Technical Report 2014-2

PIT-TAGGED ADULT SALMON AND STEELHEAD CONVERSION FROM MCNARY DAM TO LOWER GRANITE DAM, 2002-2013

A Report for Study Code ADS-W-13-1

by

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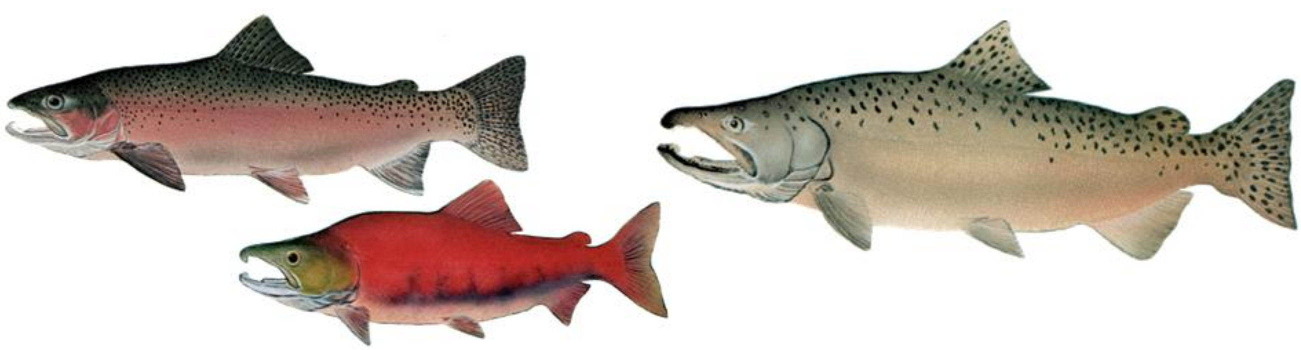

For

U.S. Army Corps of Engineers
Walla Walla District, Walla Walla WA

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Executive Summary

The overarching objective in this study was to estimate conversion rates for adult Snake River salmon and steelhead (*Oncorhynchus* spp.) from McNary Dam past Ice Harbor and Lower Granite dams. This was addressed using ~80,000 adult PIT-tag detection histories for fish tagged as juveniles upstream from Lower Granite Dam that were archived in the PIT Tag Information System (PTAGIS). We made annual estimates for the years 2002-2013 for the four Snake River distinct population segments (DPSs): spring–summer Chinook salmon, fall Chinook salmon, sockeye salmon, and summer steelhead. Additional objectives included assessments of inter-basin straying, the fate of 'unsuccessful' migrants, and how conversion rates were associated with fish origin (hatchery, wild), source population, adult migration timing, and Snake River water temperature.

We emphasize that this was a retrospective and opportunistic evaluation. Fish included in the analyses were from a large number of populations that varied in relative abundance through time. There was no 'control' or experimental groups within any DPS that were consistently present across study years. Therefore, while the results should be broadly representative of adult migration survival in the study area, results and among-group comparisons should be interpreted cautiously. Annual reach conversion rate estimates for the aggregated samples varied among years, among river reaches, among DPSs, and among origin groups (Table A). The lowest annual mean conversion estimates through the combined McNary-Lower Granite reach were for wild steelhead (mean = 0.901) and hatchery steelhead (0.914). The highest annual means were for hatchery fall Chinook salmon (0.947) and wild spring–summer Chinook salmon (0.957).

Table A. Annual mean and standard deviation and total (i.e., data from all years combined) reach conversion estimates for PIT-tagged sockeye salmon, spring–summer and fall Chinook salmon, and steelhead from Snake River distinct population segments (DSP's) in 2002-2013. Reaches: McNary-Ice Harbor, Ice Harbor-Lower Granite, and McNary-Lower Granite. w = wild; h = hatchery. Note that these are raw estimates, uncorrected for harvest or straying.

	Conversion estimates								
	MCN-ICH			ICH-LGR			MCN-LGR		
	Annual		**Total**	Annual		**Total**	Annual		**Total**
	Mean	SD		Mean	SD		Mean	SD	
Sockeye (w)[1]	-	-	**1.000**	-	-	**0.714**	-	-	**0.714**
Sockeye (h)[2]	*0.986*	*0.028*	**0.967**	*0.948*	*0.086*	**0.914**	*0.945*	*0.108*	**0.884**
Spr-Sum Chinook (w)	*0.986*	*0.006*	**0.984**	*0.966*	*0.018*	**0.967**	*0.957*	*0.022*	**0.951**
Spr-Sum Chinook (h)	*0.981*	*0.011*	**0.979**	*0.960*	*0.014*	**0.963**	*0.944*	*0.023*	**0.943**
Fall Chinook (w)	*0.978*	*0.034*	**0.975**	*0.958*	*0.034*	**0.957**	*0.942*	*0.050*	**0.932**
Fall Chinook (h)	*0.976*	*0.016*	**0.966**	*0.966*	*0.008*	**0.964**	*0.947*	*0.025*	**0.932**
Steelhead (w)	*0.938*	*0.031*	**0.935**	*0.962*	*0.016*	**0.958**	*0.901*	*0.035*	**0.896**
Steelhead (h)	*0.950*	*0.039*	**0.939**	*0.957*	*0.015*	**0.951**	*0.914*	*0.043*	**0.892**

[1] total *n* = 7; [2] the relatively large 2013 sample was influential

There were persistent population- and group-specific differences in reach conversion within DPS. These included a tendency for lower conversion by aggregated hatchery versus aggregated wild groups, though we note that wild fish were generally under-represented in all DPSs. There was strong evidence that fish that were PIT-tagged as juveniles at Lower Granite Dam and then barged

downstream had lower adult conversion than comparison groups that migrated in-river. We likely underestimated transport effects because we did not attempt to differentiate fish that were: (1) PIT-tagged upstream from Lower Granite Dam and then collected and transported; or (2) fish that were collected and transported at dams other than Lower Granite Dam. (These specific histories are not readily retrieved from PTAGIS).

Migration timing and Snake River water temperatures encountered by adult migrants co-varied and it was difficult to separate timing and temperature effects. In general, warm Snake River water temperatures (and later migration timing) were associated with lower conversion rates for wild spring–summer Chinook salmon and especially for sockeye salmon. Many Snake River sockeye salmon strayed into the upper Columbia River when Snake River water temperatures were greater than ~18 °C and a similar threshold temperature was evident for spring–summer Chinook salmon. In contrast, late-timed fall Chinook salmon had lower conversion rates and encountered cooler Snake River water temperatures than earlier-timed fish. Similarly, steelhead that entered the study reaches in late fall or in spring following overwintering encountered cold water temperatures and had lower conversion rates that migrants that entered during the peaks of those runs.

In total, ~6,000 adults had PIT detection histories that suggested the fish did not pass Lower Granite Dam. A large majority (73-90% per DPS) of these 'unsuccessful' fish were last detected at the adult fishway antennas at McNary or Ice Harbor dams. The actual fate of these fish was unknown, but presumably included a mix of harvest, other mortality, and undetected straying to non-natal sites. Relatively small percentages (< 7% per DPS) of the unsuccessful groups were last detected in juvenile bypass systems at Snake or lower Columbia River dams. The remainders were probable strays based on final PIT detections in non-natal areas that were widely distributed. Potential strays accounted for ~15% of unsuccessful sockeye salmon and steelhead, 6-7% of unsuccessful spring–summer Chinook salmon, and 22-25% of unsuccessful fall Chinook salmon. Within DPS, some populations had much higher stray rates than others, and juvenile barging was associated with higher straying for spring–summer and fall Chinook salmon and steelhead.

Summaries included in this report are intended to provide a more complete data baseline for Snake River adults. The conversion rate estimates and supporting analyses suggest that several inter-related factors likely have contributed to recent estimates that fall below the adult performance standards established for Snake River fish in the Federal Columbia River Power System (FCRPS) Biological Opinions (BiOp).

Introduction

Adult Pacific salmon and steelhead (*Oncorhynchus* spp.) migrating to natal sites in the Snake River must pass up to eight dams and their reservoirs, including four in the lower Columbia River and four in the lower Snake River. Losses and migration delays at each hydroelectric project must be minimized to maintain the native fish runs and achieve the recovery goals outlined by the Northwest Power Planning Council (NWPPC) and NOAA Fisheries (NOAA). Adequate upstream passage and continued high survival through the Federal Columbia River Power System (FCRPS) of returning adults are primary requirements of the 2008 Biological Opinion ("BiOp"), the 2010 Supplemental BiOp, and the recently-released 2014 BiOp.

In many recent estimates, adult conversion rates (i.e., survival) between Bonneville and McNary dams and between McNary and Lower Granite dams using PIT-tag detection of adults tagged as juveniles have been below the standards established in the BiOp for three ESUs: Snake River spring-summer Chinook salmon (*O. tshawytscha*), Upper Columbia River spring Chinook salmon, and Snake River steelhead (*O. mykiss*). Standards for endangered Snake River sockeye salmon are currently being developed.

The overarching objective of this report was to provide a synthesis of conversion rate estimates for upstream-migrant Snake River salmon and steelhead from McNary Dam past Ice Harbor and Lower Granite dams from 2002-2013. Conversion rate estimates were calculated using detection records retrieved from the Pacific States Marine Fisheries Commission's PIT Tag Information System database (PTAGIS) for the four major Snake River distinct population segments (DPSs): Snake River spring–summer Chinook salmon, Snake River fall Chinook salmon, Snake River sockeye salmon (*O. nerka*), and Snake River steelhead (for DPS details see: http://www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead).

Additional report objectives address concerns raised in the BiOp, which identifies a need to examine factors such as adult run timing, population effects, and FCRPS environmental or operational effects that could explain why conversion rates have fallen below BiOp targets for the under-performing groups. For example, many adult salmon and steelhead experience stressful temperature conditions as they migrate through the FCRPS and have seasonal behavioral and mortality responses to high water temperatures (e.g., Naughton et al. 2005; Goneia et al. 2006; Keefer et al. 2005, 2009). At a finer spatial scale, Snake River dam fishways often have gradients of higher water temperatures from fishway exits to lower ladder sections, and this has been associated with slowed adult passage at the dams (e.g., Caudill et al. 2013). In the juvenile management realm, downstream transportation is a central recovery strategy for Snake River populations but downtream barging has consistently been associated with reduced adult conversion rates and higher adult straying (e.g., Keefer et al. 2008b; Marsh et al. 2012; Keefer and Caudill 2014). The ever-expanding PTAGIS dataset provides an opportunity to better understand the magnitude of such effects on adult conversion through the targeted reaches.

The PIT-tag dataset used in this report was built by querying PTAGIS to identify upstream-migrant Chinook salmon, sockeye salmon, and steelhead at McNary, Ice Harbor, and Lower Granite dams in 2002-2013. The data were used to address the following specific objectives:

1) estimate annual DPS-specific conversion rates from McNary-Ice Harbor, Ice Harbor-Lower Granite, and McNary-Lower Granite dams;

2) estimate conversion rates for hatchery- versus wild-origin fish within DPS;

3) estimate population-specific conversion rates for groups with sufficient numbers of fish;

4) evaluate potential effects of migration timing and Snake River water temperature on conversion past Lower Granite Dam; and

5) summarize the final detection locations for fish that did not pass Lower Granite Dam, including potential strays to non-natal sites.

Methods

Data source

Our initial PTAGIS queries identified all Chinook salmon, sockeye salmon, and steelhead detected inside adult fishways at McNary, Ice Harbor, and Lower Granite dams in 2002-2013. (Note that adult fishways at McNary and Ice Harbor dams were not fully monitored in 2002 and that adult and juvenile passage routes were combined at Ice Harbor Dam starting in 2005, which affected query output.) These datasets were then reduced using several screens to exclude fish that we considered inappropriate for estimating upstream conversion rates for Snake River populations that originated upstream from Lower Granite Dam. The excluded groups included:

1) fish tagged as juveniles at sites outside the Snake River basin;

2) fish tagged as adults at any location (e.g., adults collected at Bonneville Dam, steelhead kelts collected in tributaries or at juvenile bypass facilities, etc.);

3) fish detected in adult fishways that were likely outmigrating juveniles;

4) fish tagged as juveniles at Lower Monumental or Ice Harbor dams (potential origin downstream from Lower Granite Dam);

5) fish released in the Tucannon River basin or at Lyons Ferry Hatchery (origin downstream from Lower Granite Dam);

6) upstream-migrant steelhead detected in 2013, as many had not completed migration when this report was written in winter-spring 2013-2014.

We next queried PTAGIS for PIT interrogations (i.e., detections) or recaptures at sites upstream from Lower Granite Dam using the codes in the reduced datasets. This helped identify salmon and steelhead that passed Lower Granite Dam undetected and allowed us to more precisely estimate detection probabilities and conversion rate confidence intervals (see estimation methods below). Lastly, we reviewed complete migration histories for all fish in the reduced datasets that did not pass Lower Granite Dam according to PIT detections. These histories allowed us to identify strays (e.g., to lower Columbia River tributaries and Columbia River sites upstream from McNary Dam), some reported mortalities, and fish that fell back downstream (e.g., they were detected at juvenile bypass systems, the Bonneville corner collector, or fish ladders downstream from McNary Dam). We note that the steelhead histories were the most challenging to assemble and interpret because some steelhead overwinter in the study reaches (e.g., Keefer et al. 2008a) requiring queries in two calendar years. In addition, detections of post-spawn kelts as they moved downstream (e.g., Evans et al. 2004; Keefer et al. 2008b; Keefer and Caudill *in review*) required additional screening. In all species, some individual fish histories were ambiguous (i.e., some misinterpretations regarding fish age or migration direction were likely), but these were just a small fraction of the total samples and should not have substantively affected results or conclusions.

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; Buchanan et al. 2006) 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 (accounting for undetected fish) and survival probabilities. The generally high detection efficiency of PIT-tagged fish in the adult fishway at Columbia and Snake River dams allows calculation of relatively precise, unbiased estimates of adult reach conversion. We calculated annual conversion estimates separately for wild and hatchery sockeye salmon, spring–summer Chinook salmon, fall Chinook salmon, and steelhead. We also made population-specific estimates for those groups with adequate sample size across several years. We did not attempt to separate populations into year classes as juvenile emigration timing was often ambiguous.

We used program MARK (White and Burnham 1999) to estimate conversion rates from the PIT detection histories at McNary, Ice Harbor, and Lower Granite dams (Figure 1) plus detections at sites upstream from Lower Granite Dam. 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 reaches. 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.

Estimating conversion rates from Ice Harbor-Lower Granite and McNary-Lower Granite required information on the detection efficiency of the PIT tag array at Lower Granite Dam. We used PIT tag recovery data (i.e., recaptures and interrogations) from sites upstream from Lower Granite Dam to address this computational need. Most recoveries were at hatchery traps and weirs and therefore more hatchery than wild fish were detected above Lower Granite Dam in most sample groups. Additionally, the number of PIT recovery sites substantially increased over the study period. In some early samples, there were no reported recoveries and consequently no way to estimate Lower Granite detection probabilities. In these cases, we made simple point estimates of reach conversion rates (i.e., the number that were detected at Lower Granite Dam divided by the number detected at Ice Harbor or McNary Dam). Given the generally high detection efficiency at Lower Granite Dam (>99% in most samples) we are confident that the point estimates approximated the true values. Similarly, we assumed that tag loss during upstream migration was negligible, but for both reasons, some survival estimates may very slightly underestimate true survival values.

Importantly, we made no adjustments to our conversion rate estimates for harvest or straying. All estimates were based solely on the PIT detection data and therefore require no a priori *assumptions about harvest or straying rates. We think that applying uniform harvest or straying adjustments would potentially lead to biased results, both within and among years. Note that these raw estimates are in contrast to the 'adjusted' conversion rate data presented in the 2008 and 2014 BiOps.*

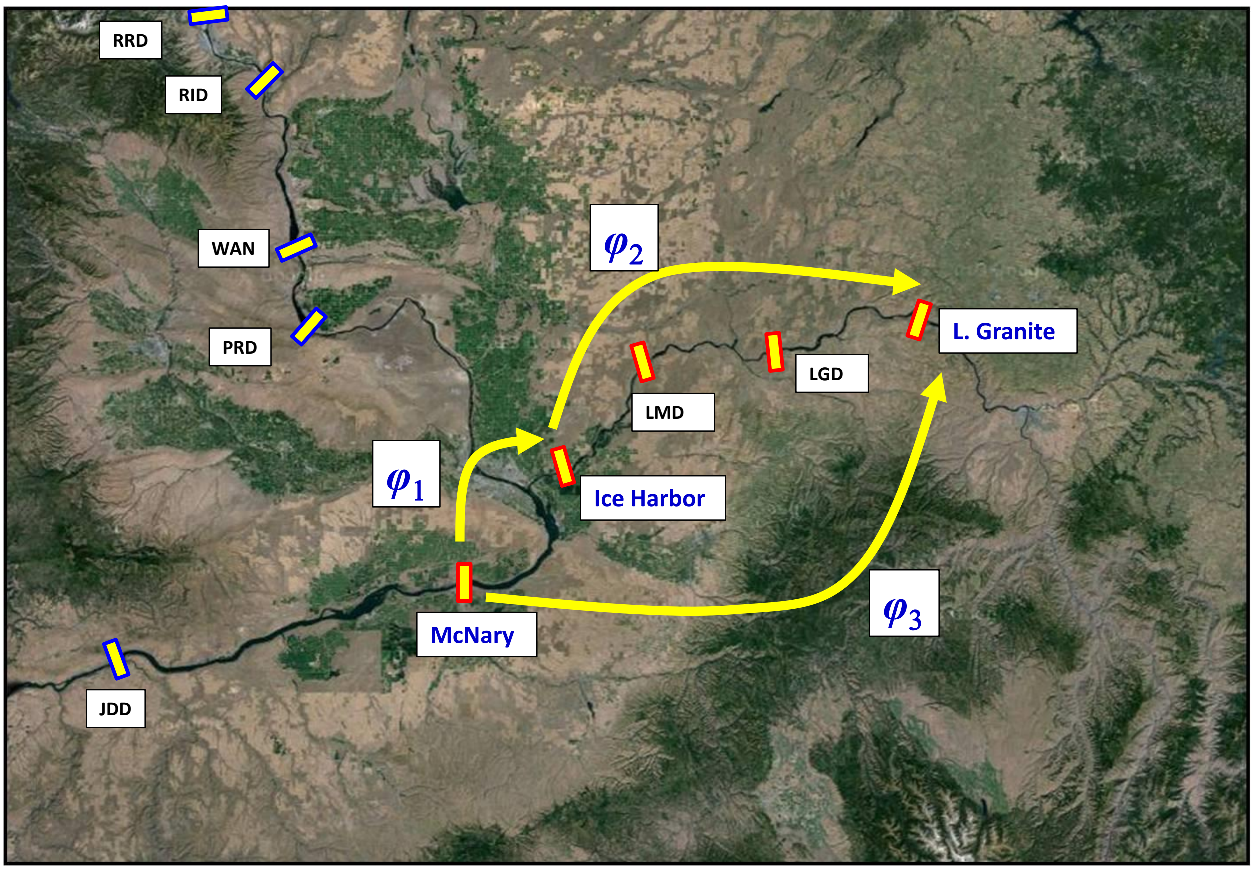

Figure 1. Map of the study area showing the three reaches where conversion rates (φ) were estimated for PIT-tagged adult salmon and steelhead: McNary Dam to Ice Harbor Dam (φ_1), Ice Harbor Dam to Lower Granite Dam (φ_2), and McNary Dam to Lower Granite Dam (φ_3). Detection probabilities (ρ) were also estimated at the three dams using PIT interrogation records from upstream sites.

Migration timing and temperature covariates

We used logistic regression (Agresti 2012) to evaluate the relationships among Snake River water temperature, adult migration date, and adult conversion. In these models the binary response variable was 'pass Lower Granite Dam' (yes, no) and the predictor variables included: (1) the date that each fish was first detected at either McNary Dam or Ice Harbor Dam; and (2) the Snake River water temperature recorded at Ice Harbor Dam on the same date (source: USACE water quality monitoring [WQM] site at Ice Harbor Dam). Most adults rapidly passed through the McNary reservoir (i.e., < 2 d, Keefer et al. 2004) and we think that the high day-to-day correlation among Snake River water temperatures resulted in little bias for the McNary passage date models. Two exceptions were that some overwintering steelhead passed McNary Dam well before they entered the Snake River and some mid-summer steelhead held temporarily (i.e., staged) in the McNary-Ice Harbor reach.

Final distribution of 'unsuccessful' fish

Few fish that did not pass Lower Granite Dam could be fully accounted for (i.e., their ultimate fate was unknown). Instead, we used the complete PIT migration histories to identify the last PIT detection location for each fish, which included dozens of interrogation sites distributed among adult fishways, juvenile bypass systems, instream monitoring arrays, and at hatcheries and weirs. A very small number were reported harvested or had mortality information associated with recovered tags. We then summarized the final location data into five categories: (1) adult fishway at a lower main stem Columbia or Snake River dam; (2) juvenile bypass or other downstream passage route at a main stem dam; (3) inter-basin stray into a non-natal tributary along the migration route or into the upper Columbia River (including at upper Columbia River dams); (4) reported mortality; or (5) detection in the Columbia River estuary.

It is important to recognize that the number of PIT interrogation sites substantively increased from 2002 through 2013, especially in tributaries. Consequently, proportionately more fish were last detected at main stem sites in early study years and increasing proportions were last detected outside the main stem (i.e., in tributaries and at collection facilities) in later years. Direct year-to-year comparisons of final detection locations should be made cautiously.

Donor population straying estimates

Inter-basin straying can vary widely among populations and management groups (*reviewed by* Keefer and Caudill 2014). Consequently, identifying which juvenile release groups contributed to straying from the Snake River, and at what rates, should be useful for assessing how much straying contributes to lowered conversion rates. Donor stray rates estimate the proportion of a population that emigrates to another population, in contrast to recipient stray rates, which estimate the proportion of a population composed of immigrants (Keefer and Caudill 2014). Estimation of recipient stray rates was beyond the scope of the study. We estimated donor population straying estimates by dividing the number of strays from a release site by the total number of fish from that release site that were detected in the study area (i.e., at

McNary or Ice Harbor dams). These estimates should be considered minimum estimates of straying from the study populations because they did not include: (1) strays that did not reach McNary Dam (i.e., they strayed to downstream sites); (2) strays that entered unmonitored tributaries, which was especially likely in early study years; and (3) strays that passed Lower Granite Dam but did not return to natal sites. The reported straying estimates should, however, be useful for relative comparisons across management groups.

Results

Sockeye salmon: sample summary

In the 2002-2013 queries, 7 wild (Table 1) and 627 hatchery (Table 2) sockeye salmon were identified as Snake River fish. All were tagged as juveniles at sites in the upper Salmon River. The most abundant hatchery-origin samples were tagged at Redfish Lake Creek trap and the Sawtooth trap.

Sockeye salmon: conversion estimates

Wild fish, total estimates, all tag groups: Point estimates for the 7 wild sockeye salmon were 1.000 (MCN-ICH), 0.714 (ICH-LGR), and 0.714 (MCN-LGR).

Hatchery fish, total estimates, all tag groups: Point estimates for the 627 hatchery sockeye salmon were 0.967 (MCN-ICH), 0.914 (ICH-LGR), and 0.884 (MCN-LGR).

Wild fish, annual estimates, all tag groups: Annual samples ≤ 2 precluded meaningful estimates.

Hatchery fish, annual estimates, all tag groups: CJS estimates for the MCN-ICH reach ranged from 0.911 to 1.000 (Figure 2). Estimates for the other reaches ranged from 0.723 to 1.000 (ICH-LGR) and from 0.654 to 1.000 (MCN-LGR). The lowest conversions were in 2013 for all reaches and many of the 1.000 estimates were associated with very small sample sizes.

Sockeye salmon: environmental covariates

The probability of passing Lower Granite Dam substantially decreased as Snake River water temperature increased (Figure 3). The logistic regression model that used temperature on the detection date at McNary Dam indicated that conversion probability sharply decreased when Snake River temperatures reached ~18 °C (Wald $\chi^2 = 66.3$, $P < 0.001$, $n = 608$). The model using temperature on the date of Ice Harbor detection had similar results (Wald $\chi^2 = 49.5$, $P < 0.001$, $n = 558$). Models using detection date rather than water temperature indicated later migrants were less likely to pass Lower Granite Dam, but the effect size was smaller.

Sockeye salmon that strayed were detected at McNary and/or Ice Harbor dams during the second half of the migration period, when water temperatures were higher (Figure 3). This may indicate that warm conditions in the lower Snake River act as a deterrent to sockeye salmon.

Sockeye salmon: Final detections

Wild fish: Two of the 7 wild sockeye salmon did not pass Lower Granite Dam. Final detection locations for these fish were the Lower Monumental juvenile bypass system (1) and the Ice Harbor adult fishway (1).

Hatchery fish: A total of 73 hatchery sockeye salmon did not pass Lower Granite Dam (Table 3). The majority (*n* = 56, 77%) was last detected at one of the adult fishways with the largest number at Ice Harbor Dam (*n* = 44, 60%). Five (7%) fish were last detected at juvenile bypasses and 11 (15%) were considered strays.

Final detection sites for the stray group were at upper Columbia River dams (*n* = 9 of 11, 82%) and in the Entiat River (*n* = 2 of 11, 18%). All 11 strays were tagged at the Redfish Lake Creek trap as juveniles; the stray estimate for this group was 3.99% (*n* = 276 adults detected at McNary or Ice Harbor dams).

Table 1. Numbers of PIT-tagged **wild sockeye salmon** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
ALTULC										1		
PETTLC			1					1				
RLCTRP					1			1				2
Total			**1**		**1**			**2**		**1**		**2**

Table 2. Numbers of PIT-tagged **hatchery sockeye salmon** detected at McNary, Ice Harbor, and/or Lower Granite dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
PETTL	1							1	6	1		
PETTLC			1							1	1	
RLCTRP		1				1	9	10	28	59	30	138
SAWTRP							2	4		292	41	
Total	**1**	**1**	**1**			**1**	**11**	**15**	**34**	**353**	**72**	**138**

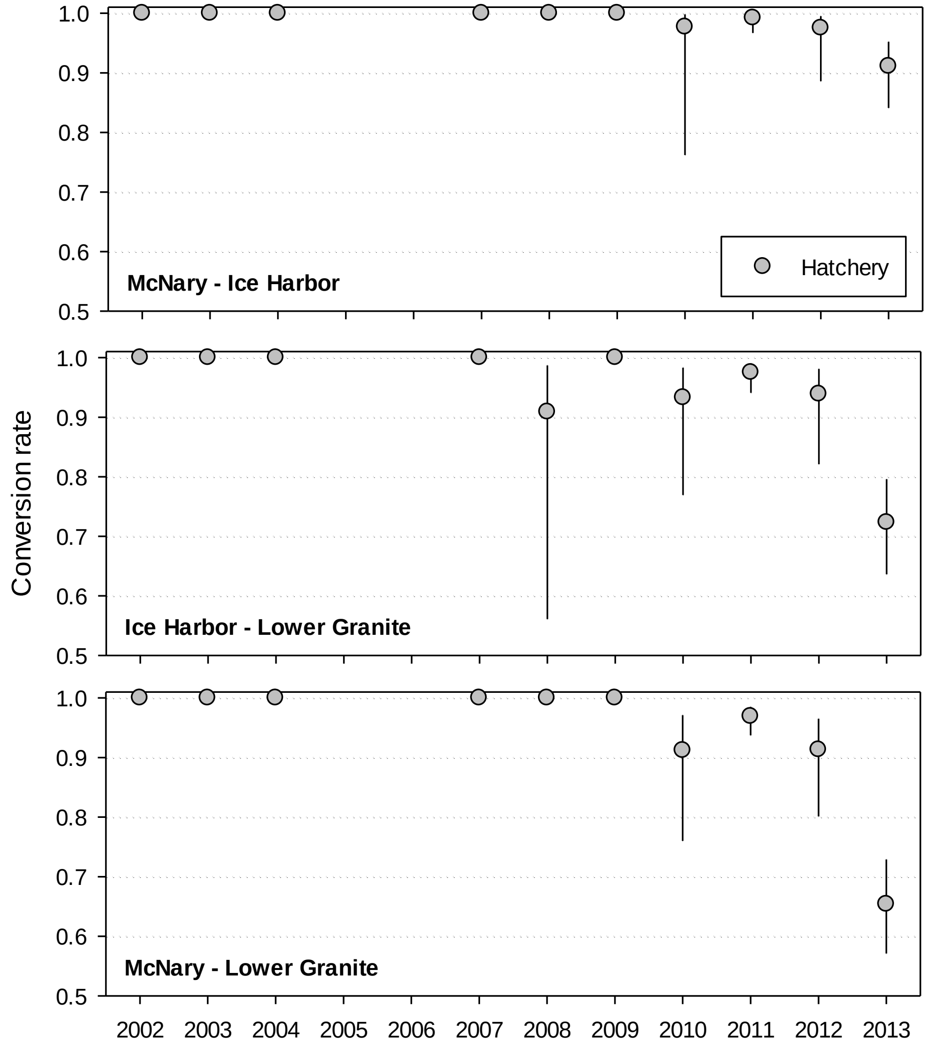

Figure 2. Reach-specific annual conversion rate estimates for **hatchery sockeye salmon** with 95% profile likelihood confidence intervals. Estimates were not adjusted for harvest or straying. Sample sizes are the totals in Tables 2.

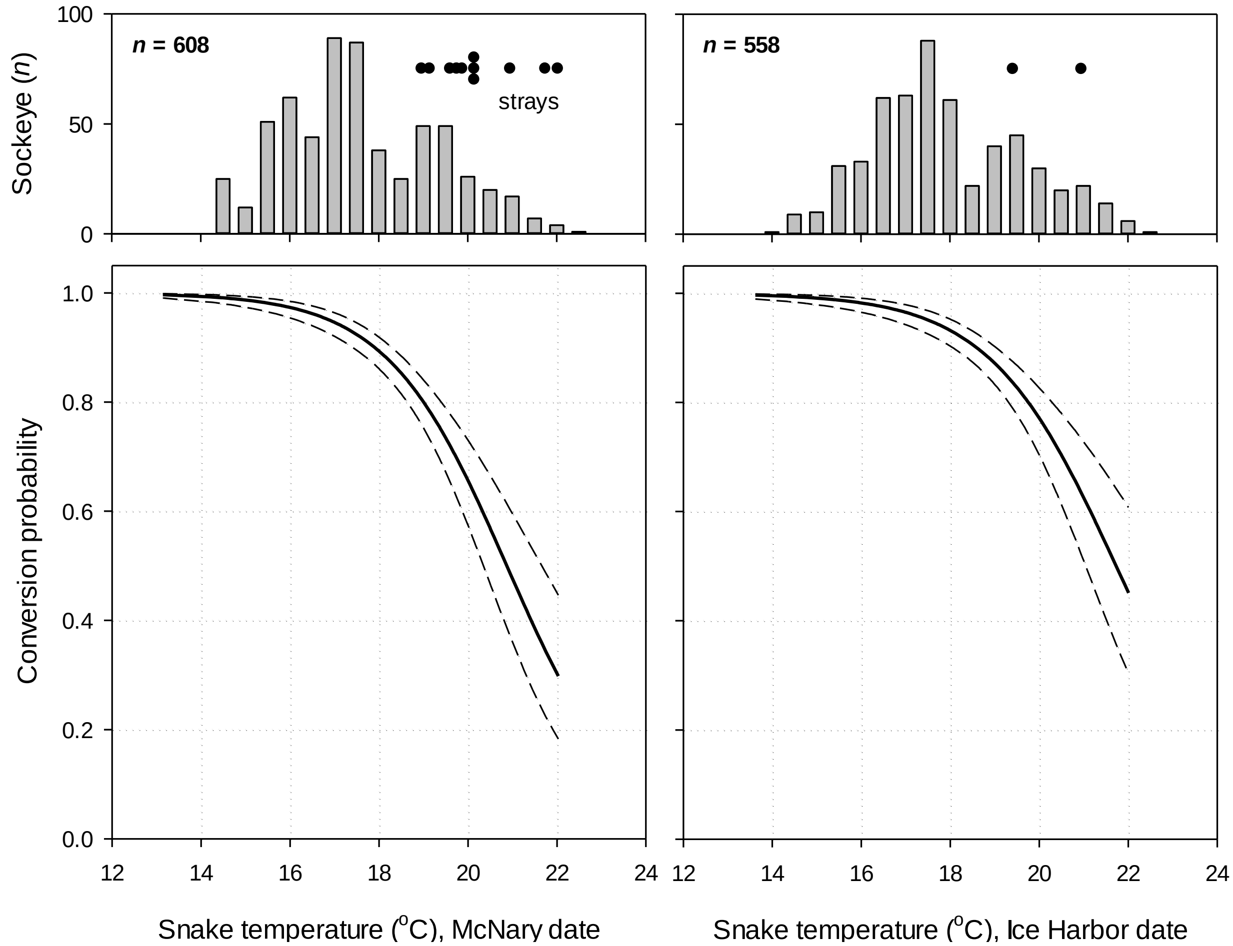

Figure 3. Estimated probability (±95% CI) that sockeye salmon would pass Lower Granite Dam, using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of salmon in each 0.5 °C temperature bin and circles (●) represent fish that strayed.

Table 3. Numbers of PIT-tagged **hatchery sockeye salmon** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
***n* that did not pass LGr**							1		3	15	7	47
Adult fishways along route												
Bonneville										1		
McNary										4		7
Ice Harbor							1		2	8	4	29
Juvenile bypass systems												
McNary										1		
Lower Monumental										1		1
Little Goose											1	1
Strays												
Entiat												2
Upper Columbia dams									1		1	7
Adult fishway (%)							***100***		***67***	***87***	***71***	***77***
Juvenile bypass (%)										***13***	***14***	***4***
Strays (%)									***33***		***14***	***19***

Spring-Summer Chinook salmon: sample summary

In the 2002-2013 queries, 7,831 wild (Table 4) and 26,060 hatchery (Table 5) spring-summer Chinook salmon were identified as Snake River fish. The most abundant wild-origin samples were collected at Lower Granite Dam and were assigned to either in-river (n = 1,759) or barge (1,498) treatments. Other wild groups with at least 200 fish across years included: Imnaha trap (820), Salmon River trap (550), Johnson Creek trap (301), Grande Ronde trap (266), and Big Creek (228).

The most abundant hatchery samples were associated with hatcheries in the Comparative Survival Study (CSS) (e.g., Tuomikoski et al. 2013) or smolt collections at Lower Granite Dam (Table 5). Groups with > 500 fish across years included: Rapid River Hatchery (n = 6,227), Knox Bridge (4,881), Dworshak National Fish Hatchery (2,747), Lower Granite in-river (2,388), Imnaha River weir (2,360), Lower Granite barge (1,053), Ice Harbor tailrace (908), Catherine Creek pond (874), and Lostine River pond (542).

Spring-Summer Chinook salmon: conversion estimates

Wild fish, total estimates, all tag groups: Point estimates for the 7,831 wild spring–summer Chinook salmon were 0.984 (MCN-ICH), 0.967 (ICH-LGR), and 0.951 (MCN-LGR).

Hatchery fish, total estimates, all tag groups: Point estimates for the 26,060 hatchery spring–summer Chinook salmon were 0.979 (MCN-ICH), 0.963 (ICH-LGR), and 0.943 (MCN-LGR).

Wild fish, annual estimates, all tag groups: CJS estimates for the MCN-ICH reach ranged from 0.973 in 2012 to 0.995 in 2003 (Figure 4). Estimates for the ICH-LGR reach ranged from 0.930 in 2006 to 0.986 in 2004. In the combined MCN-LGR reach, estimates ranged from 0.917 in 2006 to 0.975 in 2004. Most 95% confidence intervals were ± 3% or less.

Hatchery fish, annual estimates, all tag groups: CJS estimates for the MCN-ICH reach ranged from 0.964 in 2006 to 0.996 in 2003 (Figure 4). Estimates for the ICH-LGR reach ranged from 0.928 in 2006 to 0.979 in 2005. In the combined MCN-LGR reach, estimates ranged from 0.894 in 2006 to 0.969 in 2005. Most 95% confidence intervals were ± 2% or less.

Wild vs hatchery comparisons, annual estimates, all tag groups: In the MCN-ICH reach, annual CJS conversion rate estimates were higher for wild fish than for hatchery fish in 8 of 11 years. Differences in estimates between wild and hatchery fish were small (*mean* = +0.005). Patterns were similar in the ICH-LGR reach, with higher estimates for wild fish in 9 of 11 years (*mean difference* = 0.006) and in the combined MCN-LGR reach (higher for wild fish in 9 years, *mean difference* = 0.011).

Wild fish, annual estimates, individual release sites: Annual point estimates for the combined MCN-LGR reach for the 10 wild groups with the largest total sample size are shown in Figure 5. Sample sizes varied widely among groups and years and so direct comparisons should be made cautiously. However, there was some evidence for persistent differences among groups. The lowest total MCN-LGR estimates were for the Lower Granite barged (LGRRBR, *total* = 0.927), the Secesh River trap (SECTRP, 0.945), and the Snake River trap (SNKTRP, 0.946) samples. The highest total estimates were for the Lower Granite in-river (LGRRRR, 0.966), Marsh Creek trap (MARTRP, 0.956), and Johnson Creek trap (JOHTRP, 0.953) samples (Figure 5).

Hatchery fish, annual estimates, individual release sites: Annual point estimates for the combined MCN-LGR reach for the 10 largest hatchery groups are shown in Figure 6. The lowest total estimates were for the Lower Granite barged (LGRRBR, *total* = 0.893), Powell pond (POWP, 0.910), and the Dworhak National Fish Hatchery main stem release (DWORMS, 0.921) samples. The highest total estimates were for the Knox Bridge (KNOX, 0.966), Imnaha River weir (IMNAHW, 0.958), and Lostine River pond (LOSTIP, 0.956) samples (Figure 6).

Spring-Summer Chinook salmon: environmental covariates

Wild fish: The probability of passing Lower Granite Dam substantially decreased as Snake River water temperature increased (Figure 7). The logistic regression model that used temperature on the detection date at McNary Dam indicated that conversion steadily decreased, with no obvious inflection point (Wald $\chi^2 = 61.2$, $P < 0.001$, $n = 7{,}666$). The model using temperature on the date of Ice Harbor detection had similar results (Wald $\chi^2 = 80.5$, $P < 0.001$, $n = 6{,}828$). Models using detection date rather than water temperature indicated later migrants were less likely to pass Lower Granite Dam, with rapidly decreasing probabilities after mid- to late July. Effect sizes for detection date were similar to those for temperature.

Wild spring–summer Chinook salmon that strayed were detected at McNary and/or Ice Harbor Dam almost exclusively during the middle and late migration periods. This may indicate that warm conditions in the lower Snake River act as a deterrent to some spring–summer Chinook salmon.

Hatchery fish: The probability of passing Lower Granite Dam was not associated with Snake River water temperature on the detection date at McNary Dam (Wald $\chi^2 = 0.2$, $P = 0.622$, $n = 25{,}649$, Figure 8). In contrast, the model using temperature on the date of Ice Harbor detection showed a slight decrease in conversion probability as temperature increased (Wald $\chi^2 = 12.7$, $P < 0.001$, $n = 23{,}043$). Models using detection date rather than water temperature indicated later migrants were slightly *more* likely to pass Lower Granite Dam if they passed McNary Dam later in the migration (Wald $\chi^2 = 2.8$, $P = 0.097$, $n = 25{,}649$) but slightly *less* likely to pass Lower Granite if they passed Ice Harbor Dam later in the migration (Wald $\chi^2 = 6.3$, $P = 0.012$, $n = 23{,}043$).

Hatchery spring–summer Chinook salmon that strayed were detected at McNary and/or Ice Harbor Dam almost exclusively during the middle and late migration periods.

Spring-Summer Chinook salmon: Final detections

Wild fish: A total of 381 wild spring–summer Chinook salmon did not pass Lower Granite Dam (Table 6). A large majority (*n* = 343, 90%) was last detected at one of the adult fishways, with the largest number at Ice Harbor Dam (*n* = 228, 60%). Twelve (3%) fish were last detected at juvenile bypasses, 3 (~1%) were reported mortalities, and 23 (6%) were considered strays.

Final detection sites for the 23 strays were widely distributed. Four (17% of 23) were in tributaries downstream from McNary Dam, 6 (26%) were in Columbia River tributaries upstream from McNary Dam, and 6 (26%) were at upper Columbia River dams. The final 7 (30%) were in the Tucannon River.

Hatchery fish: A total of 1,475 hatchery spring–summer Chinook salmon did not pass Lower Granite Dam (Table 7). The majority (*n* = 1,326, 90%) was last detected at one of the adult fishways, with the largest number at Ice Harbor Dam (*n* = 829, 56%). Twenty-eight (2%) fish were last detected at juvenile bypasses, 18 (1%) were reported mortalities, and 103 (7%) were considered strays.

Final detection sites for the stray group were at upper Columbia River dams (*n* = 53 of 103, 51%), in tributaries upstream from McNary Dam (30, 29%), in tributaries downstream from McNary Dam (16, 16%), or in the Tucannon River (4, 4%).

Spring-Summer Chinook salmon: Donor population straying estimates

Wild fish: In total, 23 of 7,831 (0.29%) wild fish were considered strays to sites downstream from Lower Granite Dam (Figure 9). Ten release groups produced strays and five had denominator sample sizes > 100 fish: the Secesh River trap (SECTRP, *stray* = 1/182 = 0.55%), Grande Ronde trap (GRNTRP, 2/266, 0.75%), Salmon River trap (SALTRP, 1/550, 0.18%), Imnaha River trap (IMNTRP, 1/820, 0.12%), and the Lower Granite barged treatment (LGRRBR, 13/1,498, 0.87%).

Hatchery fish: In total, 104 of 26,060 (0.40%) hatchery fish were considered strays (Figure 9). Fourteen release groups produced strays, but only five of these had denominator sample sizes > 1,000 fish: the Lower Granite barged treatment (LGRRBR, 25/1,053, 2.37%), the Imnaha River weir (IMNAWH, 5/2,360 = 0.21%), Dworshak hatchery (DWORNF, 29/2,747, 1.06%), Knox Bridge (KNOXB, 6/4,880, 0.12%), and Rapid River hatchery (RAPH, 6/6,227, 0.10%).

Table 4. Numbers of PIT-tagged **wild spring–summer Chinook salmon** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
AMERR	3	1		1					1	1	15	12
BIG2C	1	3		2			1	23	70	67	31	30
CAMASC	2								1	2	2	4
CATHEC	6	7		1	2	2	3	6	9	20	11	12
CFCTRP	7	4		1	1	3	6	2	8	8	12	6
CLWTRP			3	1	2	2		6	8	3	9	5
COLTKC					1					1	4	5
CROTRP	3	1			1	2		1		1	3	4
FISTRP	3	1					1		2	2	1	
GRAND2	4	4		4	5	1	3	4	13	7	6	13
GRNTRP		5		10	10	11	31	36	54	63	30	16
HAYDNC								4	8	5	5	6
HERDC	1							1	2	2	1	3
IMNAHR	12	8					2	2	2	7	1	
IMNAHW	13	10	4									
IMNTRP	102	76	43	27	35	18	22	81	157	137	84	38
JOHTRP	45	34	30	5	6	11	36	14	36	30	30	24
KNOXB							1	14	20	29	35	9
LAKEC	12	11	4		1			9	20	16	9	5
LEMHIR	2	1				1		4	7	16	8	9
LEMHIW	7	11		2	2	2	3	13	12	9	3	17
LGRRBR	21	126	69	29	44	38	124	220	365	257	130	75
LGRRRR	345	525	230	108	23	10	60	92	124	110	69	63
LOLOC	5	6			2	1	5	8	3	6	13	6
LOOKGC	2	1		5		1		7	11	13	4	6
LOONC	4	1					2		1		2	1
LOSTIR	15	16		3	3	5	9	13	14	28	12	10
LSFTRP	20	27	2							4	19	14
MARTRP	12	9		4	1	1	1	16	50	48	20	19
MEADOC	5	3		1	1	1	26	12	18	9	5	1
MINAMR	1	4		2	2	2	3	9	26	12	8	4
NEWSOC	3	4		1		1	3	1		1	7	5
PAHTRP	8	3	1		3	3	4	7	9	4	6	14
REDTRP	5	6			2		3	1	1	4	5	2
SALEFT							4	3	1	6	4	1
SALTRP	25	52	37	16	28	19	43	58	106	72	42	52
SAWTRP	8	10		11	9	9	21	12	23	24	21	22
SECESR	16	11	8	3	1	4	9	15	20	13	6	10
SECTRP							7	40	73	22	18	23
SFSTRP	13	16	2	2	4	2	5	5				
SNKTRP	10	37	9	5	2	4	13	8	20	39	20	17
VALEYC	3			1			2	1	8	4	1	1
Other[1]	12	24	5	6	1	4	4	5	9	7	12	8
Total	**778**	**1076**	**447**	**251**	**192**	**158**	**456**	**752**	**1309**	**1109**	**729**	**574**

[1] Other includes sites with < 10 fish across years: BEARVC, CAPEHC, CHAMBC, CHAMWF, CLEARC, CLWR, ELKC, IHRTAL, JOHNSC, MARSHC, PAPOOC, RAPIDR, RPDTRP, SALREF, SALRSF, SNAKE3, SNAKE4, SQUAWC, SULFUC, WHITSC, YANKFK, YANKWF

Table 5. Numbers of PIT-tagged **hatchery spring–summer Chinook salmon** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
CATHEP	7	29	53	26	20	27	65	110	218	187	85	47
CLEARC	2				2	2	5	1	26	140	93	64
CROOKR						10	70	34	8	26	8	64
CROTRP								20	37	10		
DWOR				4	1	5	15	2				
DWORMS	15	79	10									
DWORNF	238	262	239	83	117	163	317	346	236	328	268	150
GRANDP	2		2	4		2	8	11	17	9	7	5
GRANDR	10	3										
GRNTRP		1	9	3	1	4	9	16	19	21	15	3
IHRCOL			1	9								
IHRTAL			8	7		59	136	181	242	175	76	24
IHRTRB			3	12								
IMNAHR	3	1							11	12		12
IMNAHW	341	181	179	91	47	67	183	481	330	236	134	90
IMNTRP	40	22	8	1								
JOHNSC	17	20	13	14	7	23	46	73	54	11	6	14
KNOXB	830	581	511	278	150	259	486	635	372	301	189	289
KOOS	10	3	6	1			2	11	67	67	62	44
LGRRBR					1	45	170	317	471	47	2	
LGRRRR			2	2		141	493	399	646	443	205	57
LOLOC	1	3	4					2	1	11	9	5
LOOH	9				5		1	7	13	26	19	14
LOOKGC	5	4	1	1								
LOSTIP	49	58	88	37	12	24	39	69	54	63	30	19
MEADOC			7	1	3	1		1	10	9	6	7
NEWSOC		1	2			1	4	8	12	7	3	6
NPTH								2	9	7	1	6
PAHP	6	1	2	2				57	88	75	10	19
POWP	4		2			13	69	91	115	70	51	42
RAPH	445	659	1067	393	102	179	397	832	1161	576	232	184
REDP		1				6	65	58	53	71	48	21
SALTRP	26		26	5	5	4	22	25	38	35	17	11
SAWT			1				40	90	59	52	42	33
SAWTRP	7	1	2									
SELWY1								31	92	137	92	52
SNKTRP	20		10	1	1	6	21	16	34	29	6	9
YANKFK							2			6	7	3
Other[1]	3	4	3	1			1	1	2	3	2	9
Total	**2090**	**1915**	**2259**	**976**	**474**	**1041**	**2666**	**3927**	**4496**	**3188**	**1725**	**1303**

[1] Other includes sites with < 10 fish across years: BEARC, CATHEC, CLWR, CROOKP, LGSTAL, LOSTIR, MOOS2C, PAPOOC, PETEKC, SALRSF, SFSTRP, SNAKE2, SQUAWC, STOLP

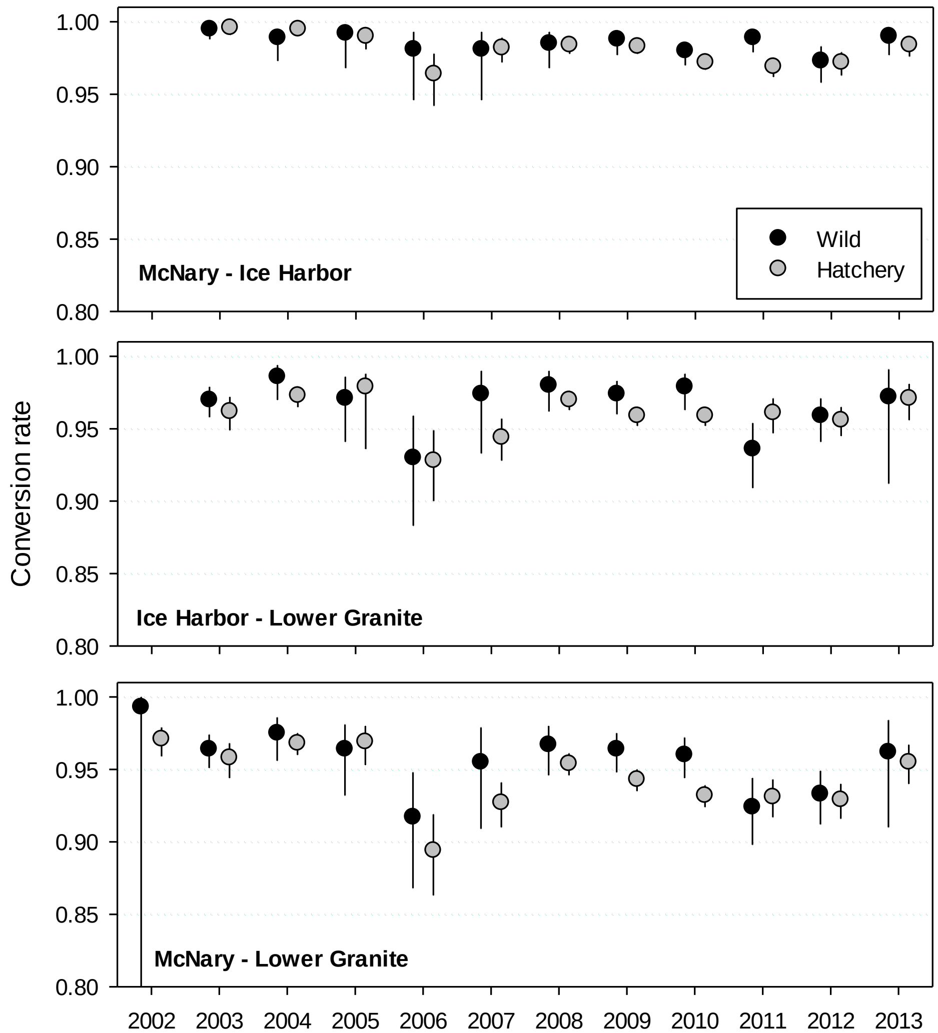

Figure 4. Reach-specific conversion rate estimates for **spring–summer Chinook salmon** with 95% profile likelihood confidence intervals. Estimates were not adjusted for harvest or straying. Sample sizes are the totals in Tables 4 and 5.

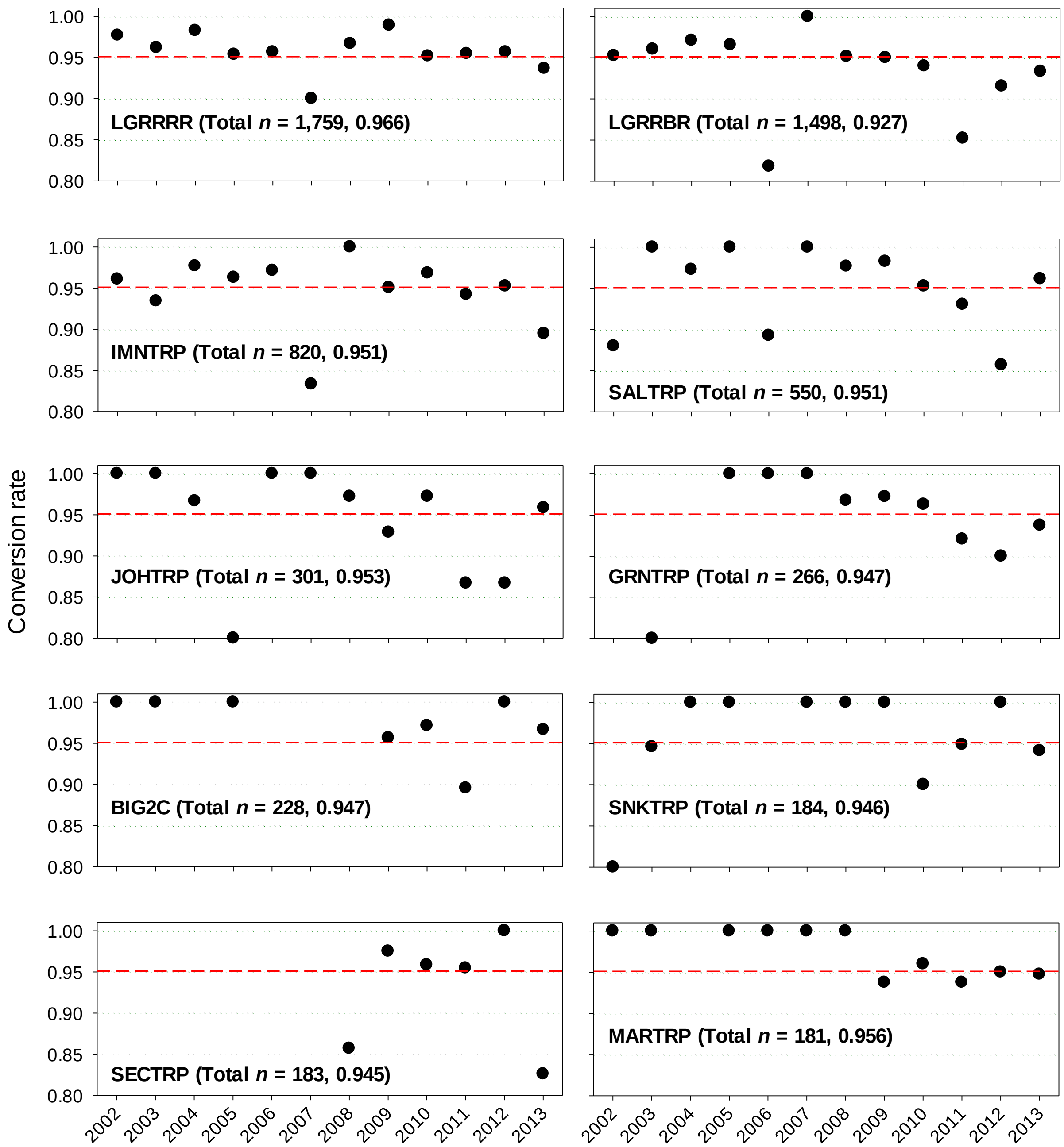

Figure 5. McNary-Lower Granite conversion rate point estimates for **wild spring–summer Chinook salmon** from the ten release sites with the highest numbers of fish. Estimates were not adjusted for harvest or straying. Annual sample sizes are in Table 3; parentheses show the total sample size and conversion estimate for each release site. Red dashed line shows the estimate for all wild fish in all years (0.951).

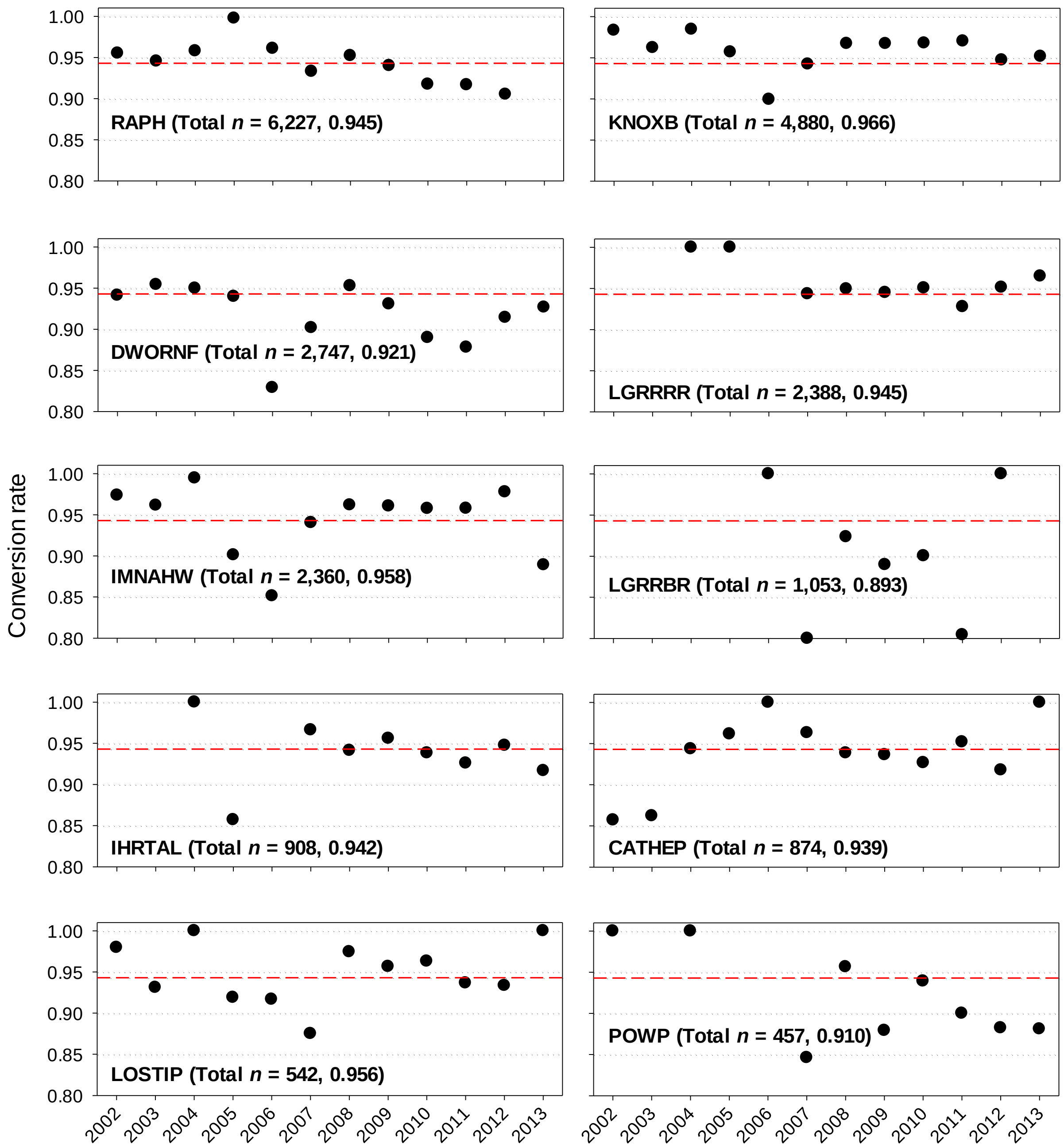

Figure 6. McNary-Lower Granite conversion rate point estimates for **hatchery spring–summer Chinook salmon** from the ten release sites with the highest numbers of fish. Estimates were not adjusted for harvest or straying. Annual sample sizes are in Table 4; parentheses show the total sample size and conversion estimate for each release site. Red dashed line shows the estimate for all wild fish in all years (0.943).

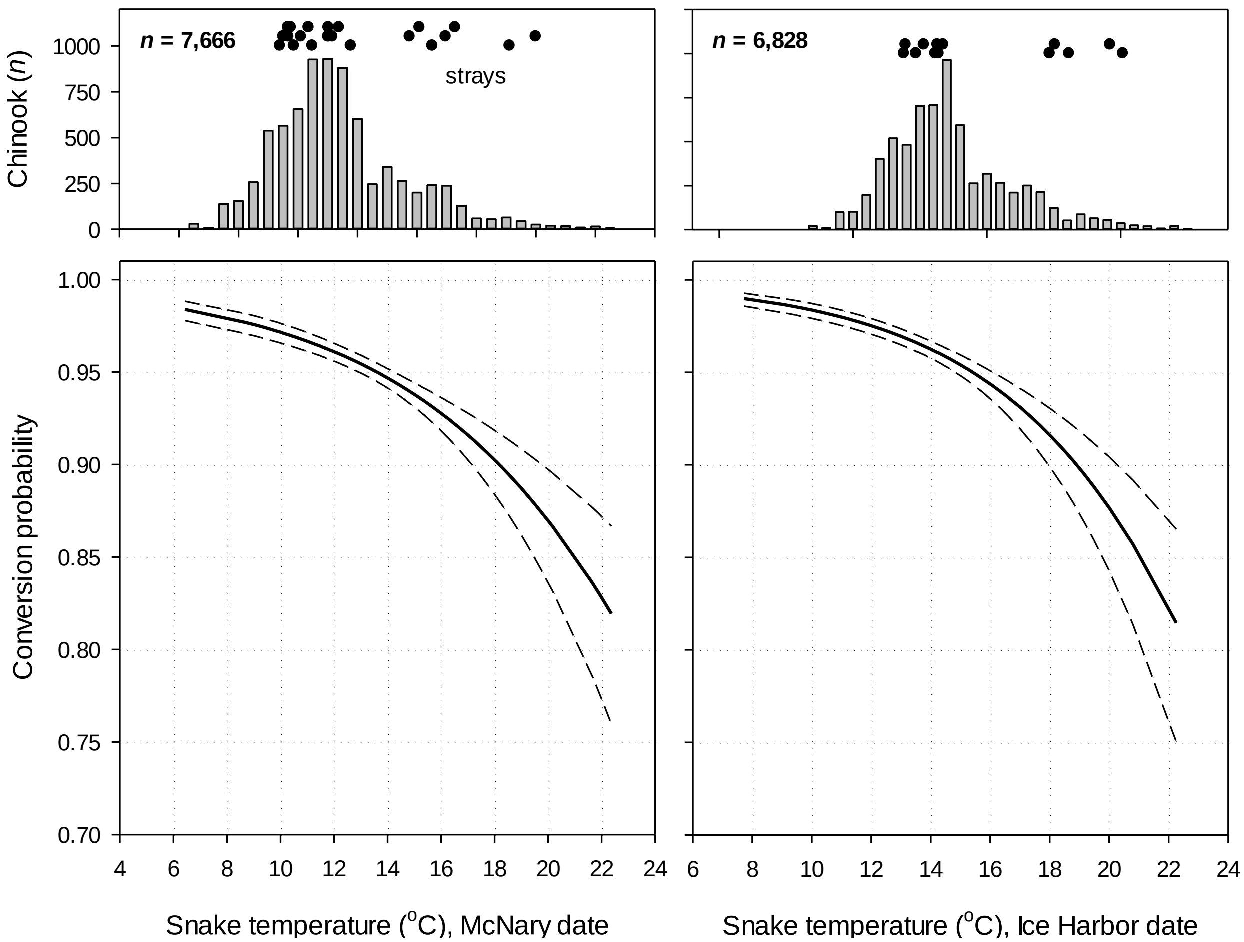

Figure 7. Estimated probability (±95% CI) that **wild spring–summer Chinook salmon** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of salmon in each 0.5 °C temperature bin and circles (●) represent fish that strayed.

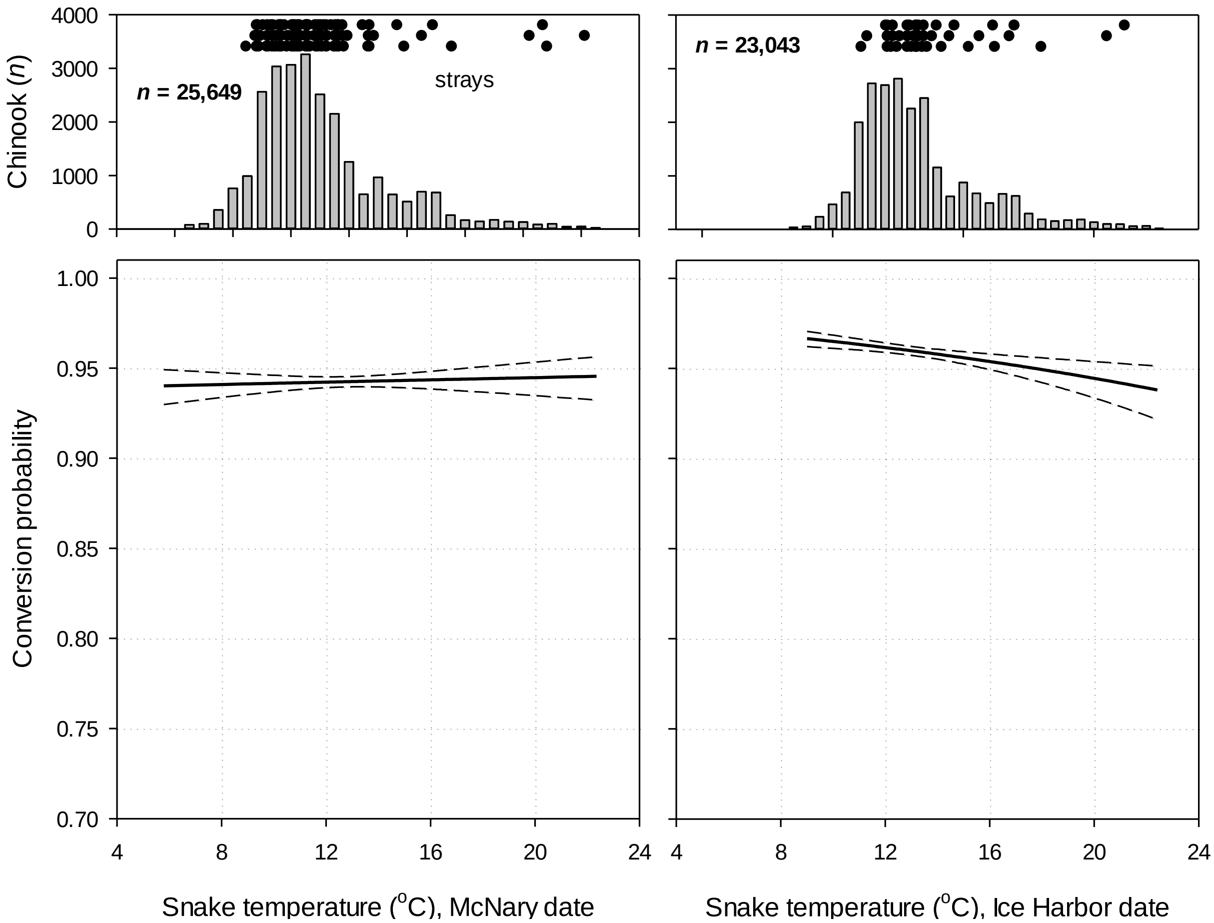

Figure 8. Estimated probability (±95% CI) that **hatchery spring–summer Chinook salmon** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of salmon in each 0.5 °C temperature bin and circles (●) represent fish that strayed.

Table 6. Numbers of PIT-tagged **wild spring–summer Chinook salmon** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
***n* that did not pass LGr**	22	38	11	9	16	7	15	27	58	97	48	33
Adult fishways along route												
Bonneville									3			
McNary	22	6	5	2	2	3	6	8	22	13	17	6
Ice Harbor		31	6	7	11	4	8	15	26	70	24	26
Juvenile bypass systems												
John Day									1			
McNary								1	1	3		
Little Goose									1	4	1	
Strays												
Deschutes											1	1
John Day							1		1			
Tucannon					2					3	2	
Wenatchee										1		
Entiat								1	1	1		
Methow								1	1			
Upper Columbia dams		1			1				1	1	2	
Reported mortality												
Badger Island								1			1	
Columbia River										1		
Snake River												
Adult fishway (%)	***100***	***97***	***100***	***100***	***76***	***100***	***93***	***85***	***88***	***86***	***85***	***97***
Juvenile bypass (%)								***4***	***5***	***7***	***2***	
Strays (%)		***3***			***24***		***7***	***7***	***7***	***6***	***10***	***3***
Reported mortality (%)								***4***		***1***	***2***	

Table 7. Numbers of PIT-tagged **hatchery spring–summer Chinook salmon** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
***n* that did not pass LGr**	62	89	71	32	50	75	122	228	308	256	118	64
Adult fishways along route												
Bonneville	1		1	2	4	5	3	3	9	12	5	
McNary	60	9	11	7	9	10	36	49	112	85	44	20
Ice Harbor		79	58	22	29	49	74	133	166	127	53	39
Juvenile bypass systems												
Bonneville							1			1	1	1
John Day											1	
McNary						3	1	3	1	4		
Lower Monumental									1	2		1
Little Goose					1		1	1		3	1	
Strays												
Fifteenmile										1		
Hood						1						
Klickitat											2	
Deschutes								1	2			
John Day							3	4	1			1
Yakima								2	1	2	1	
Tucannon										2	2	
Wenatchee						2		5	2	3	1	1
Entiat								1	1	1		
Methow								2	2		3	
Upper Columbia dams	1		1		6	4	1	18	9	10	3	
Reported mortality												
Badger Island					1	1	1		1	1	1	
Crescent Island							1					
Columbia River										2		
Snake River		1		1				6				1
Adult fishway (%)	***98***	***99***	***99***	***97***	***84***	***85***	***93***	***81***	***93***	***88***	***86***	***92***
Juvenile bypass (%)					***2***	***4***	***2***	***2***	***1***	***4***	***3***	***3***
Strays (%)	***2***		***1***		***12***	***9***	***3***	***14***	***6***	***7***	***10***	***3***
Reported mortality (%)		***1***		***3***	***2***	***1***	***2***	***3***	***<1***	***1***	***1***	***2***

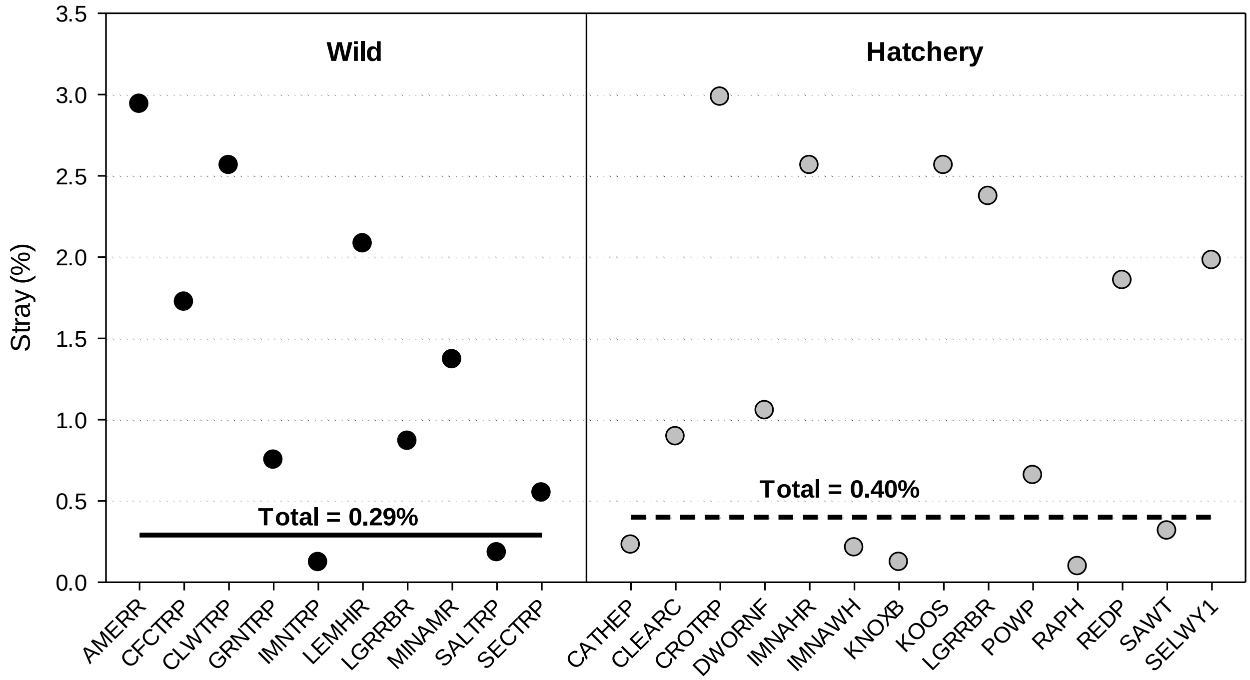

Figure 9. Donor population stray rates estimated for all wild and hatchery **spring–summer Chinook salmon** (horizontal lines) and for all release groups that produced strays. Denominator sample sizes are the totals in Tables 4 and 5. Straying was calculated as: the number identified as strays by PIT detections divided by the total detected at McNary or Ice Harbor dams. Does not include strays that did not reach McNary Dam or strays that entered unmonitored tributaries (i.e., all estimates are minimums).

Fall Chinook salmon: sample summary

In the 2002-2013 queries, 355 wild (Table 8) and 19,379 hatchery (Table 9) fall Chinook salmon were identified as Snake River fish. The most abundant wild-origin samples were collected in the Snake River main stem above Lower Granite Dam (*n* = 90-152) or the lower Clearwater River (50).

The most abundant hatchery samples (*n* > 500 fish across years) included: Big Canyon Creek Acclimation Faclity (*n* = 5,702), Snake River main stem sites (299-1,042), Captain John Acclimation Pond (2,571), Pittsburg Landing Acclimation Facility (2,104), and the lower Grande Ronde River (588).

Fall Chinook salmon: conversion estimates

Wild fish, total estimates, all tag groups: Point estimates for the 355 wild fall Chinook salmon were 0.975 (MCN-ICH), 0.957 (ICH-LGR), and 0.932 (MCN-LGR).

Hatchery fish, total estimates, all tag groups: Point estimates for the 19,379 hatchery fall Chinook salmon were 0.966 (MCN-ICH), 0.964 (ICH-LGR), and 0.932 (MCN-LGR).

Wild fish, annual estimates, all tag groups: CJS estimates for the MCN-ICH reach ranged from 0.959 in 2009 to 1.000 in several years (Figure 10). Few fish were detected at sites upstream from Lower Granite Dam. Therefore, point estimates for the ICH-LGR reach ranged from 0.909 in 2006 to 1.000 in several years. In the combined MCN-LGR reach, point estimates ranged from 0.852 in 2006 to 1.000 in the small samples of 2004 and 2005.

Hatchery fish, annual estimates, all tag groups: CJS estimates for the MCN-ICH reach ranged from 0.943 in 2013 to 1.000 in 2004 (Figure 10). Point estimates for the ICH-LGR reach ranged from 0.952 in 2013 to 0.978 in 2008. In the combined MCN-LGR reach, point estimates ranged from 0.898 in 2013 to 0.992 in 2002.

Wild vs hatchery comparisons, annual estimates, all tag groups: In the MCN-ICH reach, annual CJS conversion rate estimates were higher for wild fish than for hatchery fish in 10 of 11 years. Differences were large (*mean* = +0.036 in wild) compared to the spring–summer Chinook salmon estimates, but we note that samples of wild fall Chinook salmon were small in most years. Patterns were mixed in the ICH-LGR reach, with higher estimates for wild fish in 5 of 11 years (*mean difference* = +0.021) but higher for hatchery fish in 6 of 11 years (*mean* = -0.033). Results were similarly mixed in the combined MCN-LGR reach (Figure 10).

Hatchery fish, annual estimates, individual release sites: Annual point estimates for the combined MCN-LGR reach for the 8 largest hatchery groups are shown in Figure 11. The lowest total estimates were for the Cedar Flats Acclimation Facility (CEFLAF, *total* = 0.868) and the Lukes Gulch Acclimation Facility (LUGUAF, *total* = 0.888) samples. The highest total estimates were for the Snake River (SNAKE3, 0.939) and Captain John Rapids Acclimation Facility (CJRAP, 0.936) samples (Figure 11).

Fall Chinook salmon: environmental covariates

Wild fish: The probability of passing Lower Granite Dam was mixed in relation to Snake River water temperature (Figure 12). The logistic regression model that used temperature on the detection date at McNary Dam indicated that conversion decreased non-significantly as temperature increased (Wald χ^2 = 1.2, P = 0.180, n = 347). The model using temperature on the date of Ice Harbor detection showed no relationship (Wald χ^2 = 0.4, P = 0.535, n = 339). Models using detection date rather than water temperature indicated later migrants were equivocal (P = 0.650 for McNary passage date P = 0.791 for Ice Harbor passage date).

Hatchery fish: The probability of passing Lower Granite Dam was not associated with Snake River water temperature on the detection date at McNary Dam (Wald χ^2 = 0.3, P =0.305, n = 19,202, Figure 13). In contrast, the model using temperature on the date of Ice Harbor detection showed that conversion probability increased substantially as temperature increased (Wald χ^2 = 40.6, P < 0.001, n = 18,462). Models using detection date rather than water temperature indicated later migrants were substantially less likely to pass Lower Granite Dam if they passed McNary Dam later in the migration (Wald χ^2 = 15.5, P < 0.001, n = 19,202) or if they passed Ice Harbor Dam later in the migration (Wald χ^2 = 39.2, P < 0.001, n = 18,462).

Hatchery fall Chinook salmon that strayed were detected at McNary and/or Ice Harbor Dam throughout the run, though there were proportionately more strays later in the migration.

Fall Chinook salmon: Final detections

Wild fish: A total of 24 wild fall Chinook salmon did not pass Lower Granite Dam (Table 10). Most (n = 18, 75%) were last detected at one of the adult fishways at Ice Harbor or McNary dams. The remaining six (25%) fish were considered strays that were last detected at several mid- and upper Columbia River sites.

Hatchery fish: A total of 1,322 hatchery fall Chinook salmon did not pass Lower Granite Dam (Table 11). The majority (n = 971, 73%) was last detected at one of the adult fishways with the largest number at Ice Harbor Dam (n = 512, 39%). Sixty-one (5%) fish were last detected at juvenile bypasses, and 289 (22%) were considered strays.

Final detection sites for the stray group were at upper Columbia River dams (n = 112 of 322, 35%), in tributaries upstream from McNary Dam (138, 43%), in tributaries downstream from McNary Dam (11, 3%), in the Tucannon River (28, 9%), or at Lyons Ferry Hatchery (19, 6%) (Table 11).

Fall Chinook salmon: Donor population straying estimates

Wild fish: In total, 6 of 355 (1.69%) wild fish were considered strays to sites downstream from Lower Granite Dam (Figure 14). Three release groups produced strays: the Snake River main stem collections (SNAKE3, 1/152, 0.66% and SNAKE4, 3/90, 3.33%) and the Lower Granite barged treatment (LGRRBR, 2/31, 6.45%).

Hatchery fish: In total, 289 of 19,379 (1.49%) hatchery fish were considered strays (Figure 14). Thirteen release groups produced strays, and five of these had denominator sample sizes > 1,000 fish: Pittsburg landing (PLAP, 40/2,104, 1.90%), Snake River main stem sites (SNAKE3, 58/4,775 = 1.21% and SNAKE4, 64/2,296, 2.79%), Captain John Rapids acclimation facility (CJRAP, 29/2,571, 1.13%), and the Big Canyon Creek acclimation facility (BCCAP, 56/5,702, 0.98%).

Table 8. Numbers of PIT-tagged **wild fall Chinook salmon** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
CLWR					1	6	6	7	4	4	8	14
GRANDR	1											
LGRRBR		1			1	7	1	12	7	2		
LGRRRR		9	4	1		2		3	2		2	
SALTRP								1				
SNAKE2							1					
SNAKE3			4	8	6	12	12	16	13	21	23	37
SNAKE4			1	1	3		6	10	18	19	11	21
SNKTRP		3	1	1			1					
Total	**1**	**13**	**10**	**11**	**11**	**27**	**27**	**49**	**44**	**46**	**44**	**72**

Table 9. Numbers of PIT-tagged **hatchery fall Chinook salmon** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
BCCAP	72	88	40	11	43	347	367	762	673	878	1211	1210
CEFLAF						22	20	30	31	46	106	124
CJRAP	9	15	21	7	3	32	19	370	390	438	614	653
CLWR	39	3					1	2	1		15	52
CLWRMF							1	17				
COUGRC					19	15	14	1				
GRAND1								56	66	87	197	182
HCD		2	1	4	1	26	30	6				
IHRTAL						3			1	2	1	
LGRRBR						3	5	11	1			
LGRRRR				1	1	5	9	14	11	7	6	3
LGRRTR						1	4	4	6	5	2	3
LUGUAF						9	8	44	33	56	92	159
NLVP			2			1	2	17	16	10	10	25
NPTH			1	2		4	6	10	9	8	22	50
PLAP	10	12	11	11	4	59	43	408	316	340	384	506
SNAKE3		100	201	93	58	202	255	756	689	662	717	1042
SNAKE4			6	2	3	19	34	822	625	242	244	299
SNKTRP			2	2	1	4						
Total	**130**	**220**	**285**	**133**	**114**	**756**	**819**	**3343**	**2869**	**2781**	**3621**	**4308**

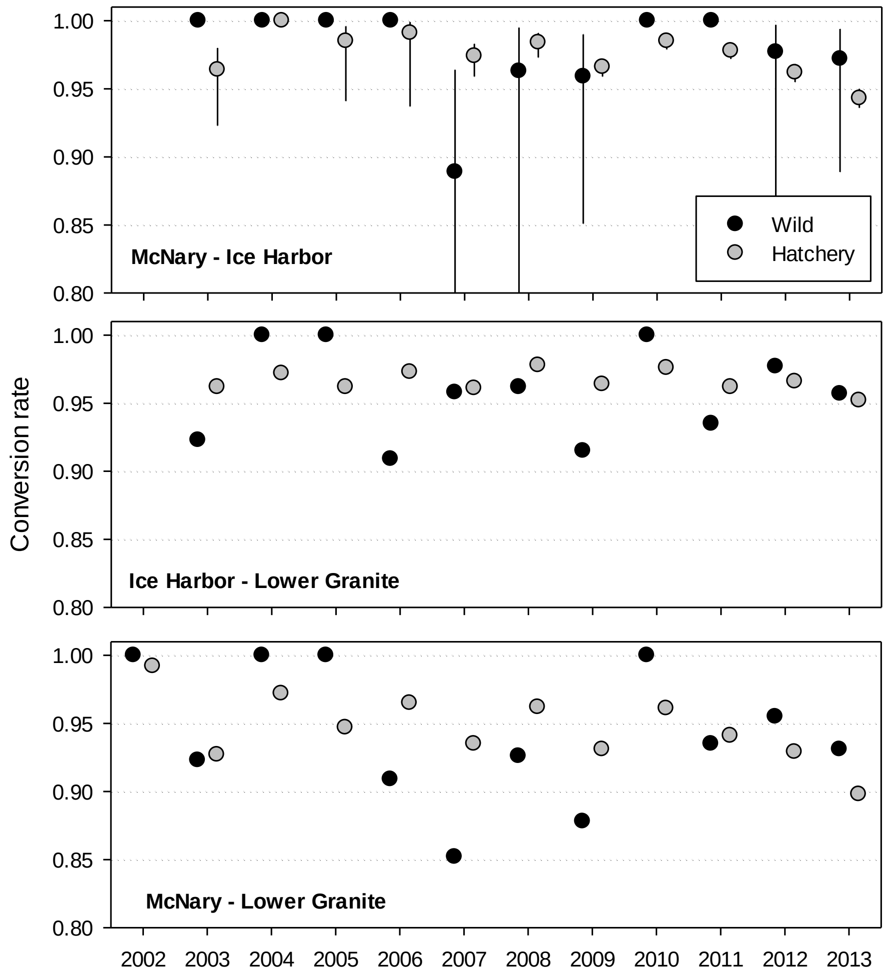

Figure 10. Reach-specific conversion rate estimates for **fall Chinook salmon** with 95% profile likelihood confidence intervals. Estimates were not adjusted for harvest or straying. Sample sizes are the totals in Tables 8 and 9. Symbols without error bars are point estimates rather than CMJ estimates because few or zero fall Chinook salmon were detected upstream from Lower Granite Dam.

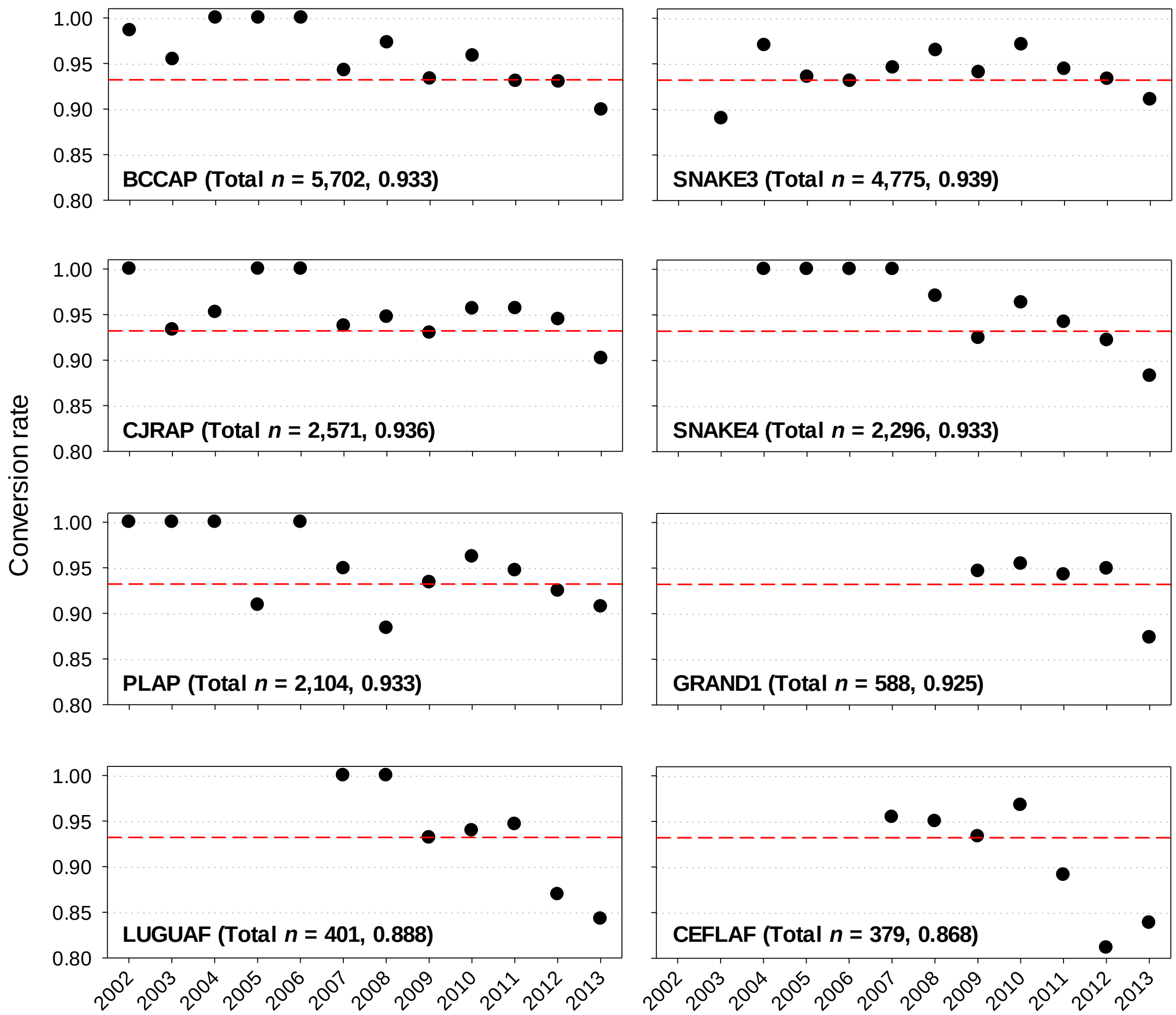

Figure 11. McNary-Lower Granite conversion rate point estimates for **hatchery fall Chinook salmon** from the eight release sites with the highest numbers of fish. Estimates were not adjusted for harvest or straying. Annual sample sizes are in Table 9; parentheses show the total sample size and conversion estimate for each release site. Red dashed line shows the estimate for all hatchery fish in all years (0.932).

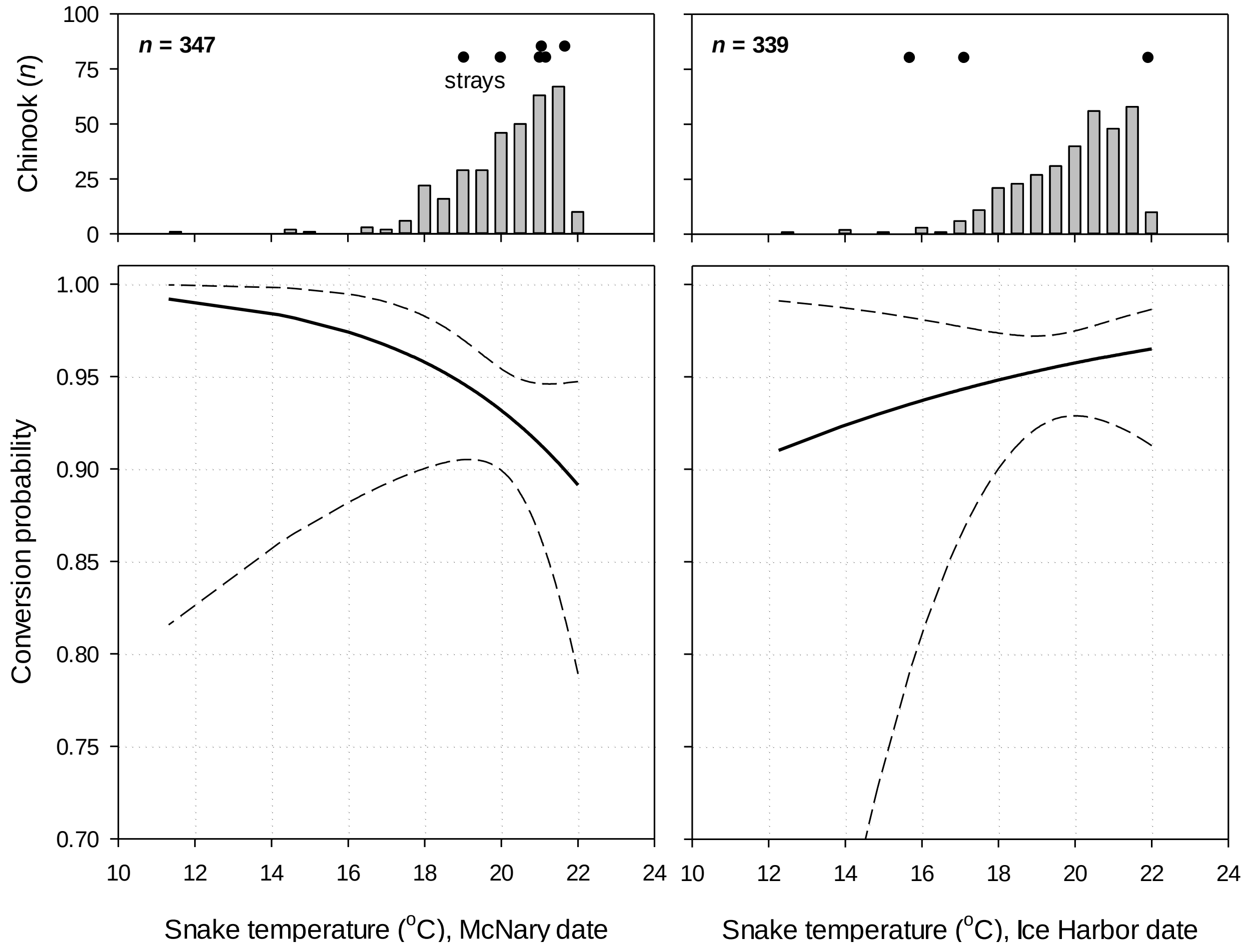

Figure 12. Estimated probability (±95% CI) that **wild fall Chinook salmon** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of salmon in each 0.5 °C temperature bin and circles (●) represent fish that strayed.

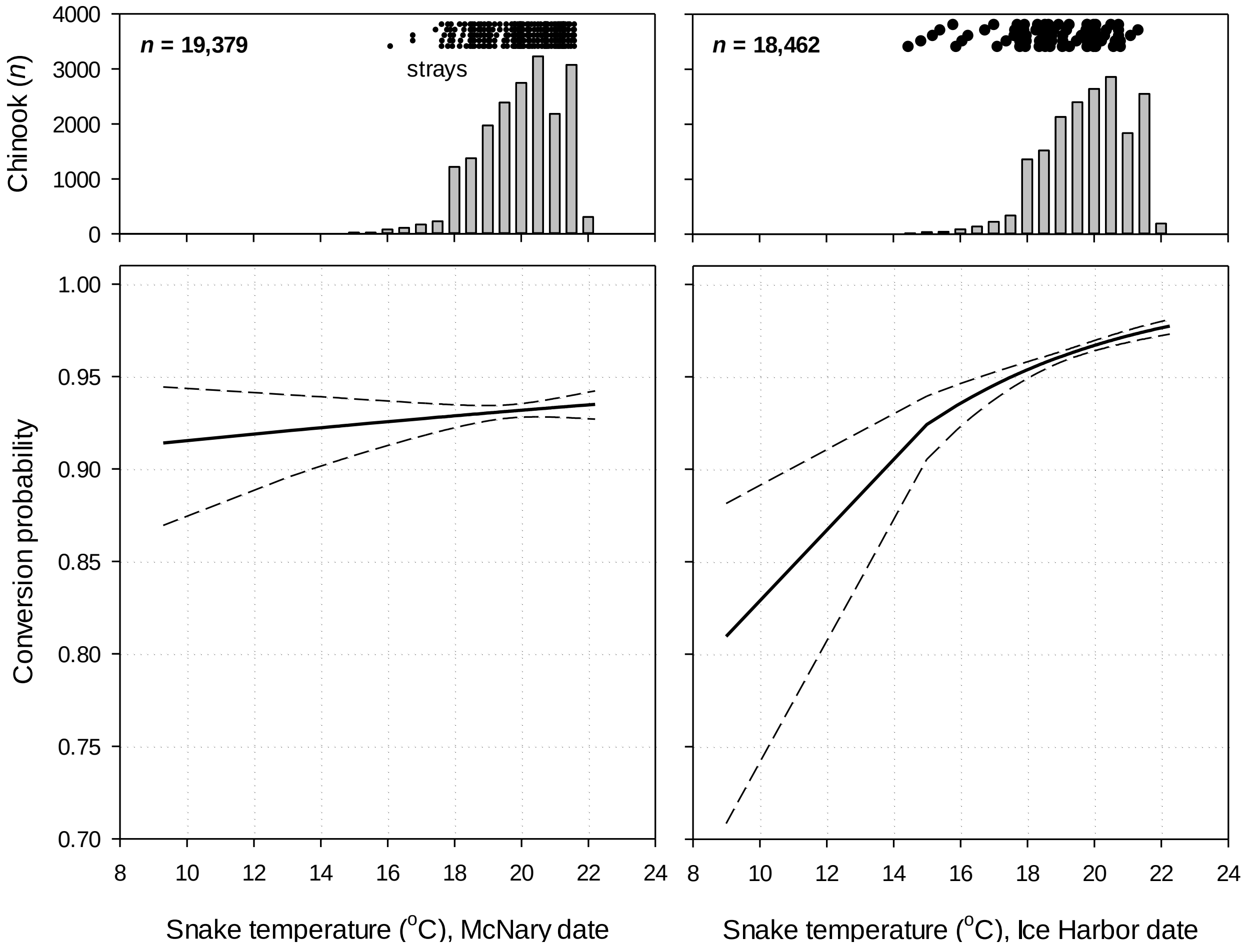

Figure 13. Estimated probability (±95% CI) that **hatchery fall Chinook salmon** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of salmon in each 0.5 °C temperature bin and circles (●) represent fish that strayed.

Table 10. Numbers of PIT-tagged **wild fall Chinook salmon** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
n **that did not pass LGr**		1			1	4	2	6		3	2	5
Adult fishways along route												
McNary						4	1	1				1
Ice Harbor	1				1		1	3		3		2
Strays												
Walla Walla								1				1
Yakima											1	1
Tucannon								1				
Methow												
Upper Columbia dams											1	
Adult fishway (%)	***100***	***100***			***100***	***100***	***100***	***67***		***100***		***60***
Juvenile bypass (%)												
Strays (%)								***33***			***100***	***40***

Table 11. Numbers of PIT-tagged **hatchery fall Chinook salmon** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
***n* that did not pass LGr**	1	16	8	7	4	49	31	230	112	165	258	441
Adult fishways along route												
Bonneville								2				
McNary		8		3	2	20	9	56	41	57	105	156
Ice Harbor		7	8	4	2	19	13	60	56	86	84	173
Juvenile bypass systems												
John Day								4		1	4	
McNary		1				1	3	8		2	2	9
Lower Monumental							1	5		3	4	4
Little Goose								1	2	1	2	3
Strays												
Deschutes												1
John Day								2				
Umatilla								3		1	4	
Walla Walla								3	1	2		4
Yakima						1		33	6	4	27	14
Lyons Ferry						2	3	14				
Tucannon						4		10	1	3	10	
Wenatchee								4		2	2	4
Entiat											2	
Methow								1				7
Okanogan												2
Upper Columbia dams						2	2	24	5	3	12	64
Adult fishway (%)		**94**	**100**	**100**	**100**	**80**	**71**	**51**	**87**	**87**	**73**	**75**
Juvenile bypass (%)		**6**				**2**	**13**	**8**	**2**	**4**	**5**	**4**
Strays (%)						**18**	**16**	**41**	**12**	**9**	**22**	**22**

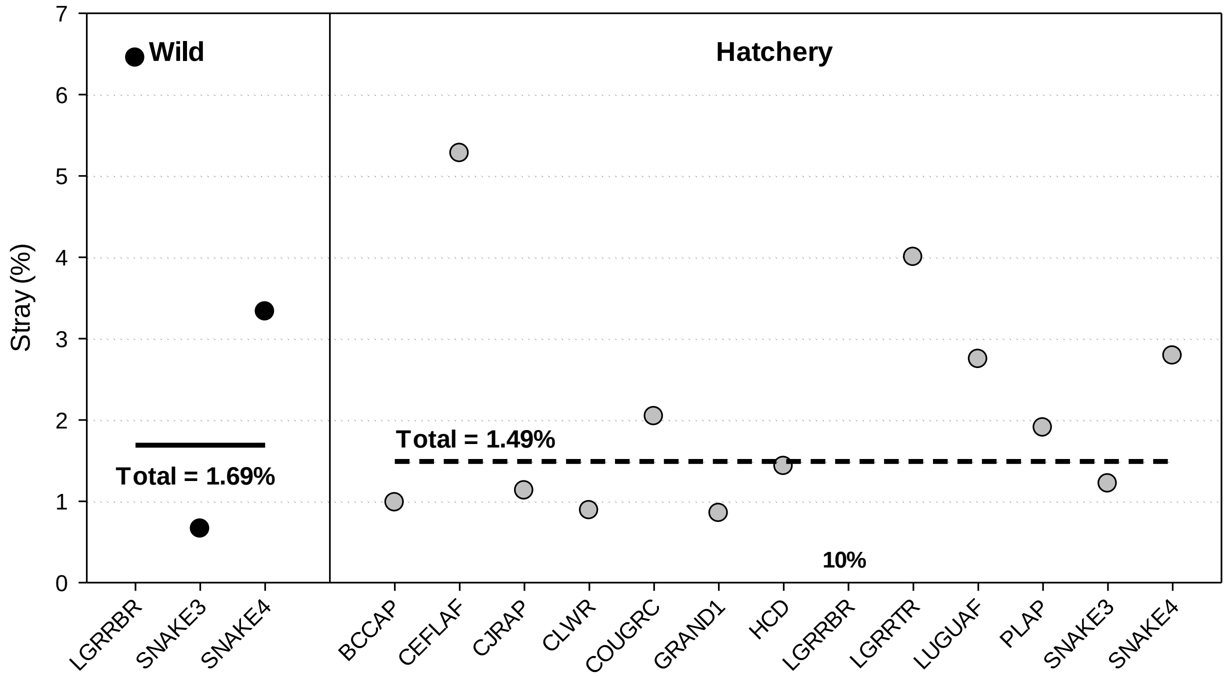

Figure 14. Donor population stray rates estimated for all wild and hatchery **fall Chinook salmon** (horizontal lines) and for all release groups that produced strays. Denominator sample sizes are the totals in Tables 8 and 9. Straying was calculated as: the number identified as strays by PIT detections divided by the total detected at McNary or Ice Harbor dams. Does not include strays that did not reach McNary Dam or strays that entered unmonitored tributaries (i.e., all estimates are minimums).

Steelhead: sample summary

In the 2002-2012 queries, 8,586 wild (Table 12) and 16,963 hatchery (Table 13) steelhead were identified as Snake River fish. The most abundant wild-origin samples were collected at Lower Granite Dam and were assigned to either barge (*n* = 2,463) or in-river (719) treatments. Other wild groups with at least 200 fish across years included: Imnaha trap (719) and Fish Creek trap (262).

The most abundant hatchery samples were also associated with smolt collections at Lower Granite Dam (Table 13). Groups with > 600 fish across years included: Lower Granite barge (4,029), Lower Granite in-river (1,502), Wallowa Hatchery (*n* = 1,023), Little Salmon River (1,006), Little Sheep Facility (861), Dworshak National Fish Hatchery main stem releases (763), Pahsimeroi trap (757), and Salmon River (Middle Fork to Pahsimeroi, 609). Five release groups had 500-600 fish: Big Canyon Facility, South Fork Clearwater River, Sawtooth trap, Big Sheep Creek, and Snake River (Salmon River to Hells Canyon Dam).

Steelhead: conversion estimates

Wild fish, total estimates, all tag groups: Point estimates for the 8,586 wild steelhead were 0.935 (MCN-ICH), 0.958 (ICH-LGR), and 0.896 (MCN-LGR).

Hatchery fish, total estimates, all tag groups: Point estimates for the 16,963 hatchery steelhead were 0.939 (MCN-ICH), 0.951 (ICH-LGR), and 0.892 (MCN-LGR).

Wild fish, annual estimates, all tag groups: Few fish were detected at sites upstream from Lower Granite Dam in the earlier study years, limiting opportunity for CJS estimates. Combined CJS and/or point estimates for the MCN-ICH reach ranged from 0.879 in 2007 to 0.991 in 2004 (Figure 15). Point estimates for the ICH-LGR reach ranged from 0.923 in 2011 to 0.973 in 2004. In the combined MCN-LGR reach, point estimates ranged from 0.877 in 2010 to 0.964 in 2004.

Hatchery fish, annual estimates, all tag groups: Point and/or CJS estimates for the MCN-ICH reach ranged from 0.870 in 2007 to 1.000 in 2004 (Figure 15). Estimates for the ICH-LGR reach ranged from 0.940 in 2011 to 0.989 in 2066. In the combined MCN-LGR reach, estimates ranged from 0.828 in 2007 to 0.980 in 2004.

Wild vs hatchery comparisons, annual estimates, all tag groups: In the MCN-ICH reach, annual conversion rate estimates were higher for wild fish than for hatchery fish in 3 of 11 years (*mean difference* = +0.010) and higher for hatchery fish in the other 8 years (*mean* = -0.020). Patterns were mixed in the ICH-LGR reach, with higher estimates for wild fish in 5 of 10 years (*mean* = +0.010) but higher for hatchery fish in 5 of 10 years (*mean* = -0.011). Results were similarly mixed in the combined MCN-LGR reach (Figure 15).

Wild fish, annual estimates, individual release sites: Annual point estimates for the combined MCN-LGR reach for the 6 largest wild groups are shown in Figure 16. The lowest total estimates were for the small sample from Asotin Creek (ASOTIC, *total* = 0.837, *n* = 141) and the

Lower Granite barged group (LGRRBR, *total* = 0.843) samples. The highest total estimates were for the Lower Granite in-river group (LGRRRR, 0.944) and the Imnaha Trap group (IMNTRP, 0.924) samples (Figure 16).

Hatchery fish, annual estimates, individual release sites: Annual point estimates for the combined MCN-LGR reach for the 8 largest hatchery groups are shown in Figure 17. The lowest total estimates were for Lower Granite barged group (LGRRBR, *total* = 0.806) and the Little Sheep Facility (LSHEEF, *total* = 0.883). The highest total estimates were for the Lower Granite in-river group (LGRRRR, 0.956) and the Salmon River main stem (SALR3, 0.923) (Figure 17).

Steelhead: environmental covariates

Wild fish: The probability of passing Lower Granite Dam increased as water temperatures increased, largely reflecting low conversion for late fall and overwintering groups (Figure 18). Both terms were statistically significant in the logistic regression model that used temperature + temperature^2 on the detection date at McNary Dam (Wald χ^2 = 159.4, P < 0.001, n = 8,315). The model using temperature on the date of Ice Harbor detection showed a similar relationship (Wald χ^2 = 141.8, P < 0.001, n = 6,702). The model using McNary detection date rather than water temperature indicated that late fall and early spring migrants were far less likely to pass Lower Granite Dam (Figure 19, Wald χ^2 = 160.0, P < 0.001, n = 8,315).

Hatchery fish: The probability of passing Lower Granite Dam increased as water temperatures increased, also reflecting lower conversion by early (i.e. post-overwintering spring) and late fall migrants (Figure 20). Both terms were statistically significant in the logistic regression model that used temperature + temperature^2 on the detection date at McNary Dam (Wald χ^2 = 432.8, P < 0.001, n = 16,703). The model using temperature on the date of Ice Harbor detection showed a similar relationship (Wald χ^2 = 471.2, P < 0.001, n = 15,510). The model using McNary detection date rather than water temperature indicated that late fall and early spring migrants were far less likely to pass Lower Granite Dam (Figure 21, Wald χ^2 = 421.8, P < 0.001, n = 16,703).

Steelhead: Final detections

Wild fish: A total of 892 wild steelhead did not pass Lower Granite Dam (Table 14). Most (n = 671, 75%) were last detected at one of the adult fishways at Ice Harbor or McNary dams. Fifty-eight (7%) fish were last detected at juvenile bypasses; detection timing of these fish suggested a mix of pre- and post-spawn (i.e., kelts) individuals. A total of 138 (15%) steelhead were considered strays. These fish were detected at a variety of sites, including tributaries downstream from McNary Dam (n = 74 of 135 strays, 55%), Columbia River tributaries and dams upstream from McNary Dam (n = 45, 33%), and the Tucannon River (n =16, 12%).

Hatchery fish: A total of 1,829 hatchery steelhead did not pass Lower Granite Dam (Table 15). The majority (n = 1,438, 79%) was last detected at one of the adult fishways with the largest numbers at McNary (*n* = 725, 40%) and Ice Harbor (*n* = 686, 38%) dams. Ninety-five (5%) fish were last detected at juvenile bypasses, and 276 (15%) were considered strays. Individual fish were reported as mortalities or were detected in the estuary.

Final detection sites for the stray group were at upper Columbia River dams (*n* = 97 of 276, 35%), in tributaries upstream from McNary Dam (124, 45%), in tributaries downstream from McNary Dam (119, 43%; mostly in the John Day River), and in the Tucannon River (25, 9%) (Table 15).

Steelhead: Donor population straying estimates

Wild fish: At a minimum, 138 of 8,586 (1.61%) wild fish were considered strays to sites downstream from Lower Granite Dam (Figure 22). Sixteen release groups produced strays and six of these had denominator sample sizes > 100 fish: Snake River trap (SNKTRP, 3/131, 2.29%), Asotin Creek (ASOTOC, 7/141 = 4.96%), Fish Creek trap (FISTRP, 1/388, 0.26%), the Imnaha River trap (IMNTRP, 7/649, 1.08%), the Lower Granite in-river group (LGRRRR, 12/2,477, 0.48%), and the Lower Granite barged group (LGRRBR, 96/3/446, 2.79%).

Hatchery fish: In total, 276 of 16,963 (1.63%) hatchery fish were considered strays (Figure 22). Twenty-nine release groups produced strays, and seven of these had denominator sample sizes > 750 fish: Pahsimeroi trap (PAHTRP, 10/757, 1.32%), Dworshak Hatchery main stem releases (DWORMS, 1/763, 0.13%), Little Sheep facility (LSHEEF, 16/861, 1.86%), Little Salmon River (LSALR, 19/1,006, 1.89%), Wallowa Hatchery (WALH, 8/1,023, 0.78%), Lower Granite in-river group (LGRRRR, 9/1,502, 0.60%), and Lower Granite barged group (LGRRBR, 122/4,029, 3.03%).

Table 12. Numbers of PIT-tagged **wild steelhead** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite).

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
ASOTIC						10	18	24	22	32	35	n/a
BIG2C				1	2			37	14	18	12	n/a
BIGBEC					3	18	6	15	13	26	28	n/a
CAMASC	1			1	3	2	4	2	1			n/a
CATHEC	1	2	5	2	3	3	4	7	9	15	10	n/a
CFCTRP	2	1	7	3	2		5	5	29	23	17	n/a
CHAMBC	10	5	5	3	1	4	9	6				n/a
CLEARC	2			1		1	1	8	1			n/a
CLWTRP			1	4	4	8	4	16	14	7	8	n/a
FISHC	1	1	1	2		2		4				n/a
FISTRP	58	15	10	16	9	18	40	60	90	40	32	n/a
GEDNEC	3	3	4		3			2				n/a
GRAND2		2	1	2	1	2	5	8	8	5	4	n/a
GRNTRP		1	5		1	9	5	10	18	17	13	n/a
HAYDNC							1	10	7	8	8	n/a
IMNTRP	18	31	35	27	12	30	91	126	98	119	62	n/a
JOHTRP	6	3	2	1	3	2	3	4	8	2	4	n/a
KNOXB								4	9	11	5	n/a
LEMHIR							2	14	8	25	11	n/a
LEMHIW				1		2	1	11	7	6		n/a
LGRRBR	212	271	104	83	60	253	441	770	685	344	223	n/a
LGRRRR	890	326	329	129	15	69	63	148	196	171	141	n/a
LOOKGC		5	5	10	4	5	3	8	8	4	3	n/a
LOSTIR	5	6	6	7	2	5	3	8	11	20	15	n/a
LSALR							8	9				n/a
MINAMR	1	2		5	2	3	6	9	10	11	8	n/a
PAHTRP						1		3	7	3	1	n/a
POTREF									2	6	7	n/a
RPDTRP						3		6	5	4	4	n/a
SALTRP	1	1		1			5	7	2	3	1	n/a
SECESR	2	2	2		1		1	3	4			n/a
SECTRP						1	2	2	5	8	3	n/a
SFSTRP			2	2	1		3	6	2			n/a
SNKTRP	11	13	13	4		2	8	27	19	24	10	n/a
Other[1]	49	13	14	7	8	5	9	12	8	31	18	n/a
Total	**1273**	**704**	**551**	**313**	**140**	**457**	**752**	**1392**	**1331**	**987**	**686**	**N/A**

[1] Other includes sites with < 10 fish across years: AMERR, ASOTNF, ASOTSF, BARGAC, BEARVC, BOULDC, BRUSHC, CABINC, CEDA2C, CHAMWF, CHARLC, CORRAC, CROTRP, GEDCWF, GRANDR, HORSEC, IMNAHR, JOHNSC, LAKEC, LAPC, LBCWF, LBEARC, LGRTAL, LICKC, LOCHSA, LOLOC, LOONC, LSFTRP, MARTRP, MOOS2C, MOOS2N, NEWSOC, OHARAC, PANTHC, PINE2C, POTR, RAPIDR, RAPR, REDTRP, SALMF2, SALRMF, SALRSF, SAWTRP, SELWYR, SQUAWC, STORMC, SULFUC, WBIRDC, WHITSC, WIMPYC, YANKFK, YANKWF, YELLJC

Table 13. Numbers of PIT-tagged **hatchery steelhead** detected at McNary, Ice Harbor, and/or Lower Granite Dam fishways in 2002-2013, by juvenile release site (relsite). Note: 2013 data pending.

Relsite	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
BCANF	4	5	4			6	5	169	146	138	100	n/a
BSHEEC			1			5	4	265	116	106	16	n/a
CLEARC	13		2					2	36	65	1	n/a
CLWRSF	11		3	11	3	1	6	18	127	209	171	n/a
COTP	3							183	91	143	68	n/a
CROOKP	3	1	1		1	2	4	3				n/a
CROOKR					1		5	4	35	14	13	n/a
DWORMS	16	5	8	6	10	3	18	34	229	215	219	n/a
GRANDR	12	1										n/a
GRNTRP		20	11	11	4	35	33	143	56	44	31	n/a
HCD	1	2	8	2	1							n/a
IMNTRP	19	19	34	24	25	20	20	5				n/a
KOOS										10	49	n/a
LEMHIR		3	4	3	2	5	1					n/a
LGRRBR	19		1	1		641	1033	1636	518	108	72	n/a
LGRRRR	59	104	103	55	41	111	128	386	206	174	135	n/a
LGRTAL	11	3				2						n/a
LGSTAL						6	3	2	3	2		n/a
LOLOC				3		4	4	3	19	9	3	n/a
LSALR		1	3	7	5	6	13	302	266	263	140	n/a
LSHEEF	1	4	3	2	2	3	3	294	216	211	122	n/a
MEAD2C						5	16	7	14	1		n/a
MILL2C				2	3	5	8		1			n/a
PAHSIW						8	4			2	4	n/a
PAHTRP		3	7	1				35	200	321	190	n/a
REDP	1	1			14	18	70	2	5	29	36	n/a
REDR	1		1	4				1	39	9		n/a
SALEFT								18	15	1	42	n/a
SALR		19	7									n/a
SALR3			5	3	2	11	7	285	116	113	67	n/a
SALR4			2	1	3	5	5	1	34	59	25	n/a
SALREF						1		26	55	97	30	n/a
SALTRP	5	5	2	3	3	9	16	47	18	16	5	n/a
SAWT	3	4	1	1	1	6	2	1	38	151	221	n/a
SAWTRP				1				445	90	22	1	n/a
SLAT2C							4	26	25	9		n/a
SNAKE2						6	6					n/a
SNAKE4						4	5	14	128	245	104	n/a
SNKTRP	9	24	15	10	3	22	14	77	37	31	22	n/a
SQUAWC		1	1	1				17	78	84	11	n/a
SQUAWP	1		2	4	1	2	3	1	4			n/a
VALEYC			3	2		4	5	37	25	6		n/a
WALH	5	4	4	1	56	86	73	330	184	173	107	n/a
YANKFK	1		5	6		1	4	108	45	52	59	n/a
Other[1]	18	7	8	6	1				4	2		n/a
Total	**216**	**236**	**249**	**171**	**182**	**1043**	**1522**	**4927**	**3219**	**3134**	**2064**	**N/A**

[1] Other includes sites with < 10 fish across years: AMERR, LGRBYP, LGSBPS, LGSBYP, LGSGAT, LMNBYP, NEWSOC, REDRSF, SALR1, SALRNF, SLATEC

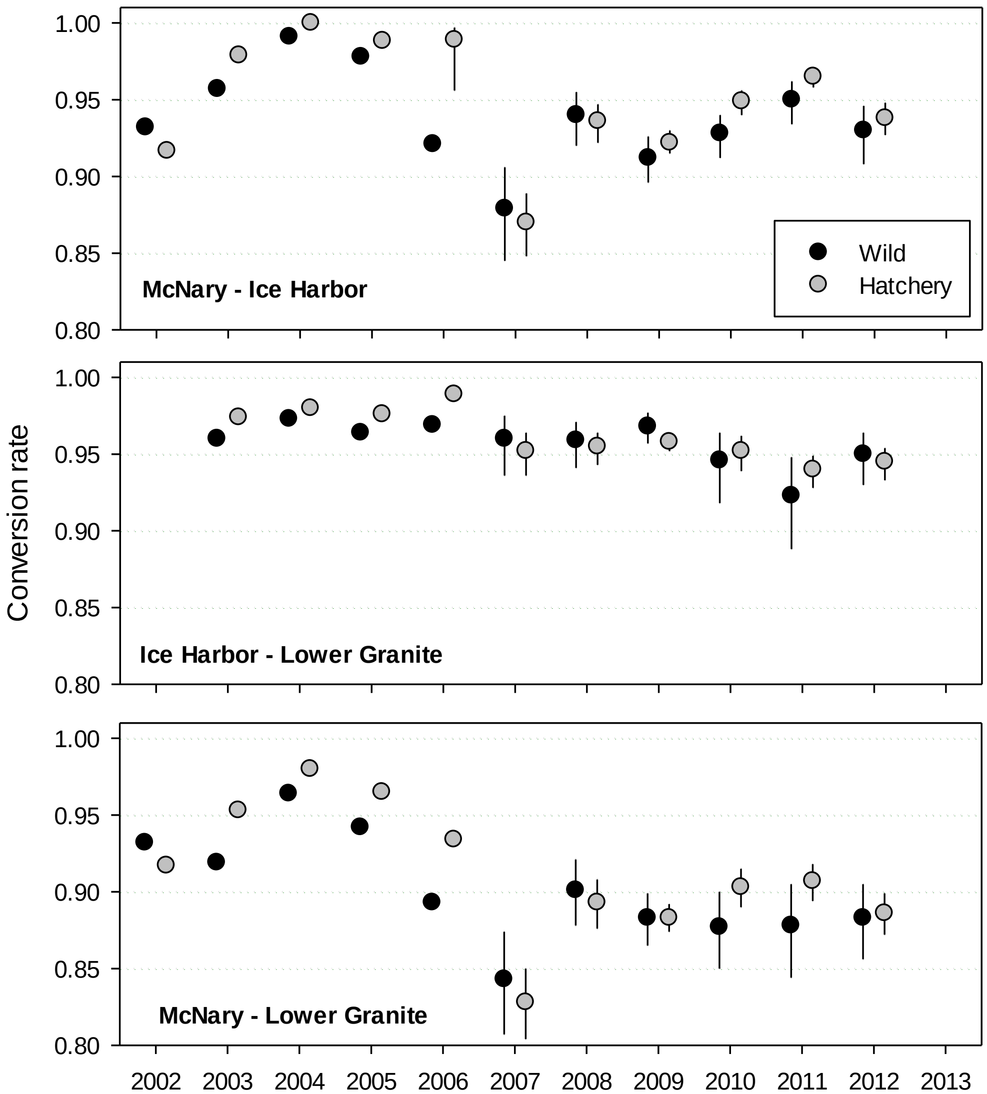

Figure 15. Reach-specific conversion rate estimates for **steelhead** with 95% profile likelihood confidence intervals. Estimates were not adjusted for harvest or straying. Sample sizes are the totals in Tables 12 and 13. Symbols without error bars are point estimates rather than CMJ estimates because few or zero fish were recaptured upstream from Lower Granite Dam.

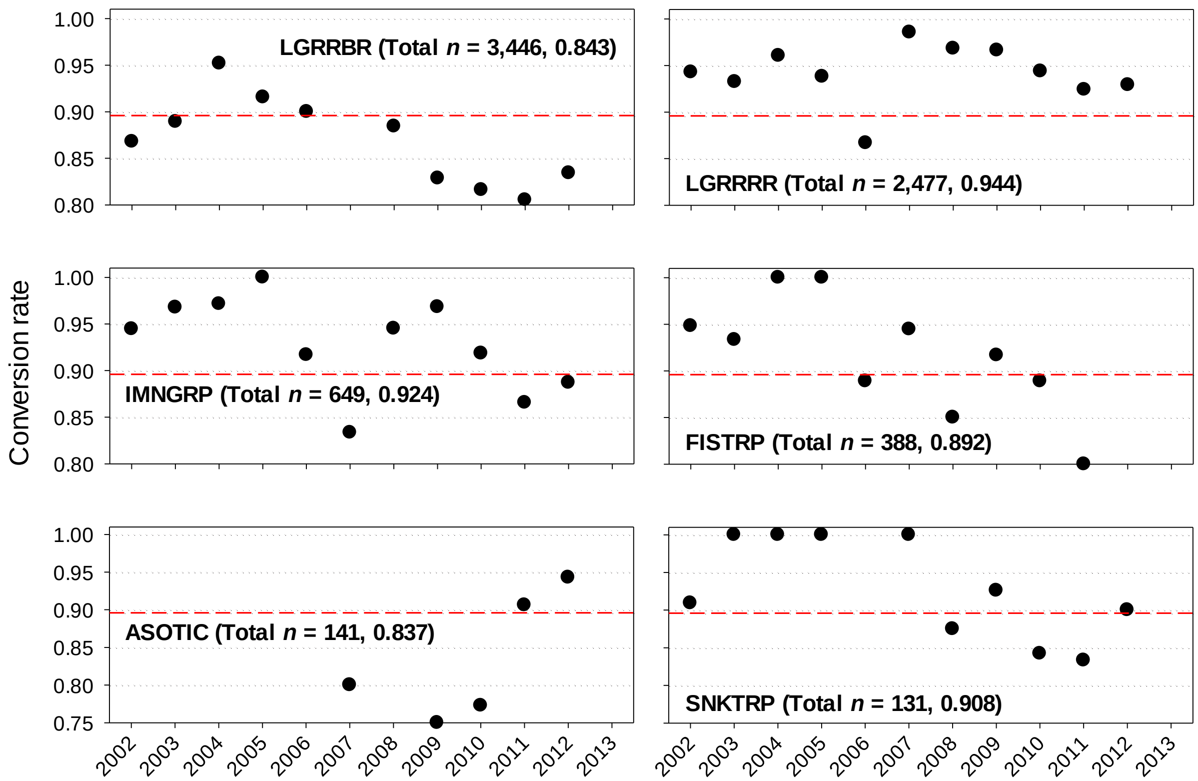

Figure 16. McNary-Lower Granite conversion rate point estimates for **wild steelhead** from the six release sites with the highest numbers of fish. Estimates were not adjusted for harvest or straying. Annual sample sizes are in Table 12; parentheses show the total sample size and conversion estimate for each release site. Red dashed line shows the estimate for all hatchery fish in all years (0.896).

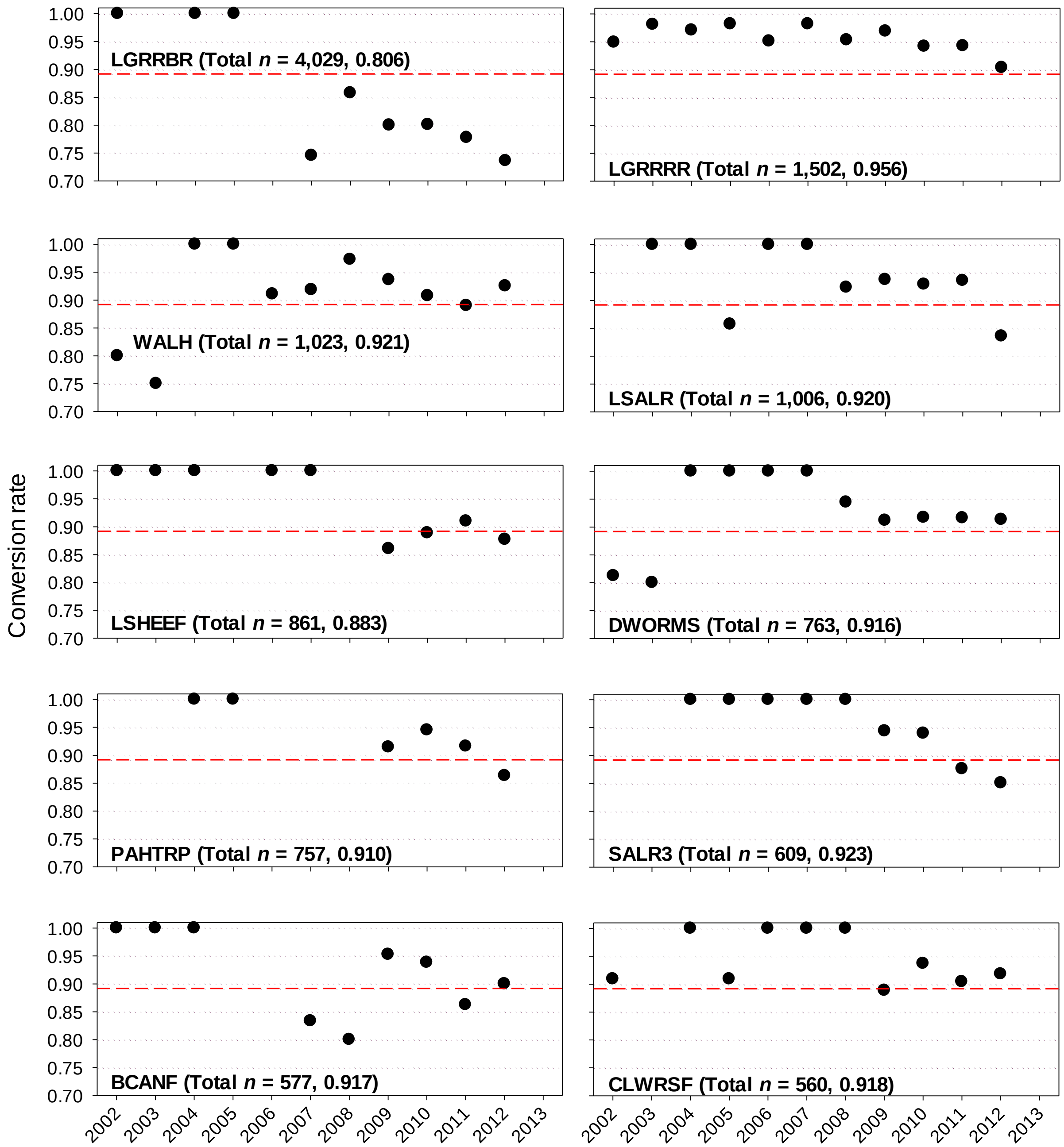

Figure 17. McNary-Lower Granite conversion rate point estimates for **hatchery steelhead** from the eight release sites with the highest numbers of fish. Estimates were not adjusted for harvest or straying. Annual sample sizes are in Table 13; parentheses show the total sample size and conversion estimate for each release site. Red dashed line shows the estimate for all hatchery fish in all years (0.892).

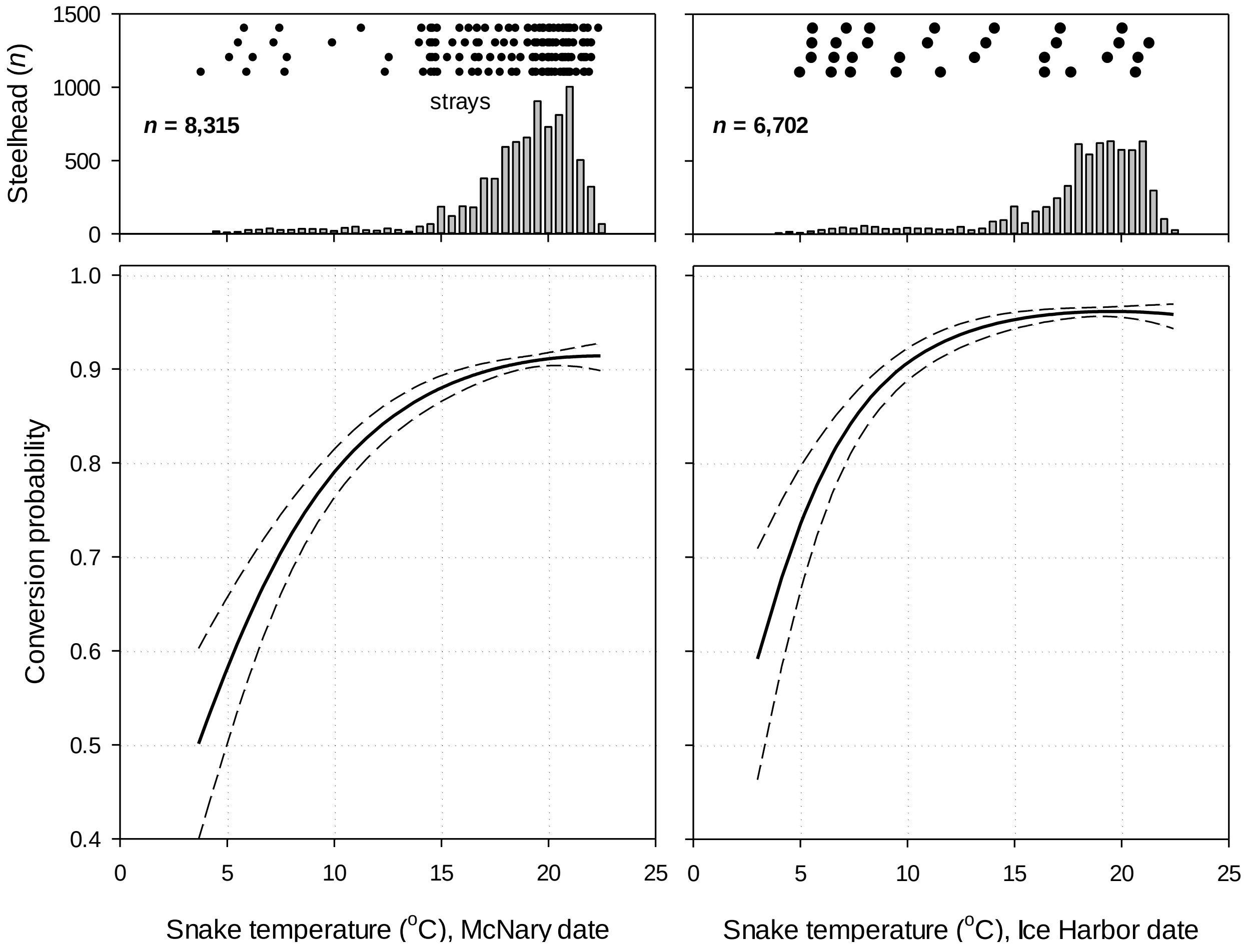

Figure 18. Estimated probability (±95% CI) that **wild steelhead** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of steelhead in each 0.5 °C temperature bin and circles (●) represent fish that strayed. Note quadratic model.

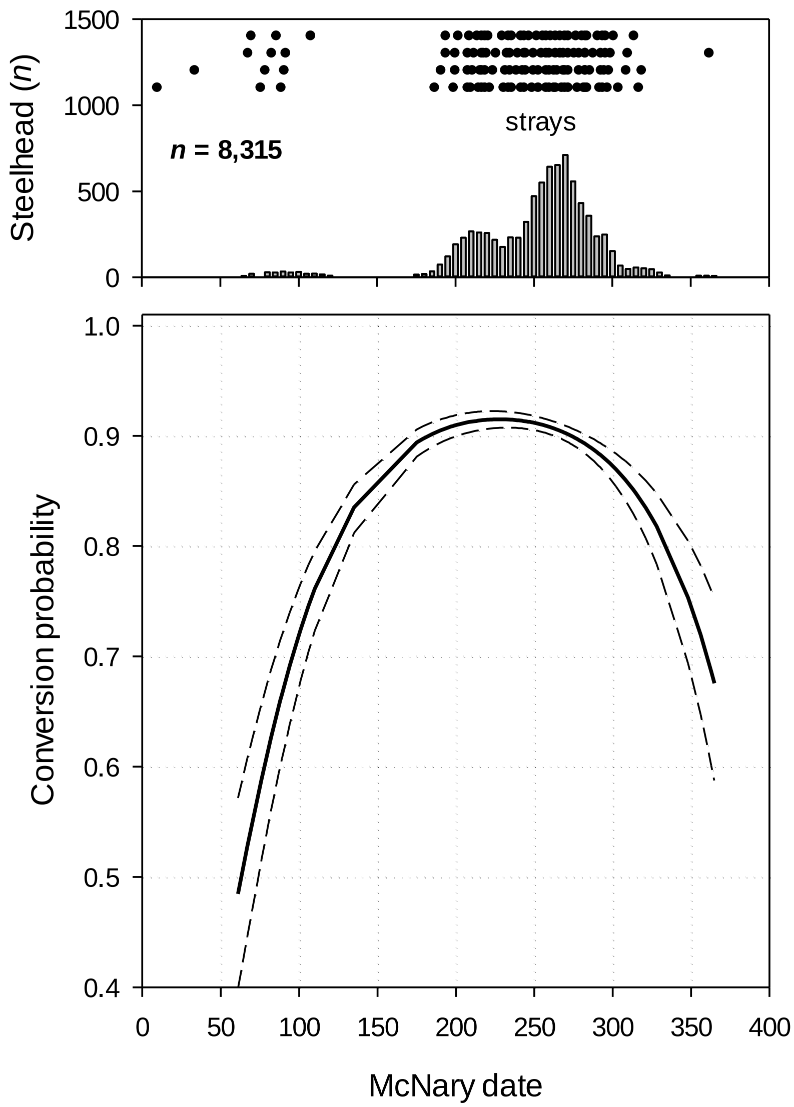

Figure 19. Estimated probability (±95% CI) that **wild steelhead** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variable was the date that each fish passed McNary Dam. Histogram shows the number of steelhead in each bin and circles (●) represent fish that strayed. Note quadratic model.

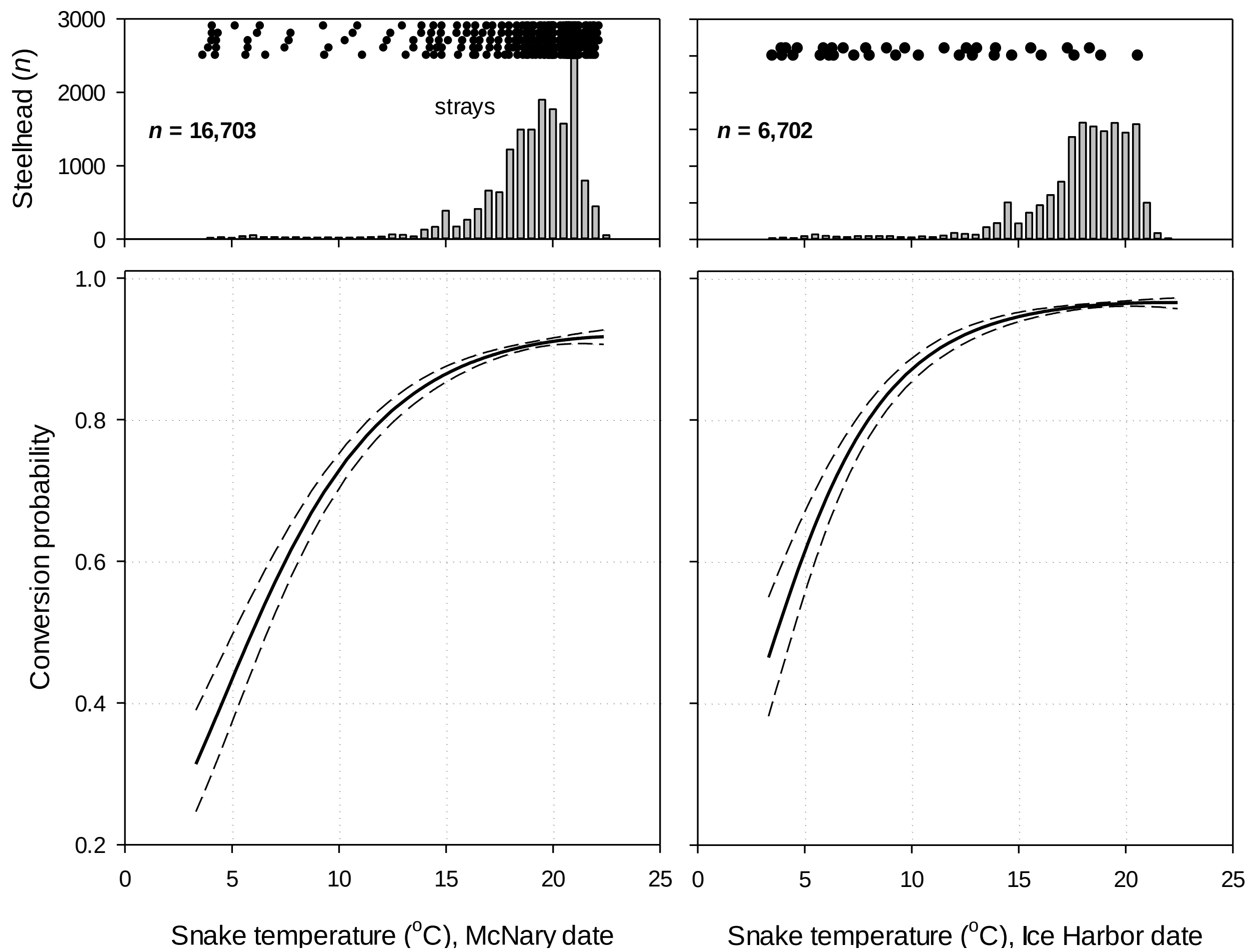

Figure 20. Estimated probability (±95% CI) that **hatchery steelhead** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variables were Snake River water temperatures on the date that each fish passed McNary Dam (left) or Ice Harbor Dam (right). Histograms show the number of steelhead in each 0.5 °C temperature bin and circles (●) represent fish that strayed. Note quadratic model.

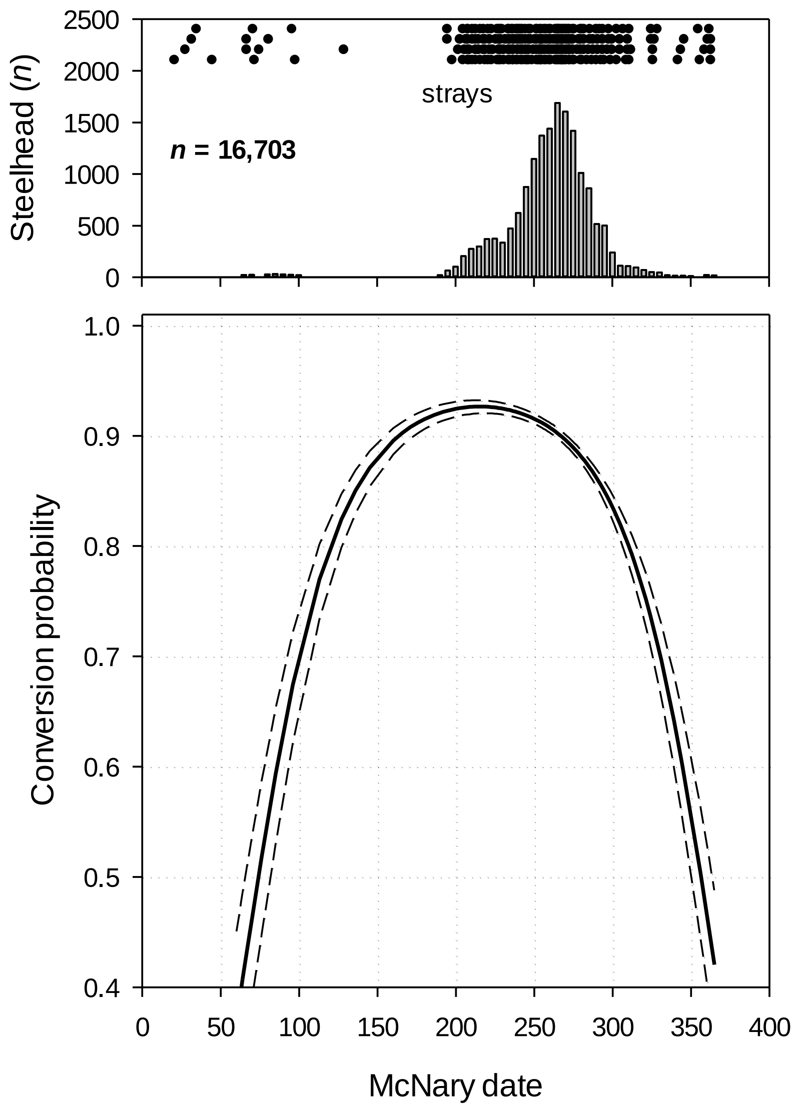

Figure 21. Estimated probability (±95% CI) that **hatchery steelhead** would pass Lower Granite Dam, estimated using logistic regression with all study years combined. Predictor variable was the date that each fish passed McNary Dam. Histograms show the number of salmon in each bin and circles (●) represent fish that strayed. Note quadratic model.

Table 14. Numbers of PIT-tagged **wild steelhead** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
***n* that did not pass LGr**	86	57	20	18	15	71	74	161	174	136	80	
Adult fishways along route												
Bonneville	3		1			4	2	6	4	1	1	n/a
McNary	79	26	1	5	7	28	34	71	68	46	29	n/a
Ice Harbor		24	15	11	3	14	24	25	65	74	22	n/a
Juvenile bypass systems												
Bonneville						4		3	1		2	n/a
John Day					1		2	2	2	1		n/a
McNary	1	6	2	1	3	1		3	3	2	3	n/a
Lower Monumental							1	4		2		n/a
Little Goose						1	1	2	2	1	1	n/a
Strays												
Hood										1		
Fifteenmile							1	2			1	
Deschutes						2			1	3	1	n/a
Rock								3	4		1	
John Day						10	5	27	8		2	n/a
Umatilla								1			1	
Walla Walla						1		1	1	1	3	
Yakima							1	1		1		n/a
Tucannon				*1*	*1*	*1*	*1*	*1*	*4*	*1*	*6*	n/a
Wenatchee						1	1					n/a
Entiat												n/a
Methow												n/a
Okanogan										1	1	
Upper Columbia dams	3	1	1			4	1	8	10	1	5	n/a
Mortality												
Badger Island									1			
L Miller Island											1	
Estuary												
TWX								1				n/a
Adult fishway (%)	***95***	***88***	***85***	***89***	***67***	***65***	***81***	***63***	***79***	***89***	***65***	
Juvenile bypass (%)	***1***	***11***	***10***	***6***	***27***	***8***	***5***	***9***	***5***	***4***	***8***	
Strays (%)	***3***	***2***	***5***	***6***	***7***	***27***	***14***	***27***	***16***	***7***	***26***	
Mortality (%)									***<1***		***1***	
Estuary (%)								***<1***				

Table 15. Numbers of PIT-tagged **hatchery steelhead** detected at McNary or Ice Harbor Dam fishways in 2002-2013 that did not pass Lower Granite Dam (LGr), with final detection locations.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
***n* that did not pass LGr**	18	11	5	6	12	178	162	571	328	304	234	
Adult fishways along route												
Bonneville						7	1	13	4		2	n/a
The Dalles											2	n/a
McNary	16	4		1	2	92	79	232	129	82	88	n/a
Ice Harbor		6	5	5	10	33	56	159	136	188	100	n/a
Juvenile bypass systems												
Bonneville						6	2	12	1	1		n/a
John Day						1	1	6	4		1	n/a
McNary	1					6	4	26	3	3	1	n/a
Lower Monumental						2	1		2	2	1	n/a
Little Goose								4	6	1		n/a
Strays												
Hood						1	2					n/a
Klickitat											1	n/a
Fifteenmile								3	4	1		n/a
Deschutes								3				n/a
Rock								3	1	2		n/a
John Day						21	7	58	10	1	5	n/a
Umatilla						1	1				1	n/a
Walla Walla							2	5	2		1	n/a
Yakima								2			6	n/a
Tucannon						1		9	10	2	3	n/a
Methow							1	2	1		3	n/a
Okanogan									1		1	n/a
Upper Columbia dams	1	1				7	5	32	14	21	18	n/a
Mortality												
Badger Island								1				n/a
Estuary												
TWX								1				n/a
Adult fishway (%)	***89***	***91***	***100***	***100***	***100***	***74***	***84***	***71***	***82***	***89***	***82***	***n/a***
Juvenile bypass (%)	***6***					***8***	***5***	***8***	***5***	***2***	***1***	***n/a***
Strays (%)	***6***	***9***				***17***	***11***	***20***	***13***	***9***	***17***	***n/a***
Mortality (%)								***<1***				***n/a***
Estuary (%)								***<1***				***n/a***

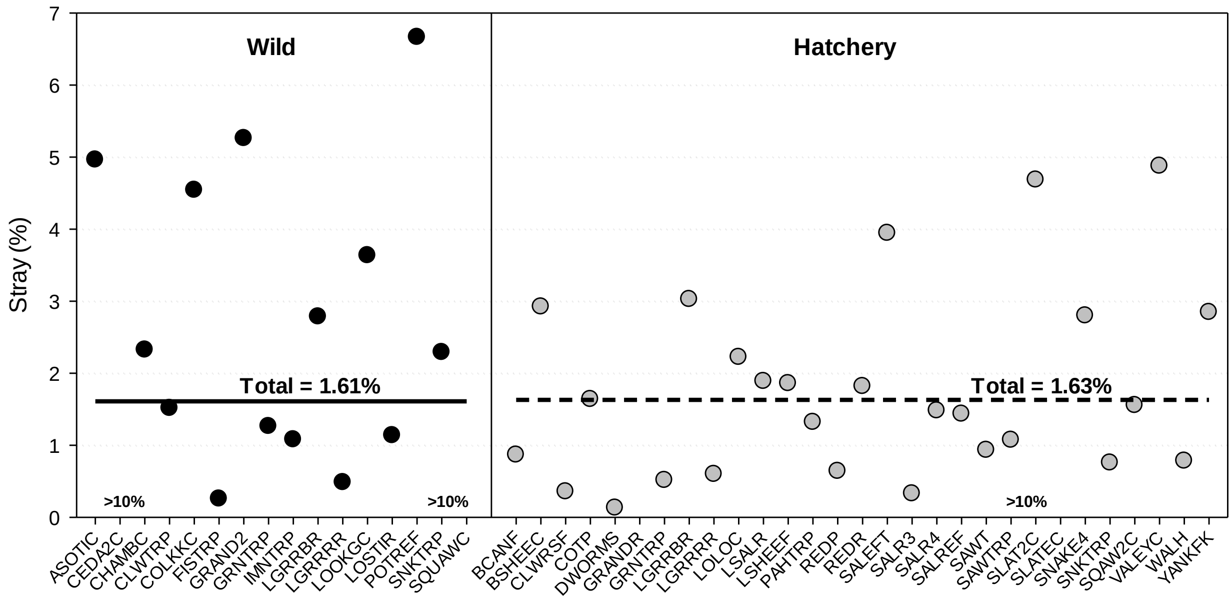

Figure 22. Donor population stray rates estimated for all wild and hatchery **steelhead** (horizontal lines) and for all release groups that produced strays. Denominator sample sizes are the totals in Tables 12 and 13. Straying was calculated as: the number identified as strays by PIT detections divided by the total detected at McNary or Ice Harbor dams. Does not include strays that did not reach McNary Dam or strays that entered unmonitored tributaries (i.e., all estimates are minimums).

Discussion

Cautions and caveats

The reach conversion estimates reported here were derived from a diverse but clearly non-random sampling of Snake River salmon and steelhead populations. Juveniles were PIT-tagged by many organizations for a variety of reasons – but very few were specifically or consistently tagged to evaluate upstream conversion rates (the Comparative Survival Study is a partial exception). Some of the tagged groups were almost certainly less suitable than others for estimating upstream conversion, but we did not censor any group because objectives for the juvenile tagging projects were not investigated. All PIT-tagged fish that originated upstream from Lower Granite Dam were included in the summaries in an effort to be as broadly representative of the Snake River DPS's as possible. The estimates therefore also combined all upstream-migrant age classes (e.g., jack and adult Chinook salmon, 1-sea 'A-group' and 2-sea 'B-group' steelhead, etc.). Perhaps most importantly, the PIT-tagged samples were skewed towards hatchery populations in almost all years and DPS's. As juveniles, wild Snake River populations were generally under-sampled, sampled infrequently or inconsistently across years, or were not sampled at all.

One of the primary challenges for interpreting the results was the evolution of the PIT monitoring infrastructure from 2002-2013. In the earliest years, PIT interrogation antennas were located primarily at main stem dams, with limited additional detection capability in tributaries or at hatchery and trapping facilities. By 2013, nearly 300 interrogation sites were listed on the PTAGIS website, including instream arrays and antennas at management-related facilities throughout the Columbia River basin.

Consequently, the PIT migration histories became more detailed over time and the ability to assign 'fates' for individual fish to sites outside of the main stem Columbia and Snake rivers substantively changed. As with the ever-changing PIT-tagged sample composition, the improved spatial resolution of the monitoring array makes year-to-year comparisons challenging. In particular, more fish were identified as strays in recent study years as a result of the increased tributary monitoring. Data from these recent years are probably the most appropriate for developing conversion rate 'adjustments' related to straying behavior (see additional comments on straying below).

The ability to detect PIT tags at sites upstream from Lower Granite Dam was a methodological constraint that also affected conversion estimates and confidence intervals. Some populations, particularly fall Chinook salmon and wild spring–summer Chinook salmon and steelhead, were unlikely to be detected upstream from Lower Granite Dam, especially in early study years. In several cases, the lack of detections meant that detection efficiency at Lower Granite Dam could not be calculated and we had to rely on point estimates of conversion rates rather than CJS estimates. In these cases, the point estimates will underestimate the true conversion rate because some fish may have passed undetected (i.e., these would have been treated as unsuccessful). Given the generally high detection efficiency at the Lower Granite array (generally >99%), we think it was unlikely that conversions were substantively underestimated. Nonetheless, such constraints should be considered when evaluating or comparing reach conversion estimates among years and populations.

Objective 1: Annual conversion rate estimates

The upstream migration histories for slightly fewer than 80,000 PIT-tagged fish were used to estimate reach conversion rates that were unadjusted for harvest or straying. The sockeye and fall Chinook salmon groups were almost entirely (≥98%) hatchery-origin fish, as were ~77% of spring–summer Chinook salmon and ~66% of steelhead. Many populations were used to make the annual estimates for each DPS (except sockeye salmon), and the composition of annual samples varied greatly from year to year. Several groups had much greater relative influence on the estimates given their abundance. These included some production hatchery populations and the mixed-stock groups collected and PIT-tagged at Lower Granite Dam.

The large samples allowed us to precisely estimate conversion rates through the three study reaches in most year×DPS combinations. Most 95% confidence intervals were within ±3%. The exceptions were wild fall Chinook salmon (total n = 355) and hatchery sockeye salmon, for which there were modest sample sizes in recent years only (total n = 627). The wild sockeye salmon sample (total n = 7) was anecdotal only.

Average annual conversion estimates for the MCN-ICH reach were in a narrow range between 0.976 and 0.986 for sockeye, spring–summer Chinook, and fall Chinook salmon (see Table A in Executive Summary). Steelhead conversion through this reach averaged slightly lower at 0.938 for wild fish and 0.950 for hatchery fish. The annual means through ICH-LGR were also in a narrow range for all species: the lowest mean was for hatchery sockeye salmon (0.948) and the highest was for wild spring–summer Chinook salmon (0.967). Average annual estimates for the ICH-LGR reach were lower than in the MCN-ICH reach for hatchery sockeye salmon and all Chinook salmon groups. In contrast, estimates for steelhead were higher through the ICH-LGR reach than through the MCN-ICH reach. A variety of factors presumably contributed to the among-DSP differences.

Conversion from McNary Dam to Lower Granite Dam (MCN-LGR) is used as one of the adult performance standards in the BiOp (Table 16). To the best of our understanding, the BiOp used fixed rates of adult harvest and straying in the MCN-LGR reach to adjust the PIT-based MCN-LGR conversion/survival estimates, and BiOp estimates were calculated for two periods. In contrast, we report the raw conversion estimates, which require no assumptions regarding variation in space or time of harvest or stray rates, and provide minimum estimates of survival. Despite the methodological differences, the mean MCN-LGR estimates we report were quite similar to those in the 2014 BiOp for spring–summer Chinook salmon and fall Chinook salmon, in part because most harvest occurs downstream of McNary Dam. Our mean estimates for steelhead were higher than the 2008-2012 mean reported in the BiOp but lower than the mean reported for 2002-2007 (Table 16). Our annual mean estimate for sockeye salmon was higher than both the 2002-2007 and 2008-2012 BiOp means, but we note that several years in this summary had very small sockeye salmon sample size and conversion estimates near 1.000. We consider all estimates for the sockeye salmon DPS to be less reliable than those for the other species.

Table 16. Mean reach conversion (survival) estimates from McNary to Lower Granite Dam from this study and from Table 3.3-1 in the 2014 BiOp. Estimates in this study were based on the raw numbers, with no adjustment for harvest or straying. BiOp estimates include adjustments for harvest and straying and may have used subsets of the PIT data. (The methods used for the BiOp analyses were not well documented, with multiple references to additional source materials, and are thus difficult to interpret.)

	MCN-LGR Conversion (Survival) Estimates		
	2002-2013 mean Unadjusted (this study)	2008 BiOp Standard (2002-2007 data)	2008-2012 BiOp Average
Sockeye (w)	**-**	**0.887**[2]	**0.930**
Sockeye (h)	[1]**0.945**		
Spr-Sum Chinook (w)	**0.957**	**0.959**	**0.941**
Spr-Sum Chinook (h)	**0.944**		
Fall Chinook (w)	**0.942**	**0.920**	**0.969**
Fall Chinook (h)	**0.947**		
Steelhead (w)	**0.901**	**0.946**	**0.887**
Steelhead (h)	**0.914**		

[1] several years had very small sample size
[2] sockeye salmon estimates were in the 2008 BiOp, but were too preliminary to be performance standards.

Objective 2: Hatchery- versus wild-origin fish

Despite the potentially confounding issues described above regarding the composition of the annual PIT-tagged samples, there was some evidence that hatchery fish had lower conversion rates than wild fish in several cases. Annual reach conversion estimates were higher for wild- than for hatchery-origin spring–summer and fall Chinook salmon in a majority of years in the MCN-ICH reach. Most estimates were also higher for wild spring–summer Chinook salmon through the ICH-LGR reach and through the combined MCN-LGR reach. In contrast, annual differences between wild- and hatchery-origin steelhead were in mixed directions in all reaches, as were estimates for fall Chinook salmon in the ICH-LGR reach. There were too few wild sockeye salmon for comparisons.

The lower – *on average* – conversion rates for hatchery spring–summer and fall Chinook salmon likely reflected a mix of harvest effects (e.g., recreational harvest was legal at times for fin-clipped fish) and effects associated with hatchery practices (e.g., lower homing was possible for some hatchery populations compared to wild populations). Perhaps most importantly, some of the differences in conversion rates between wild- and hatchery-origin samples within a year were almost certainly due to the relative abundance of the populations included in each annual sample. Population- and life history-specific traits, such as run timing, spawn site selection, age-class composition, and ancestral source (for hatchery groups), all have the potential to affect behavior and survival through the study reaches. Better resolution of the role that hatchery rearing has on adult conversion may be possible by comparing better-matched wild and hatchery groups rather than the aggregate approach used here.

Objective 3: Population-specific estimates

We generated dozens of population-specific annual conversion rate estimates, but present data only for the most abundant groups and only for the MCN-LGR reach (Figures 5, 6, 11, 16, 17). These data would be appropriate for addressing questions related to changes to conversion rates through time (e.g., trend analyses). A thorough mining of the population-specific data would include detailed information on river environment, individual covariates (e.g., fish age, run timing, etc.), fisheries, and potentially project operations.

There were some persistent group-specific differences in reach conversion rates within each DPS. For example, wild spring–summer Chinook salmon in the Lower Granite barged group (LGRRBR, a mixed-stock group) had conversion rates that were consistently ~1-3% lower than the other most abundant wild populations, including the most direct comparison group (i.e., LGRRRR, Lower Granite in-river, mixed-stock). A similar barging effect was evident for hatchery spring–summer Chinook salmon, with barged fish having MCN-LGR conversion estimates that were 5-6% lower than several of the most abundant hatchery groups. The Dworshak NFH spring Chinook salmon group released in the main stem Clearwater River as juveniles also stood out as having low conversion through the study area relative to other hatchery groups, on average.

MCN-LGR conversion estimates for the most abundant hatchery fall Chinook salmon populations differed by as much as 5-7% with all years' data combined. The lowest estimates were for hatchery salmon from the Cedar Flats (CEFLAF, Selway River) and Lukes Gulch (LUGUAF, South Fork Clearwater River) acclimation facilities. Both of these groups had adult returns starting in 2007 (i.e., no data in 2002-2006) and total samples of < 500 fish. The higher conversion estimates among the abundant hatchery groups were for the SNAKE3 group (mixed-stock, Clearwater River to Salmon River reach) and the Caption John Rapids facility (CJRAP, Snake River between Lewiston, Idaho and the Grande Ronde River), both of which had adults in almost all years. Relatively few fall Chinook salmon were in the LGRRBR group, but conversion for these fish was well below the estimates for most comparison groups.

A barging effect was also evident for steelhead: the MCN-LGR conversion rate for transported wild steelhead (LGRRBR, mixed-stock) was ~10% lower than for in-river wild steelhead (LGRRRR, mixed-stock) with all years' data combined. Barged wild fish had lower conversions in most annual comparisons as well. Barged hatchery steelhead had MCN-LGR conversion rates were up to 15% lower than their in-river counterparts and this transport effect was evident in almost all years. The only exceptions were prior to 2006, when the barged hatchery samples had < 20 fish per year. The highest MCN-LGR conversion rates among the more abundant steelhead populations were for the Imnaha trap (IMNTRP) wild fish and the Salmon River (SALR) hatchery fish.

The barging effect on adult salmon and steelhead conversion has been reported previously in several studies (e.g., Keefer et al. 2008b; Marsh et al. 2012; Keefer and Caudill 2014) and warrants some additional comments. First, we did not attempt to correct for potential differences in juvenile migration timing between the LGRRBR and LGRRRR groups, although it is likely that the emigration timing of juveniles differed between groups within year and these differences may affect subsequent adult behavior and survival. Second, some fish in the LGRRRR were likely collected and barged from other lower Snake River dams. This suggests that the conversion differences between the LGRRBR and LGRRRR groups that we report are likely conservative with regards to transport effects. Third, we did not attempt to identify the many additional juveniles from upstream tagging groups (including sockeye and fall Chinook salmon) that were collected and barged from the Snake River dams, as this was also well beyond the study scope. However, we think it is likely that transport of varying proportions of the groups PIT-tagged upstream from Lower Granite Dam likely contributed to some of the among-year and among-population variability in MCN-LGR conversion estimates. Fourth, Snake River barging protocols differ from year to year, and some of the samples included experimental treatments that may have affected adult conversion. For example, in some years wild or hatchery fish were preferentially transported. In other years, experimental barged groups were released in the Columbia River Estuary to assess whether release closer to the Pacific Ocean provided a survival advantage relative to fish released downstream from Bonneville Dam (e.g., Marsh et al. 2012). These and other factors need to be more thoroughly evaluated to fully quantify the effects of barging on adult conversion.

Objective 4: Migration timing and water temperature effects

Seasonal effects on conversion rate were found for each DPS, though the magnitude of these effects differed considerably. We focused our analyses on Snake River water temperature and migration timing effects, which tend to strongly co-vary with river discharge. With all data combined, there was a sharp reduction in MCN-LGR and ICH-LGR conversion of sockeye salmon as Snake River water temperatures increased above ~18-19 °C. These temperatures consistently occurred late in the sockeye salmon migrations, but the sockeye models were most influenced by the relatively large 2013 sample, which encountered higher than average temperatures and temperature issues inside the Lower Granite Dam Fishway (NOAA 2014 BiOp). The predicted probability of Lower Granite passage was almost 50% lower for sockeye salmon that encountered the warmest Snake River temperatures. The sharp reduction in conversion for late migrants that encounter warmer water is consistent with previous sockeye salmon studies using radiotelemetry and/or PIT-tagged fish in the Columbia River (Naughton et al. 2005; Fryer 2007; Fryer et al. 2012) and in the Snake River (Keefer et al. 2008d), and observations of delay at fish ladders associated with temperature differences (Caudill et al. 2013).

Warm temperatures were also associated with reduced conversion by wild spring–summer Chinook salmon, though the effect was not as large as for sockeye salmon. At the lowest Snake River temperatures encountered by wild spring–summer Chinook salmon (~7-10 °C) the probability of reach conversion past Lower Granite Dam was > 95%. The probability decreased as the Snake River warmed (and migration date increased), particularly above ~18 °C. Predicted conversion rates were ~85% at temperatures near 20 °C. Somewhat unexpectedly, this pattern was not repeated in the hatchery spring–summer Chinook salmon analysis, where there was little evidence for a water temperature-conversion rate relationship (i.e., no statistically significant relationship using the full dataset).

Temperature and migration timing effects for fall Chinook salmon were mixed, with relatively few statistically important relationships. The exception was that conversion past Lower Granite Dam was higher early and at warmer Snake River water temperatures for hatchery fall Chinook that reached Ice Harbor Dam. Predicted conversion for the latest fall migrants (mostly in November, temperatures mostly < 12 °C) was ~10% lower than the estimates for fish that passed in August-early September when temperatures were often > 20 °C.

Seasonal effects were somewhat more complex for steelhead due to their protracted migration through the study reaches. In general, predicted conversion rates were lowest for steelhead that entered the study area late in the fall (e.g., November-December) prior to the onset of overwintering for some fish (Keefer et al. 2008a) or in the spring (March-May) after overwintering. These migrants encountered cool to cold water temperatures when they passed McNary Dam and/or entered the Snake River. This large seasonal effect may have masked some of the potential relationships between warm water temperature and steelhead conversion. We note that the lower apparent survival by the overwintering PIT-tagged Snake River fish is partially in contrast to results for radio-tagged overwintering fish described in Keefer et al. (2008a). However, there are several important differences between the two studies that likely account for some of the difference. First, harvest downstream from McNary Dam was included in the radiotelemetry study but not the PIT study. Second, the radiotelemetry study included steelhead from populations throughout the Columbia River basin upstream from Bonneville Dam. Third, most of the radio-tagged steelhead were of unknown origin (i.e., potential strays were considered successful if they were last recorded in tributaries). And, fourth, overwintering in the Lower Granite reservoir was included in the radiotelemetry study.

We think it is likely that many Snake River steelhead avoid the warmest conditions and their potential survival effects by using cool-water refuge sites along the migration corridor (e.g., High et al. 2006; Keefer et al. 2009). Use of such sites may ameliorate high main stem water temperature effects on conversion rates. In the study reach, cooler water was potentially available at several small-volume sites (e.g., Walla Walla River, Tucannon River, Lyon’s Ferry outfall) as well as from the upper Columbia River near the Columbia-Snake confluence. Steelhead passage times from McNary to Ice Harbor Dam can be protracted in summer months (often > 2-3 weeks, Keefer et al. 2004), and some fish likely hold in the cooler water until Snake River temperatures decrease. Other behavioral explanations are also possible. Capturing the behavioral diversity of steelhead with a point estimate for temperature (i.e., upon reach entry) is difficult and probably less informative than for the other species in regards to conversion estimates.

Objective 5: Final detections of ‘unsuccessful’ fish

One of the important contributions from this work was the review of detection histories for nearly 6,000 upstream migrants that did not pass Lower Granite Dam after being detected at McNary Dam during their upriver migration. This putatively ‘unsuccessful’ group included 1,475 hatchery spring–summer Chinook salmon, 1,322 hatchery fall Chinook salmon, and 1,829 hatchery steelhead plus 73 hatchery sockeye salmon. Samples were smaller – yet still informative – for the wild groups: 381 spring–summer Chinook salmon, 24 fall Chinook salmon, and 892 steelhead.

A majority of unsuccessful fish in each DPS were last detected at one of the main stem adult fishways, primarily at McNary or Ice Harbor dams. Percentages in the adult fishway category were 73-79% for sockeye salmon, wild and hatchery fall Chinook salmon, and wild and hatchery steelhead and was 90% for spring–summer Chinook salmon in both origin types. The fate of these fish was unknown in almost all cases as only a very small number were reported as mortalities at the dams. The presumed fates were: harvest mortality, mortality following downstream fallback over dams (e.g., Keefer et al. 2005), natural mortality (e.g., predation or disease), undetected straying, or main stem spawning. The undetected straying component was most likely in early study years, while the main stem spawning was most likely for fall Chinook salmon given their spawn site selection in larger, low-gradient river reaches.

A small number of fish (2-7% for all but wild fall Chinook salmon [0%]) were last detected in juvenile bypass systems or at the Bonneville corner collector. A majority of these detections were at the Snake River dams and presumably most of the fish were diverted back into the river.

Unsuccessful fish that were identified as probable strays out of their natal basin varied among DPSs. Fifteen percent of the unsuccessful sockeye salmon were strays, with almost all of those fish last detected in the upper Columbia River. As noted above, the relatively large sockeye salmon sample in 2013, a warm migration year, was influential in this estimate. About 6-7% of the unsuccessful spring–summer Chinook salmon were considered strays. These fish were widely distributed, with final detections in tributaries up- and downstream from McNary Dam, as well as in the Tucannon River. Fall Chinook salmon had the highest percent (22-25%) of identified strays in the unsuccessful group. Many of these were last detected in mid- and upper Columbia River tributaries (especially the Yakima River) and at upper Columbia River dams. Some were also detected at Lyons Ferry Hatchery and in the Tucannon River. We note that it was not always clear with these groups what should be considered straying given hatchery practices at Lyons Ferry Hatchery (i.e., outplanting, transport, adult trapping, etc.). Most of the apparent fall Chinook salmon strays were detected considerable distances from their origin locations, suggesting the behavior was not simply selection of nearby main stem spawning sites. About 15% of unsuccessful steelhead were strays. These fish were last detected at a wide range of locations up- and downstream from McNary Dam, with the largest numbers in the John Day River and at upper Columbia River dams.

As part of the analysis of 'unsuccessful' fish, we calculated donor population stray rates to help evaluate whether some groups disproportionately contribute strays (Figures 9, 14, 22) and reduce conversion estimates. The total donor stray rates, by DPS×origin combination, were: 1.75% (hatchery sockeye, largely driven by the 2013 sample), 0.29% (wild spring–summer Chinook), 0.40% (hatchery spring–summer Chinook), 1.69% (wild fall Chinook), 1.49% (hatchery fall Chinook), 1.61% (wild steelhead), and 1.63% (hatchery steelhead). Donor stray rates varied several-fold among populations, with some groups producing no strays and others having stray rates > 5%. The LGRRBR barged group produced strays at high rates relative to the aggregated DPS×origin estimates: 0.87% (wild spring–summer Chinook), 2.37% (hatchery spring–summer Chinook), 6.45% (wild fall Chinook, small *n*), 10.00% (hatchery fall Chinook, small *n*), 2.79% (wild steelhead), and 3.03% (hatchery steelhead). These results are notable given that the LGRRBR groups were among the numerically most abundant in the PIT-tagged spring–summer Chinook salmon and steelhead samples across years. Donor population stray rates for other large (> 1,000 fish) groups were < 0.25% (RAPH, KNOXB, IMNAHW) and 1.06% (DWORNF) for spring–summer Chinook salmon, and 0.98-2.79% for several fall Chinook salmon hatchery groups (PLAP, SNAKE4, CJRAP, SNAKE3, BCCAP). They were 0.60-0.78% (LGRRRR, WALH) and 1.89% (LSALR) for hatchery steelhead, and 0.48% (LGRRRR) for wild steelhead. We note that all estimates were minimum values, with underestimation mostly driven by the limited PIT monitoring in early study years.

References

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

Buchanan, R. A., J. R. Skalski, and S. G. Smith. 2006. Estimating the effects of smolt transportation from different vantage points and management perspectives. North American Journal of Fisheries Management 26:460-472.

Caudill, C. C., M. L. Keefer, T. S. Clabough, G. P. Naughton, B. J. Burke, and C. A. Peery. 2013. Indirect effects of impoundment on migrating fish: temperature gradients in fish ladders slow dam passage by adult Chinook salmon and steelhead. PLOS ONE:e85586.

Evans, A. F., R. E. Beaty, M. S. Fitzpatrick, and K. Collis. 2004. Identification and enumeration of steelhead kelts at a Snake River hydroelectric dam. Transactions of the American Fisheries Society 133:1089-1099.

Fryer, J. K. 2007. Use of PIT tags to determine upstream migratory timing and survival of Columbia Basin sockeye salmon in 2006. Technical Report 07-01, Columbia River Inter-Tribal Fisheries Commission, Portland, OR.

Fryer, J. K., J. Whiteaker, and D. Kelsey. 2012. Upstream migration timing of Columbia Basin Chinook and sockeye salmon and steelhead in 2010. Technical Report 12-02, Columbia River Inter-Tribal Fisheries Commission, Portland, OR.

High, B., C. A. Peery, and D. H. Bennett. 2006. Temporary staging of Columbia River summer steelhead in coolwater areas and its effect on migration rates. Transactions of the American Fisheries Society 135:519-528.

Keefer, M. L., C. A. Peery, T. C. Bjornn, M. A. Jepson, and L. C. Stuehrenberg. 2004. 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, 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. T. Boggs, C. A. Peery, and C. C. Caudill. 2008a. Overwintering distribution, behavior, and survival of adult summer steelhead: variability among Columbia River populations. North American Journal of Fisheries Management 28:81-96.

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

Keefer, M. L., R. H. Wertheimer, A. F. Evans, C. T. Boggs, and C. A. Peery. 2008c. Iteroparity in Columbia River summer-run steelhead (*Oncorhynchus mykiss*): implications for conservation. Canadian Journal of Fisheries and Aquatic Sciences 65:2592-2605.

Keefer, M. L., C. A. Peery, and M. J. Heinrich. 2008d. 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., 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., and C. C. Caudill. *In review*. Estimating iteroparity in Columbia River steelhead using records archived in the Columbia River PIT tag information system (PTAGIS) database. Technical Report 2013-DRAFT of University of Idaho to U.S. Army Corps of Engineers, Portland 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.

Narum, S. R., D. Hatch, A. J. Talbot, P. Moran, and M. S. Powell. 2008. Iteroparity in complex mating systems of steelhead trout. Journal of Fish Biology 72:45-60.

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.

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.

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 Evironmental Statistics 7(2):243-263.

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.

Appendix Table 1. Release site codes and locations for PIT-tagged groups used in the summary.

Code	Site	Code	Site	Code	Site
ALTULC	Alturas Lake Ck	IHRTRB	Ice Harbor turbine	POTR	Potlatch R
AMERR	American R	IMNAHR	Imnaha R	POTREF	EF Potlatch R
ASOTIC	Asotin Ck	IMNAHW	Imnaha R Weir	POWP	Powell Pond
ASOTNF	NF Asotin Ck	IMNTRP	Imnaha R Trap	RAPH	Rapid R H
ASOTSF	SF Asotin Ck	JOHNSC	Johnson Ck	RAPIDR	Rapid R
BARGAC	Bargamin Ck	JOHTRP	Johnson Ck Trap	RAPR	Rapid R
BCANF	Big Canyon Facility	KNOXB	Knox Bridge	REDP	Red R Pond
BCCAP	Big Canyon Acc Pond	KOOS	Kooskia H	REDR	Red R
BEARC	Bear Ck	LAKEC	Lake Ck	REDRSF	SF Red R
BEARVC	Bear Valley Ck	LAPC	Lapwai Ck	REDTRP	Red R Trap
BIG2C	Big Ck	LBCWF	WF Little Bear Ck	RLCTRP	Redfish Lake Ck Trap
BOULDC	Boulder Ck	LBEARC	Little Bear Ck	RPDTRP	Rapid R Trap
BRUSHC	Brushy Fork Ck	LEMHIR	Lemhi R	SALEFT	EF Salmon R Trap
BSHEEC	Big Sheep Ck	LEMHIW	Lemhi R Weir	SALR	Salmon R
CABINC	Cabin Ck	LGRBYP	L Granite bypass	SALR1	Salmon R
CAMASC	Camas Ck	LGRRBR	L Granite barge	SALR3	Salmon R
CAPEHC	Capehorn Ck	LGRRRR	L Granite river rel	SALR4	Salmon R
CATHEC	Catherine Ck	LGRRTR	L Granite truck	SALREF	EF Salmon R
CEDA2C	Cedar Ck	LGRTAL	L Granite tailrace	SALRMF	MF Salmon R
CEFLAF	Cedar Flats Acc Fac	LGSBPS	L Goose bypass	SALRNF	NF Salmon R
CFCTRP	Crooked Fork Ck Tr	LGSBYP	L Goose bypass	SALRSF	SF Salmon R
CHAMBC	Chamberlain Ck	LGSGAT	L Goose flume	SALTRP	Salmon R Trap
CHAMWF	WF Chamberlain Ck	LGSTAL	L Goose tailrace	SAWT	Sawtooth H
CHARLC	Charley Ck	LICKC	Lick Ck	SAWTRP	Sawtooth Trap
CJRAP	Cap John Rapids A P	LMNBYP	L Monumental byp	SECESR	Secesh R
CLEARC	Clear Ck	LOCHSA	Lochsa R	SECTRP	Secesh R Trap
CLWR	Clearwater R	LOLOC	Lolo Ck	SELWY1	Selway R
CLWRMF	MF Clearwater R	LOOH	Lookingglass H	SELWYR	Selway R
CLWRSF	SF Clearwater R	LOOKGC	Lookingglass Ck	SLAT2C	Slate Ck
CLWTRP	Clearwater Trap	LOONC	Loon Ck	SLATEC	Slate Ck
COLTKC	Colt Kill Ck	LOSTIP	Lostine R Pond	SFSTRP	SF Salmon R Trap
CORRAC	Corral Ck	LOSTIR	Lostine R	SNAKE2	Snake R
COTP	Cottonwood Acc Po	LSALR	Little Salmon R	SNAKE3	Snake R
CROOKP	Crooked R Pond	LSFTRP	Low SF Salmon Tr	SNAKE4	Snake R
CROOKR	Crooked R	LSHEEF	Little Sheep Facil	SNKTRP	Snake R Trap
CROTRP	Crooked R Trap	LUGUAF	Lukes Gulch Ac Fa	SQUAWC	Squaw Ck
COUGRC	Cougar Ck	MARSHC	Marsh Ck	SQUAWP	Squaw Ck Acc Pond
DWOR	Dworshak H	MARTRP	Marsh Ck Trap	STOLP	Stolle Pond
DWORMS	Dworshak H ms rel	MEAD2C	Meadow Ck	STORMC	Storm Ck
DWORNF	Dworshak H NF rel	MEADOC	Meadow Ck	SULFUC	Sulphur Ck
ELKC	Elk Ck	MILL2C	Mill Ck	VALEYC	Valley Ck
FISHC	Fish Ck	MINAMR	Minam Ck	WALH	Wallowa H
FISTRP	Fish Ck Trap	MOOS2C	Moose Ck	WBIRDC	Whitebird Ck
GEDCWF	WF Gedney Ck	NEWSOC	Newsome Ck	WHITSC	Colt Kill Ck (old)
GEDNEY	Gedney Ck	NPTH	Nez Perce Trib H	WIMPYC	Wimpey Ck
GRAND1	Grande Ronde R	NLVP	N Lapwai Val Ac P	YANKFK	Yankee Fork
GRAND2	Grande Ronde R	OHARAC	Ohara Ck	YANKWF	WF Yankee Fork
GRANDP	Grande Ronde Pond	PAHP	Pahsimeroi R Pond	YELLJC	Yellowjacket Ck
GRANDR	Grande Ronde R	PAHSIW	Pahsimeroi R Weir		
GRNTRP	Grande Ronde Trap	PAHTRP	Pahsimeroi R Trap		
HAYDNC	Hayden Ck	PANTHC	Panther ck		
HCD	Hells Canyon Dam	PAPOOC	Papoose Ck		
HERDC	Herd Ck	PETEKC	Pete King Ck		
HORSEC	Horse Ck	PETTLC	Pettit Lake Ck		
IHRCOL	Ice Harbor coll chan	PINE2C	Pine Ck		
IHRTAL	Ice Harbor tailrace	PLAP	Pittsburg L Acc P		