1236-1251.

Keefer, M. L., and C. C. Caudill. 2014. Homing and straying by anadromous salmonids: a review of mechanisms and rates. Reviews in Fish Biology and Fisheries 24:333-368.

Keefer, M. L., C. C. Caudill, L. Sullivan, C. Fitzgeral, and K. Hatch. 2014. PIT-tagged adult salmon and steelhead conversion from McNary Dam to Lower Granite Dam, 2002-2013. Technical Report 2014-2 of University of Idaho for U.S. Army Corps of Engineers, Walla Walla District.

Lebreton, J., K. P. Burnham, J. Clobert, and D. R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62(1):67-118.

Marsh, D. M., W. D. Muir, B. P. Sandford, S. G. Smith, and D. Elliott. 2012. Alternative barging strategies to improve survival of salmonids transported from Lower Granite Dam: final report from the 2006-2008 spring/summer Chinook salmon and steelhead juvenile migrations. National Marine Fisheries Service, Seattle, WA.

Muir, W. D., S. G. Smith, J. G. Williams, and E. E. Hockersmith. 2001. Survival estimates for migrant yearling Chinook salmon and steelhead tagged with passive integrated transponders in the Lower Snake and Lower Columbia Rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

Naughton, G. P., C. C. Caudill, M. L. Keefer, T. C. Bjornn, L. C. Stuehrenberg, and C. A. Peery. 2005. Late-season mortality during migration of radio-tagged sockeye salmon (Oncorhynchus nerka) in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 62:30-47.

Naughton, G. P., C. C. Caudill, M. L. Keefer, C. A. Peery, T. C. Bjornn, and L. C. Stuehrenberg. 2006. Fallback by adult sockeye salmon at Columbia River dams. North American Journal of Fisheries Management 26:380-390.

Perry, R. W., T. Castro-Santos, C. M. Holbrook, and B. P. Sandford. 2012. Using mark-recapture models to estimate survival from telemetry data. Pages 453-475 *in* N. S. Adams, J. W.

Beeman, and J. H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Reischel, T. S., and T. C. Bjornn. 2003. Influence of fishway placement on fallback of adult salmon at the Bonneville Dam on the Columbia River. North American Journal of Fisheries Management 23:1215-1224.

Sandford, B. P., and S. G. Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River basin anadromous salmonids, 1990-1997. Journal of Agricultural, Biological and Environmental Statistics 7(2):243-263.

Stansell, R. J, K. M. Gibbons, and W. T. Nagy. 2010. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2008-2010. Fisheries Field Unit, U.S. Army Corps of Engineers, Cascade Locks, Oregon.

Tuomikoski, J. and 10 coauthors. 2013. Comparative survival study of PIT-tagged spring/summer/fall Chinook, summer steelhead, and sockeye. DRAFT 2013 Annual Report for BPA Contract #19960200.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:S120-S139.