Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2014

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Executive Summary

In 2014, we completed the 22nd year of a study to estimate survival and travel time of juvenile salmonids *Oncorhynchus* spp. passing dams and reservoirs on the Snake and Columbia Rivers. All estimates were derived from detections of fish tagged with passive integrated transponder (PIT) tags.

We tagged and released a total of 19,909 hatchery steelhead *O. mykiss*, 15,176 wild steelhead, and 17,917 wild yearling Chinook salmon *O. tshawytscha* at Lower Granite Dam on the Snake River. In addition to detections of these fish, we used detections of fish PIT-tagged by other researchers at traps and hatcheries upstream from Lower Granite Dam and at other sites on the Snake and Columbia Rivers.

Detection sites were the juvenile bypass systems at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dam, as well as the Bonneville Dam corner collector and the PIT-tag detector trawl operated in the Columbia River estuary. Survival estimates were calculated using a statistical model for tag-recapture data from single release groups (the single-release model). Primary research objectives in 2014 were:

1) Estimate reach survival and travel time in the Snake and Columbia Rivers throughout the migration period of yearling Chinook salmon and steelhead
2) Evaluate relationships between survival estimates and migration conditions
3) Evaluate the survival estimation models under prevailing conditions

In 2014, we estimated reach survival and travel time for hatchery and wild yearling Chinook salmon, hatchery sockeye *O. nerka* and coho salmon *O. kisutch*, and hatchery and wild steelhead. During most of the 2014 migration season, detections of yearling Chinook salmon and steelhead were sufficient to estimate survival and detection probabilities for daily or weekly groups leaving Lower Granite and McNary Dams.

Hatchery and wild study fish were combined in some analyses. For PIT-tagged fish detected or released at Lower Granite Dam, the respective overall percentages were 58% hatchery and 42% wild for yearling Chinook and 71% hatchery and 29% wild for steelhead. Based on collection counts at Lower Granite Dam by the Fish Passage Center, and on our estimates of daily detection probability, we estimated that 87.2% of the overall yearling Chinook salmon run in 2014 was of hatchery origin. We could not calculate this number for steelhead because separate collection counts of hatchery and wild fish were not available.

All estimates of survival in reaches of river between dams were calculated from tailrace to tailrace. Estimates of average survival in 2014 through these reaches are listed in Table E1 below for combined groups of wild and hatchery yearling Chinook salmon and steelhead.

Table E1. Average survival estimates by reach for groups of combined hatchery and wild yearling Chinook salmon and steelhead during 2014 (standard errors in parenthesis).

	Yearling Chinook salmon (SE)	Steelhead (SE)
Snake River Trap to Lower Granite Dam	0.905 (0.015)	1.018 (0.028)
Lower Granite to Little Goose Dam	0.940 (0.007)	0.953 (0.009)
Little Goose to Lower Monumental Dam	0.919 (0.010)	0.947 (0.024)
Lower Monumental to McNary Dam[a]	0.894 (0.017)	0.836 (0.032)
Lower Monumental to Ice Harbor	0.940 (0.027)	0.954 (0.055)
Ice Harbor to McNary	0.967 (0.057)	0.974 (0.079)
McNary to John Day Dam	0.912 (0.053)	1.082 (0.080)
John Day to Bonneville Dam[b]	0.752 (0.104)	0.982 (0.147)
Snake River Trap to Bonneville Dam[c]	0.497 (0.075)	0.771 (0.073)

[a] A two-project reach, including Ice Harbor Dam and reservoir.

[b] A two-project reach, including The Dalles Dam and reservoir.

[c] Entire hydropower system, including eight dams and reservoirs.

For combined groups of wild and hatchery yearling Chinook and steelhead from the Snake River Basin, we also estimated average survival through the entire hydropower system, from the Snake River smolt trap at the head of Lower Granite reservoir to the tailrace of Bonneville Dam (eight projects). These estimates were the product of average survival estimates through three reaches: Snake River smolt trap to Lower Granite Dam, Lower Granite to McNary Dam, and McNary to Bonneville Dam. During 2014, estimated survival for the entire hydropower system was 0.497 (95% CI 0.349-0.645) for Snake River yearling Chinook salmon and 0.771 (0.628-0.914) for Snake River steelhead.

We estimated survival to McNary Dam tailrace for groups of hatchery yearling Chinook salmon released from individual locations in the Upper Columbia River. These estimates ranged from 0.767 (0.034) for Chelan Hatchery fish released to Dryden Pond on the Wenatchee River to 0.280 (0.014) for Cle Elum Hatchery fish released to Jack Creek Pond on the Yakima River. Similar estimates for Upper Columbia River steelhead ranged from 0.811 (0.232) for Wells Hatchery fish released to the Methow River to 0.332 (0.043) for Wells Hatchery fish released into Twisp Acclimation Pond on the Wenatchee River.

Estimates of survival from Snake River hatcheries to Lower Granite Dam suggested substantial mortality upstream from the Snake and Clearwater River confluence. Continued development of instream PIT-detection systems for use in tributaries will be necessary if the sources of mortality in these upstream areas are to be identified.

We estimated that 35% of yearling Chinook (wild and hatchery combined) and 37% of steelhead that arrived at Lower Granite Dam had been transported. These estimates were very close to those of 2013, and estimates from both years were near the average for 2007-2014, which is considerably lower than the average for 1993-2006.

By the time transportation began at Lower Granite Dam on 1 May 2014, we estimate that 63% of wild yearling Chinook, 39% of hatchery yearling Chinook, 48% of wild steelhead, and 50% of hatchery steelhead had passed the dam. Other factors contributing to the low percentage of transported migrants in 2014 were the use of surface-bypass structures at multiple dams (removable and temporary spillway weirs, or RSWs and TSWs) and periods of relatively high spill. Fish that pass dams via the spillways cannot enter the juvenile fish facility to be collected for transportation.

We calculated travel time for yearling Chinook salmon and steelhead over individual reaches between dams and over the entire hydropower system from Lower Granite to Bonneville Dam (461 km). Travel times through the entire hydropower system were shorter than the long-term average, indicating faster migration for both yearling Chinook and steelhead for the majority of the migration.

As in other recent years, rates of PIT-tag detection were relatively low in 2014 because of high rates of spill and the use of surface-bypass structures to pass salmon at the dams. Consequently, the precision of survival estimates based on PIT-tagged fish was impaired.

We believe there is now an urgent need to develop PIT-tag detection capability through passage routes other than the juvenile bypass systems. Specifically, the region should place high priority on development and installation of PIT-monitoring systems for TSW and RSW bypass structures and for normal spill bays. As we have suggested in recent years, higher rates of detection are necessary if we are to maintain or enhance the precision of survival estimates based on data gathered from PIT-tagged smolts.

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Introduction

Accurate and precise estimates of survival are needed for depressed stocks of juvenile Chinook *Oncorhynchus tshawytscha*, sockeye *O. nerka*, and coho salmon *O. kisutch*, and steelhead *O. mykiss* that migrate through reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers. To develop recovery strategies that will optimize smolt survival during migration, information is needed on the magnitude, locations, and causes of smolt mortality. Such knowledge is necessary for strategies applied under present passage conditions as well as under conditions projected for the future (Williams and Matthews 1995; Williams et al. 2001).

From 1993 through 2014, the National Marine Fisheries Service (NMFS) estimated survival for these stocks using detections of juvenile salmonids marked with passive integrated transponder tags (PIT tags; Prentice et al. 1990a) as they pass through Snake River dams and reservoirs (Iwamoto et al. 1994; Muir et al. 1995, 1996, 2001a,b, 2003; Smith et al. 1998, 2000a,b, 2003, 2005, 2006; Hockersmith et al. 1999; Zabel et al. 2001, 2002; Faulkner et al. 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014). In 2014, NMFS completed the 22nd year of the study.

Research objectives in 2014 were:

1) Estimate reach survival and travel time in the Snake and Columbia Rivers throughout the yearling Chinook salmon and steelhead migrations
2) Evaluate relationships between survival estimates and migration conditions
3) Evaluate the performance of survival-estimation models under prevailing operational and environmental conditions

Survival from Release to Bonneville Dam

Methods

Experimental Design

The single-release (SR) model was used to estimate survival and detection probabilities for groups of PIT-tagged yearling Chinook, sockeye, and coho salmon and steelhead (Cormack 1964; Jolly 1965; Seber 1965; Skalski 1998; Skalski et al. 1998; Muir et al. 2001a). Iwamoto et al. (1994) presented background information and underlying statistical theory pertaining to the SR model.

During the 2014 migration season, fish used for these estimates were released from hatcheries, traps, and Lower Granite Dam in the Snake River Basin, and from hatcheries and dams in the Upper Columbia River. A large proportion of PIT-tagged yearling Chinook salmon used in this analysis were released in the Snake River upstream from Lower Granite Dam for the multi-agency Comparative Survival Study (Schaller et al. 2007). Study fish were detected using automatic PIT-tag monitors (Prentice et al. 1990a,b,c) operated in juvenile bypass systems at the following seven dams: Lower Granite (rkm 695), Little Goose (rkm 635), Lower Monumental (rkm 589), Ice Harbor (rkm 538), McNary (rkm 470), John Day (rkm 347), and Bonneville (rkm 234; Figure 1).

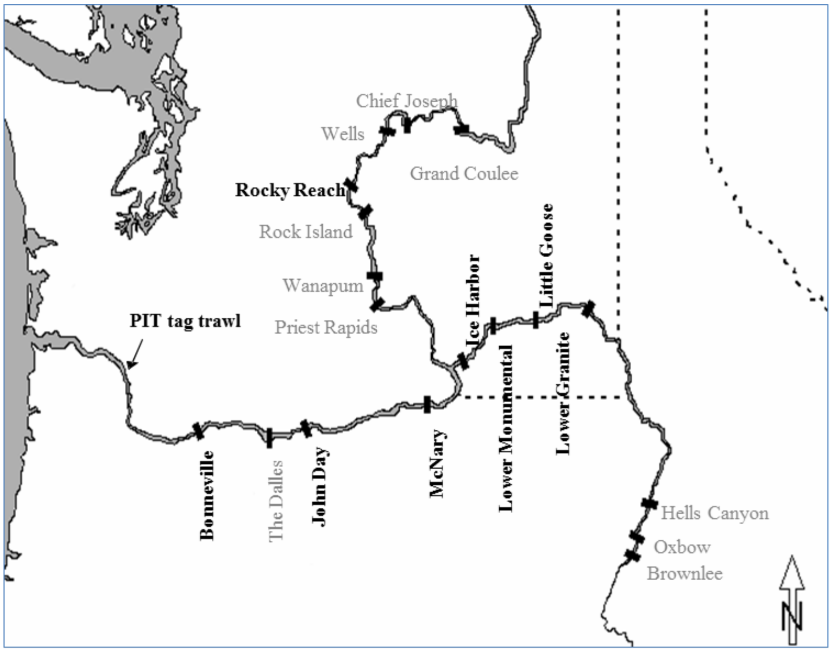

Figure 1. Study area showing sites with PIT-tag detection facilities (names in black), including dams and the PIT-tag trawl in the Columbia River estuary. Dams with names in gray do not have detection facilities.

The farthest downstream detection site for PIT-tagged fish was in the Columbia River estuary (rkm 65-84), where a pair-trawl detection system was operated (Ledgerwood et al. 2004). Since spring 2006, a PIT-tag detection system has been operated in the corner collector at Bonneville Dam Second Powerhouse. In 2014, detection probabilities at Bonneville Dam and in the pair trawl were relatively low, but were sufficient to estimate survival from John Day tailrace to Bonneville Dam tailrace for most stocks.

At Snake and Columbia River dams, most tagged fish were returned to the river after detection, which allowed for the possibility of detection (recapture) at more than one site (Marsh et al. 1999). Thus, for fish released in the Snake River Basin (upstream from Lower Granite Dam), we used records of downstream PIT-tag detections with the SR recapture model to estimate tailrace-to-tailrace survival in the following seven reaches:

- Point of release to Lower Granite Dam (various distances)
- Lower Granite to Little Goose Dam (60 km)
- Little Goose to Lower Monumental Dam (46 km)
- Lower Monumental to Ice Harbor Dam (51 km)
- Ice Harbor to McNary Dam (68 km)
- McNary to John Day Dam (123 km)
- John Day to Bonneville Dam (112 km)

At Ice Harbor Dam, the PIT-tag detection system in the juvenile bypass facility was first operated in 2005. However, because of high levels of spill at this dam, too few smolts were detected there to partition survival between Lower Monumental and McNary Dams in 2005. From 2006 to 2014, detections at Ice Harbor were sufficient to partition survival through this reach. However, low detection rates at Lower Monumental and Ice Harbor have often resulted in survival estimates with poor precision.

For fish released in the Upper Columbia River, we estimated survival in the following three reaches:

- Point of release to the tailrace of McNary Dam (various distances)
- McNary Dam tailrace to John Day Dam tailrace (123 km)
- John Day Dam tailrace to Bonneville Dam tailrace (112 km)

Study Fish

Releases from Lower Granite Dam—During 2014, we collected hatchery and wild steelhead and wild yearling Chinook salmon at the Lower Granite Dam juvenile facility. These fish were PIT tagged and released to the tailrace for the express purpose of estimating their subsequent survival. Fish were collected in approximate proportion to the numbers arriving at Lower Granite Dam except during the early and late periods of the migration season, when we tagged relatively more fish to provide sufficient numbers for analysis over these periods.

No hatchery yearling Chinook salmon were tagged specifically for this study because other researchers tagged and released sufficient numbers of these fish from Snake River Basin hatcheries and traps. We used data from these fish to estimate detection probabilities, survival probabilities, and travel time.

For both yearling Chinook salmon and steelhead tagged and released upstream from Lower Granite Dam, we created virtual daily "release groups" of fish according to date of detection at the dam. Each daily group of fish detected and returned to the river was combined with fish tagged at the dam and released on the same date. Daily release groups were then pooled into weekly groups, and we estimated survival probabilities from tailrace-to-tailrace in individual reaches between Lower Granite and McNary Dam for both daily and weekly groups. Some daily groups at the beginning and end of the season were not of sufficient sample size to form weekly cohorts with reliable estimates of either survival or travel time, so those fish were excluded from our analyses using weekly release groups.

At Lower Granite Dam, we PIT tagged and released 19,909 hatchery steelhead, 15,176 wild steelhead, and 17,917 wild yearling Chinook salmon from 9 April through 14 June 2014 (Table 1). From these numbers, total mortalities were 11, 10, and 33 for hatchery steelhead, wild steelhead, and wild yearling Chinook salmon, respectively. Each of these mortality rates was well below 1% of the total number of fish handled.

A total of 71,311 yearling Chinook salmon (41,487 hatchery origin, 29,824 wild) were either collected, tagged, and released to the tailrace of Lower Granite Dam or detected at the dam and returned to the tailrace. A total of 63,764 steelhead (45,427 hatchery origin and 18,337 wild) were similarly tagged and released or detected and returned to the tailrace of Lower Granite Dam.

Table 1. Number by date of PIT–tagged hatchery steelhead, wild steelhead, and yearling Chinook salmon released at Lower Granite Dam for survival estimates in 2014. Also included are tagging mortalities and shed tags.

	Hatchery Steelhead			**Wild Steelhead**			**Wild Yearling Chinook**		
Release date	Number released	Mort-alities	Shed tags	Number released	Mort-alities	Shed tags	Number released	Mort-alities	Shed tags
8-Apr	714	-	-	145	-	-	1,337	-	1
9-Apr	670	-	-	207	-	2	1,845	1	1
15-Apr	454	-	-	355	-	-	1,822	3	-
16-Apr	1,252	1	-	887	-	-	1,948	8	-
23-Apr	1,176	1	-	372	-	-	1,465	1	15
24-Apr	1,281	-	-	216	-	-	1,115	-	-
30-Apr	1,183	1	-	464	-	1	487	-	-
1-May	1,265	-	1	630	-	-	470	1	-
2-May	1,632	1	-	420	1	-	390	1	-
5-May	270	-	-	52	-	-	272	-	-
6-May	852	-	-	514	-	1	481	1	-
7-May	1,195	1	-	335	-	-	193	1	-
8-May	857	-	2	891	2	-	388	3	-
9-May	399	2	-	345	-	-	430	3	-
12-May	507	1	-	356	3	-	497	-	-
13-May	510	-	2	708	-	1	667	-	-
14-May	538	2	1	456	-	1	356	-	-
15-May	569	-	-	587	1	-	290	1	-
16-May	631	1	2	703	1	1	313	-	-
19-May	353	-	-	785	-	-	534	-	-
20-May	482	-	-	1,136	-	1	640	3	-
21-May	402	-	-	979	-	-	533	-	-
22-May	364	-	1	1,166	1	-	520	3	-
23-May	150	-	-	447	-	4	413	2	-
27-May	304	-	1	456	-	1	166	-	-
28-May	263	-	-	158	-	-	67	-	-
29-May	269	-	1	144	-	-	136	-	-
30-May	206	-	-	140	-	-	142	1	-
2-Jun	186	-	1	159	-	-			
3-Jun	130	-	-	96	-	-			
4-Jun	147	-	-	136	-	-			
5-Jun	165	-	-	193	-	-			
6-Jun	132	-	2	174	1	-			
9-Jun	91	-	-	119	-	-			
10-Jun	85	-	-	106	-	-			
11-Jun	88	-	-	72	-	-			
12-Jun	80	-	-	29	-	-			
13-Jun	57	-	-	38	-	-			
Totals	19,909	11	14	15,176	10	13	17,917	33	17

We estimated that 87.2% of the overall run of yearling Chinook salmon in 2014 was of hatchery origin. This estimate was based on counts of the run at large (both tagged and untagged fish) by the Fish Passage Center and our own estimates of daily detection probability at Lower Granite Dam (based on tagged fish only). We could not estimate the proportion of hatchery steelhead in the run at large because separate counts for hatchery and wild fish were not available. Proportions of hatchery fish in the combined groups used to estimate survival were 58% for yearling Chinook salmon and 71% for steelhead.

Releases from McNary Dam—For yearling Chinook salmon and steelhead tagged at all locations in the Snake River Basin and Upper Columbia River, we created virtual daily "release groups" according to day of detection at McNary Dam. Daily groups consisted of fish detected and returned to the tailrace, and daily groups were pooled into weekly groups. We estimated tailrace-to-tailrace survival from McNary to John Day and from John Day to Bonneville Dam for weekly groups only, as data were too sparse to estimate survival for daily groups.

Releases from Hatcheries and Smolt Traps—In 2014, most hatcheries in the Snake and Upper Columbia River Basins released PIT-tagged fish as part of research separate from the NMFS survival study. We analyzed data from hatchery releases of PIT-tagged yearling Chinook, sockeye, and coho salmon, and steelhead to provide survival estimates and detection probabilities from release to the tailrace of Lower Granite Dam (for fish originating in the Snake River Basin) or McNary Dam (for fish originating in the Upper Columbia River Basin) and to points downstream.

We estimated survival to Lower Granite Dam tailrace and points downstream for releases of wild and hatchery PIT-tagged yearling Chinook salmon and steelhead from the Salmon (White Bird), Snake, and Clearwater River traps, and from other smolt traps throughout the Snake River Basin.

Data Analysis

Tagging and detection data were downloaded on 13 August 2014 from the Columbia Basin PIT Tag Information System (PTAGIS), a regional database maintained by the Pacific States Marine Fisheries Commission (PTAGIS 1996-present). Data were examined for erroneous records, inconsistencies, and data anomalies. Records were eliminated where appropriate, and all eliminated PIT-tag codes were recorded with the reasons for their elimination. Very few records (<0.1%) were eliminated.

For each remaining PIT-tag code, we constructed a detection history record indicating all potential detection locations and whether the tagged fish was detected or not detected at each. Methods for data retrieval, database quality assurance/control, and construction of detection histories were the same as those used in past years and were described in detail by Iwamoto et al. (1994).

The analyses reported here were conducted using the data downloaded on the date indicated above. It is possible, for a variety of reasons, that data in the PTAGIS database may be updated in the future. Thus, future estimates provided by NMFS or employed in future analyses may differ slightly from those presented here.

Tests of Assumptions—We evaluated assumptions of the SR model as applied to the detection-history data generated from PIT-tagged juvenile salmonids in the Snake and Columbia Rivers (Burnham et al. 1987). Chi-square contingency tests were used to evaluate model assumptions, with assumption violations indicated by significant differences between observed and expected proportions of fish in different detection-history categories. In many cases, sample sizes were large enough that these tests had sufficient power to detect small deviations from model assumptions that had only marginal effect on survival estimates. Appendix A contains a detailed discussion of these tests of assumption, the extent of assumption violations, and the implications of and possible reasons for these violations.

Survival Estimates—All survival estimates presented here were calculated from the tailrace of a dam to the tailrace of a downstream dam or from a release point upstream from the hydropower system to the tailrace of a downstream dam. All survival and detection probability estimates were computed using the statistical computer program SURPH (Survival with Proportional Hazards) for analyzing release-recapture data. This program was developed at the University of Washington (Skalski et al. 1993; Smith et al. 1994) for analyses using the single-release model.

Estimates of survival probability under the SR model are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0. For practical purposes, these estimates should be considered equal to 1.0.

When estimates of survival through a particular river section were available for a series of release groups of the same stock within the migration season, we calculated a weighted average of the estimates (Muir et al. 2001a). When the series extended across most of the season, we took the weighted average to be the average for the year for the stock. For each group, weights were inversely proportional to their respective estimated relative variances (coefficient of variation squared).

We used the inverse of estimated *relative* variance rather than *absolute* variance in weighting because the variance of an estimated survival probability from the SR model is a function of the estimate itself. Consequently, lower survival estimates tend to have smaller estimated variance, which results in lower survival estimates having disproportionate influence. Use of the inverse relative variance prevented the weighted mean from being biased toward the lower estimates.

For various stocks from both the Snake and Upper Columbia Rivers, we estimated survival from point of release to Bonneville Dam (the final dam encountered by seaward-migrating juvenile salmonids). For extended reaches like this, estimates were derived as the product of appropriate estimates from shorter component reaches.

An important instance of estimated survival through an extended reach is that for fish released from the Snake River trap to Bonneville Dam tailrace. This trap is located near the head of Lower Granite reservoir, so the survival estimate is over essentially the entire eight-project hydropower system negotiated by juvenile salmonids from the Snake River Basin. For yearling Chinook salmon (hatchery and wild combined), we constructed the estimate for the extended reach from three components:

1) Estimated survival from Snake River trap to Lower Granite Dam for hatchery and wild fish tagged at and released from the trap, pooled across the migration season.
2) Weighted mean estimated survival from Lower Granite Dam to McNary Dam for daily virtual groups of fish released from Lower Granite Dam.
3) Weighed mean estimated survival from McNary Dam to Bonneville Dam for weekly virtual groups of fish released from McNary Dam.

Our methods for constructing the virtual groups and for calculating weighted means of estimates are described above.

Results

Snake River Yearling Chinook Salmon

Survival Probabilities—For weekly groups of yearling Chinook salmon, survival probabilities from Lower Granite to multiple Snake River dams were estimated over 10 consecutive weeks during 23 March-31 May. Mean estimated survival was 0.940 (SE 0.007) from Lower Granite to Little Goose, 0.919 (0.010) from Little Goose to Lower Monumental, and 0.894 (0.017) from Lower Monumental to McNary Dam (Tables 2 and 5). For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.768 (0.015).

Table 2. Estimated survival probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or tagged and released to the tailrace at Lower Granite Dam in 2014. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for daily groups. Standard errors in parentheses.

Date at Lower Granite Dam	Number released	Estimated survival of yearling Chinook salmon from Lower Granite Dam (SE) Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
23 Mar–29 Mar	358	0.919 (0.056)	0.832 (0.133)	0.836 (0.213)	0.639 (0.135)
30 Mar–5 Apr	1,209	0.881 (0.025)	0.938 (0.066)	0.845 (0.088)	0.698 (0.057)
6 Apr–12 Apr	4,738	0.925 (0.012)	0.884 (0.028)	0.860 (0.041)	0.703 (0.027)
13 Apr–19 Apr	9,862	0.947 (0.008)	0.933 (0.022)	0.826 (0.028)	0.731 (0.020)
20 Apr–26 Apr	22,285	0.881 (0.010)	0.914 (0.022)	0.947 (0.029)	0.763 (0.016)
27 Apr–3 May	10,294	0.918 (0.016)	0.999 (0.032)	0.958 (0.043)	0.879 (0.031)
4 May–10 May	13,857	1.003 (0.022)	0.945 (0.044)	0.878 (0.053)	0.832 (0.037)
11 May–17 May	4,039	0.917 (0.021)	0.910 (0.038)	0.794 (0.074)	0.662 (0.058)
18 May–24 May	4,910	0.941 (0.014)	0.894 (0.030)	0.901 (0.073)	0.758 (0.058)
25 May–31 May	1,006	0.989 (0.043)	1.018 (0.114)	0.888 (0.189)	0.895 (0.166)
Weighted mean[a]		**0.940 (0.007)**	**0.919 (0.010)**	**0.894 (0.017)**	**0.768 (0.015)**

a Weighted mean estimates for daily groups (24 Mar–31 May; see Table 5)

For weekly groups of yearling Chinook salmon, we estimated survival probabilities from McNary Dam to multiple dams on the Columbia River for six consecutive weeks during 20 April-31 May. Survival estimates averaged 0.912 (se 0.053) from McNary to John Day, 0.752 (0.104) from John Day to Bonneville, and 0.715 (0.107) for the combined reach from McNary to Bonneville Dam (Table 3).

Table 3. Estimated survival probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned to the tailrace of McNary Dam in 2014. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival of yearling Chinook salmon from McNary Dam (SE)		
Date at McNary Dam	Number Released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
20 Apr–26 Apr	2,830	0.783 (0.057)	0.728 (0.293)	0.570 (0.226)
27 Apr–3 May	8,451	0.860 (0.049)	0.617 (0.127)	0.530 (0.105)
4 May–10 May	11,607	0.924 (0.053)	0.977 (0.200)	0.902 (0.177)
11 May–17 May	16,039	1.074 (0.087)	0.918 (0.189)	0.986 (0.186)
18 May–24 May	3,906	1.378 (0.256)	0.292 (0.086)	0.402 (0.092)
25 May–31 May	860	0.880 (0.181)	0.448 (0.280)	0.394 (0.233)
Weighted mean		**0.912 (0.053)**	**0.752 (0.104)**	**0.715 (0.107)**

We calculated the product of average estimates from Lower Granite to McNary and from McNary to Bonneville Dam to provide an overall survival estimate of 0.549 (se 0.083) from Lower Granite to Bonneville Dam. For wild and hatchery yearling Chinook salmon released from the Snake River trap, estimated survival was 0.905 (0.015) from release to the tailrace of Lower Granite Dam. Thus, estimated survival probability through all eight hydropower projects encountered by Snake River yearling Chinook salmon was 0.497 (se 0.075).

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for weekly groups of hatchery and wild yearling Chinook salmon (Table 4). Weighted mean survival estimates for Lower Granite to McNary Dam tailrace was lower for wild than for hatchery groups, with the biggest difference in the Lower Monumental to McNary reach.

Table 4. Estimated survival probabilities for weekly groups of Snake River hatchery and wild yearling Chinook salmon detected and returned or tagged and released to the tailrace at Lower Granite Dam in 2014. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival from Lower Granite Dam(SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
		Hatchery yearling Chinook			
30 Mar–5 Apr	536	0.876 (0.050)	0.817 (0.103)	0.967 (0.166)	0.692 (0.092)
6 Apr–12 Apr	720	0.920 (0.041)	0.854 (0.090)	0.931 (0.136)	0.732 (0.083)
13 Apr–19 Apr	3,615	0.936 (0.018)	0.925 (0.048)	0.952 (0.066)	0.824 (0.041)
20 Apr–26 Apr	14,377	0.983 (0.017)	0.914 (0.036)	0.963 (0.045)	0.865 (0.025)
27 Apr–3 May	7,826	0.964 (0.028)	0.948 (0.047)	0.976 (0.058)	0.892 (0.038)
4 May–10 May	11,042	1.029 (0.028)	0.977 (0.057)	0.880 (0.066)	0.885 (0.048)
11 May–17 May	1,560	0.978 (0.064)	0.878 (0.094)	0.942 (0.215)	0.809 (0.172)
18 May–24 May	1,460	0.953 (0.051)	0.902 (0.098)	1.324 (0.340)	1.139 (0.272)
Weighted mean		**0.967 (0.013)**	**0.924 (0.013)**	**0.955 (0.019)**	**0.861 (0.017)**
		Wild yearling Chinook			
30 Mar–5 Apr	673	0.907 (0.028)	0.988 (0.084)	0.787 (0.103)	0.705 (0.073)
6 Apr–12 Apr	4,018	0.929 (0.013)	0.886 (0.029)	0.850 (0.042)	0.699 (0.029)
13 Apr–19 Apr	6,247	0.964 (0.009)	0.919 (0.024)	0.778 (0.030)	0.689 (0.022)
20 Apr–26 Apr	7,908	0.754 (0.012)	0.909 (0.028)	0.874 (0.036)	0.599 (0.020)
27 Apr–3 May	2,468	0.949 (0.019)	0.959 (0.038)	0.898 (0.065)	0.817 (0.052)
4 May–10 May	2,815	0.995 (0.033)	0.866 (0.063)	0.822 (0.083)	0.708 (0.056)
11 May–17 May	2,479	0.956 (0.022)	0.901 (0.040)	0.753 (0.076)	0.649 (0.061)
18 May–24 May	3,450	0.984 (0.014)	0.881 (0.030)	0.827 (0.069)	0.718 (0.056)
25 May–31 May	881	1.007 (0.047)	0.956 (0.111)	0.973 (0.224)	0.937 (0.191)
Weighted mean		**0.934 (0.025)**	**0.909 (0.010)**	**0.832 (0.017)**	**0.678 (0.022)**

We estimated survival probabilities for daily groups of yearling Chinook salmon (hatchery and wild combined) either detected at Lower Granite Dam and returned to the tailrace or PIT-tagged at the dam and released to the tailrace. These estimates were variable, and any patterns in survival through Snake River reaches during the 2014 migration season were difficult to visually separate from statistical sampling error (Table 5; Figure 2).

Table 5. Estimated survival probabilities for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or PIT tagged and released to the tailrace at Lower Granite Dam in 2014. Daily groups were pooled as needed for sufficient sample size on the dates indicated. Weighted means are of independent estimates for daily groups. Standard errors in parentheses.

		Estimated survival of yearling Chinook salmon from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
24–28 Mar	218	0.832 (0.058)	0.948 (0.174)	0.817 (0.233)	0.644 (0.149)
29 Mar	140	1.071 (0.122)	0.690 (0.210)	0.954 (0.521)	0.706 (0.335)
30 Mar	138	0.894 (0.090)	0.861 (0.213)	1.054 (0.432)	0.810 (0.281)
31 Mar	142	0.818 (0.074)	0.826 (0.166)	0.872 (0.245)	0.589 (0.135)
1 Apr	160	0.928 (0.076)	0.870 (0.158)	0.854 (0.210)	0.690 (0.134)
2 Apr	166	0.928 (0.064)	0.867 (0.154)	0.932 (0.242)	0.750 (0.157)
3 Apr	164	0.826 (0.052)	0.982 (0.155)	0.853 (0.195)	0.692 (0.122)
4 Apr	199	0.968 (0.071)	1.157 (0.262)	0.520 (0.154)	0.583 (0.117)
5 Apr	240	0.839 (0.052)	0.967 (0.151)	1.057 (0.286)	0.857 (0.196)
6 Apr	209	0.886 (0.050)	0.812 (0.107)	1.113 (0.215)	0.801 (0.130)
7 Apr	210	1.026 (0.099)	0.570 (0.090)	1.135 (0.242)	0.664 (0.133)
8 Apr	145	0.950 (0.093)	0.679 (0.127)	0.817 (0.216)	0.527 (0.120)
9 Apr	1,549	0.913 (0.022)	0.915 (0.051)	0.777 (0.061)	0.649 (0.040)
10 Apr	2,120	0.927 (0.018)	0.902 (0.040)	0.863 (0.061)	0.721 (0.043)
11 Apr	159	1.006 (0.073)	0.832 (0.161)	1.308 (0.484)	1.095 (0.358)
12 Apr	346	0.931 (0.045)	0.977 (0.136)	0.932 (0.217)	0.847 (0.164)
13 Apr	427	0.910 (0.042)	0.922 (0.100)	0.901 (0.143)	0.756 (0.096)
14 Apr	487	0.919 (0.040)	0.875 (0.094)	0.931 (0.142)	0.749 (0.089)
15 Apr	772	0.923 (0.028)	1.039 (0.088)	0.707 (0.085)	0.678 (0.060)
16 Apr	2,564	0.950 (0.013)	0.943 (0.041)	0.779 (0.050)	0.698 (0.035)
17 Apr	3,100	0.964 (0.016)	0.884 (0.034)	0.849 (0.050)	0.723 (0.035)
18 Apr	1,338	0.947 (0.026)	1.091 (0.097)	0.737 (0.085)	0.762 (0.060)
19 Apr	1,174	0.936 (0.026)	0.885 (0.061)	0.982 (0.101)	0.813 (0.066)
20 Apr	1,265	0.892 (0.026)	0.969 (0.068)	1.009 (0.109)	0.872 (0.075)
21 Apr	1,385	0.962 (0.035)	0.795 (0.057)	1.244 (0.138)	0.951 (0.088)
22 Apr	2,895	0.920 (0.026)	0.989 (0.064)	0.851 (0.069)	0.774 (0.041)
23 Apr	2,903	0.941 (0.032)	0.853 (0.057)	1.061 (0.088)	0.852 (0.050)
24 Apr	4,425	0.937 (0.024)	0.894 (0.043)	0.972 (0.058)	0.814 (0.035)
25 Apr	6,214	0.732 (0.021)	0.961 (0.059)	0.783 (0.057)	0.550 (0.024)
26 Apr	3,198	1.047 (0.042)	0.958 (0.090)	0.914 (0.104)	0.917 (0.062)
27 Apr	2,421	0.915 (0.039)	0.972 (0.080)	1.043 (0.115)	0.927 (0.074)
28 Apr	2,111	0.912 (0.044)	1.138 (0.108)	0.895 (0.108)	0.929 (0.079)
29 Apr	1,433	0.887 (0.052)	1.128 (0.127)	0.826 (0.114)	0.827 (0.078)

Table 5. Continued.

		Estimated survival of yearling Chinook salmon from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
30 Apr	910	0.992 (0.083)	0.934 (0.146)	0.803 (0.138)	0.744 (0.081)
1 May	1,073	0.920 (0.036)	0.931 (0.063)	1.023 (0.122)	0.876 (0.092)
2 May	1,076	0.954 (0.035)	0.984 (0.068)	1.046 (0.127)	0.982 (0.104)
3 May	1,270	0.911 (0.042)	0.937 (0.073)	0.884 (0.092)	0.755 (0.063)
4 May	1,864	0.986 (0.058)	1.038 (0.125)	0.924 (0.128)	0.946 (0.086)
5 May	2,321	1.016 (0.057)	0.970 (0.103)	0.985 (0.136)	0.972 (0.102)
6 May	2,785	1.034 (0.048)	0.834 (0.088)	1.007 (0.149)	0.868 (0.099)
7 May	2,192	0.894 (0.038)	0.851 (0.100)	0.904 (0.140)	0.688 (0.075)
8 May	1,865	1.009 (0.063)	1.194 (0.203)	0.550 (0.112)	0.662 (0.084)
9 May	1,744	0.962 (0.066)	0.949 (0.116)	0.842 (0.145)	0.768 (0.107)
10 May	1,086	0.942 (0.081)	0.968 (0.141)	1.002 (0.242)	0.914 (0.193)
11 May	493	0.742 (0.085)	0.961 (0.172)	1.121 (0.471)	0.800 (0.317)
12 May	342	0.987 (0.156)	0.849 (0.193)	0.851 (0.394)	0.713 (0.310)
13 May	714	0.954 (0.061)	0.858 (0.092)	0.665 (0.134)	0.545 (0.100)
14 May	780	0.936 (0.034)	0.801 (0.053)	1.082 (0.232)	0.811 (0.169)
15 May	473	0.914 (0.040)	0.914 (0.085)	1.024 (0.299)	0.856 (0.241)
16 May	522	1.073 (0.077)	0.887 (0.109)	0.556 (0.116)	0.529 (0.097)
17–19 May	2,029	0.962 (0.040)	0.966 (0.083)	0.898 (0.150)	0.835 (0.125)
20 May	881	1.010 (0.038)	0.924 (0.076)	0.813 (0.154)	0.759 (0.133)
21 May	838	0.917 (0.027)	0.929 (0.065)	1.000 (0.210)	0.852 (0.171)
22 May	662	0.990 (0.026)	0.842 (0.056)	0.740 (0.130)	0.616 (0.102)
23 May	634	1.022 (0.038)	0.818 (0.064)	0.862 (0.157)	0.721 (0.123)
24 May	581	1.026 (0.035)	0.875 (0.076)	0.730 (0.132)	0.655 (0.107)
25 May	115	1.064 (0.104)	1.122 (0.345)	0.422 (0.208)	0.503 (0.200)
26 May	125	0.953 (0.093)	1.085 (0.361)	0.417 (0.202)	0.431 (0.157)
27-31 May	766	0.986 (0.054)	0.979 (0.127)	1.156 (0.308)	1.116 (0.266)
Weighted mean		**0.940 (0.007)**	**0.919 (0.010)**	**0.894 (0.017)**	**0.768 (0.015)**

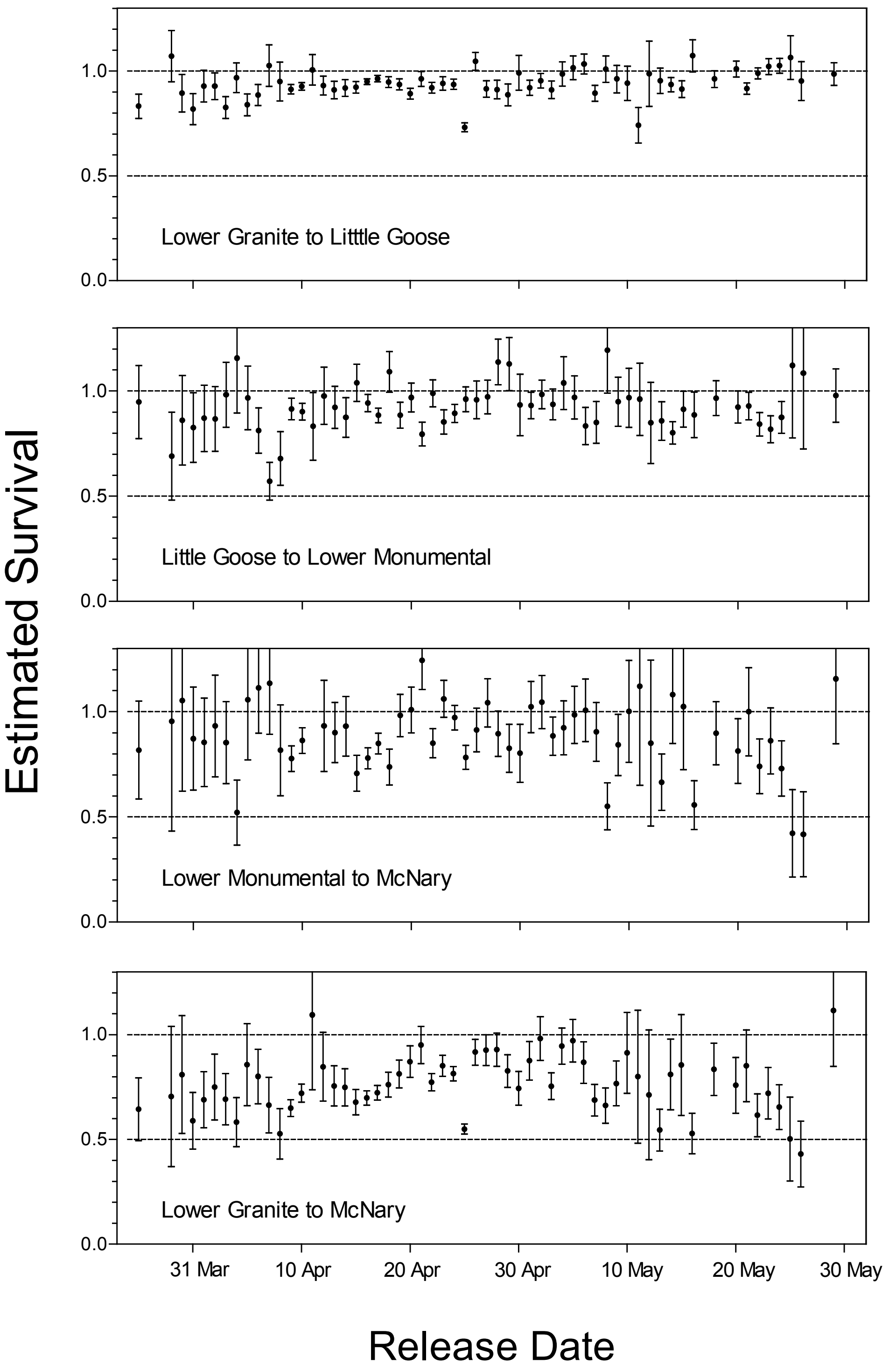

Figure 2. Estimated survival probabilities through various reaches by release date at Lower Granite Dam for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined), 2014. Bars extend one standard error above and below point estimates.

Detection Probabilities—For most weekly groups of yearling Chinook salmon, estimates of detection probability varied throughout the season with changing flow volumes, spill levels, and degrees of smoltification (Tables 6-8). Detection probability estimates were generally highest at Little Goose Dam and lowest at John Day and Bonneville Dams. Detection probability estimates were typically higher for wild than for hatchery fish released during the same week (Table 8).

Table 6. Estimated detection probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or PIT tagged and released to the tailrace of Lower Granite Dam in 2014. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon from Lower Granite Dam release groups (SE)			
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
23 Mar–29 Mar	358	0.550 (0.042)	0.260 (0.047)	0.228 (0.056)
30 Mar–5 Apr	1,209	0.551 (0.021)	0.251 (0.022)	0.281 (0.028)
6 Apr–12 Apr	4,738	0.543 (0.010)	0.296 (0.011)	0.331 (0.015)
13 Apr–19 Apr	9,862	0.572 (0.007)	0.261 (0.007)	0.306 (0.010)
20 Apr–26 Apr	20,623	0.300 (0.005)	0.193 (0.005)	0.280 (0.007)
27 Apr–3 May	10,294	0.281 (0.007)	0.249 (0.008)	0.296 (0.012)
4 May–10 May	13,857	0.240 (0.006)	0.113 (0.005)	0.172 (0.008)
11 May–17 May	4,039	0.346 (0.011)	0.392 (0.016)	0.129 (0.013)
18 May–24 May	4,910	0.489 (0.010)	0.372 (0.013)	0.111 (0.010)
25 May–31 May	1,006	0.419 (0.024)	0.202 (0.024)	0.102 (0.022)

Table 7. Estimated detection probabilities for Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or released to the tailrace of McNary Dam in 2014. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon from McNary Dam release groups (SE)		
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
20 Apr–26 Apr	2,830	0.370 (0.028)	0.159 (0.064)
27 Apr–3 May	8,451	0.269 (0.016)	0.136 (0.028)
4 May–10 May	11,607	0.186 (0.011)	0.094 (0.019)
11 May–17 May	16,039	0.078 (0.007)	0.088 (0.017)
18 May–24 May	3,906	0.062 (0.012)	0.231 (0.054)
25 May–31 May	860	0.185 (0.040)	0.254 (0.152)

Table 8. Estimated detection probabilities for Snake River hatchery and wild yearling Chinook salmon detected and returned or released to the tailrace of Lower Granite Dam in 2014. Daily groups were pooled to form weekly estimates. Standard errors in parentheses.

		Estimated detection probability for Lower Granite Dam release groups (SE)		
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery Yearling Chinook		
30 Mar–5 Apr	536	0.449 (0.034)	0.214 (0.032)	0.268 (0.042)
6 Apr–12 Apr	720	0.477 (0.028)	0.222 (0.028)	0.294 (0.039)
13 Apr–19 Apr	3,615	0.455 (0.012)	0.183 (0.011)	0.280 (0.016)
20 Apr–26 Apr	14,370	0.248 (0.006)	0.159 (0.006)	0.251 (0.008)
27 Apr–3 May	7,826	0.218 (0.008)	0.205 (0.009)	0.298 (0.014)
4 May–10 May	11,042	0.210 (0.007)	0.095 (0.006)	0.159 (0.009)
11 May–17 May	1,560	0.202 (0.017)	0.278 (0.026)	0.084 (0.020)
18 May–24 May	1,460	0.302 (0.020)	0.217 (0.023)	0.059 (0.015)
		Wild Yearling Chinook		
30 Mar–5 Apr	673	0.616 (0.026)	0.278 (0.029)	0.290 (0.036)
6 Apr–12 Apr	4,018	0.553 (0.011)	0.309 (0.012)	0.337 (0.016)
13 Apr–19 Apr	6,247	0.633 (0.008)	0.306 (0.010)	0.320 (0.012)
20 Apr–26 Apr	6,253	0.402 (0.009)	0.255 (0.009)	0.337 (0.013)
27 Apr–3 May	2,468	0.430 (0.013)	0.384 (0.017)	0.291 (0.021)
4 May–10 May	2,815	0.342 (0.014)	0.177 (0.014)	0.216 (0.019)
11 May–17 May	2,479	0.410 (0.014)	0.444 (0.020)	0.148 (0.016)
18 May–24 May	3,450	0.542 (0.012)	0.421 (0.016)	0.127 (0.012)
25 May–31 May	881	0.420 (0.026)	0.215 (0.027)	0.100 (0.023)

Snake River Steelhead

Survival Probabilities—For weekly groups of steelhead, we estimated probabilities of survival from Lower Granite Dam to multiple downstream dams for 10 consecutive weeks during 30 March-7 June. Average estimated survival was 0.953 (se 0.009) from Lower Granite to Little Goose, 0.947 (0.024) from Little Goose to Lower Monumental, and 0.836 (0.032) from Lower Monumental to McNary Dam (Table 9). For the combined reach from Lower Granite to McNary Dam tailrace, estimated survival averaged 0.740 (0.021).

Table 9. Estimated survival probabilities for weekly groups of juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of Lower Granite Dam in 2014. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for daily groups. Standard errors in parentheses.

	Estimated survival of steelhead from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
30 Mar–5 Apr	765	1.025 (0.048)	0.673 (0.081)	0.950 (0.190)	0.655 (0.112)
6 Apr–12 Apr	2,221	0.996 (0.034)	0.822 (0.077)	0.648 (0.080)	0.531 (0.047)
13 Apr–19 Apr	4,595	0.970 (0.027)	0.850 (0.064)	0.904 (0.087)	0.745 (0.050)
20 Apr–26 Apr	12,376	0.909 (0.018)	0.978 (0.048)	0.921 (0.058)	0.819 (0.035)
27 Apr–3 May	11,894	0.980 (0.017)	0.919 (0.036)	0.963 (0.064)	0.867 (0.049)
4 May–10 May	10,255	1.042 (0.025)	0.875 (0.053)	0.743 (0.074)	0.677 (0.056)
11 May–17 May	6,969	0.898 (0.024)	1.128 (0.072)	0.617 (0.085)	0.625 (0.077)
18 May–24 May	9,094	0.877 (0.012)	1.099 (0.042)	0.696 (0.081)	0.670 (0.074)
25 May–31 May	2,935	0.973 (0.022)	0.892 (0.061)	0.466 (0.070)	0.404 (0.054)
1 Jun–7 Jun	1,789	0.818 (0.049)	0.973 (0.118)	0.681 (0.137)	0.542 (0.093)
Weighted mean*		**0.953 (0.009)**	**0.947 (0.024)**	**0.836 (0.032)**	**0.740 (0.021)**

* Weighted mean of estimates for daily groups (24 Mar–31 May; see Table 12)

For steelhead detected and returned to the tailrace of McNary Dam, we estimated probabilities of survival to multiple dams downstream for 6 consecutive weeks during 20 April-31 May. Detection rates were very low at John Day and Bonneville Dams and the towed array, which resulted in survival estimates with low precision. Mean estimated survival was 1.082 (SE 0.080) from McNary to John Day, 0.982 (SE 0.147) from John Day to Bonneville, and 1.023 (SE 0.088) for the entire reach from McNary to Bonneville Dam (Table 10).

Table 10. Estimated survival probabilities for weekly groups of juvenile Snake River steelhead (hatchery and wild combined) from McNary Dam in 2014. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

	Estimated survival of steelhead from McNary Dam (SE)			
Date at McNary Dam	Number released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
20 Apr–26 Apr	1,003	1.266 (0.280)	0.986 (0.692)	1.248 (0.831)
27 Apr–3 May	3,982	1.030 (0.106)	1.106 (0.347)	1.139 (0.337)
4 May–10 May	3,469	1.321 (0.186)	0.590 (0.184)	0.779 (0.216)
11 May–17 May	2,490	0.823 (0.146)	1.542 (0.784)	1.269 (0.605)
18 May–24 May	847	0.810 (0.225)	1.297 (0.936)	1.051 (0.700)
25 May–31 May	572	1.206 (0.446)	0.993 (1.010)	1.198 (1.135)
Weighted mean		**1.082 (0.080)**	**0.982 (0.147)**	**1.023 (0.088)**

We calculated the product of mean estimates from Lower Granite to McNary and from McNary to Bonneville Dam. This product provided an overall survival estimate of 0.757 (SE 0.069) from Lower Granite to Bonneville Dam. For wild and hatchery steelhead released from the Snake River trap, estimated survival probability to Lower Granite Dam tailrace was 1.018 (0.028). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.771 (0.073).

Separate survival probabilities were estimated for weekly groups of hatchery and wild steelhead (Table 11). Tailrace-to-tailrace survival estimates through most individual and combined reaches differed substantially between wild and hatchery steelhead in some weeks, but many of those differences were likely due to sampling variation.

Table 11. Estimated survival probabilities for weekly groups of juvenile Snake River hatchery and wild steelhead detected and returned or tagged and released to the tailrace of Lower Granite Dam, 2014. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

	Estimated survival for Lower Granite Dam releases (SE)				
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
	Hatchery steelhead				
30 Mar–5 Apr	641	1.058 (0.052)	0.667 (0.084)	0.987 (0.206)	0.697 (0.125)
6 Apr–12 Apr	1,795	1.006 (0.037)	0.783 (0.077)	0.699 (0.096)	0.551 (0.058)
13 Apr–19 Apr	3,121	0.980 (0.035)	0.829 (0.077)	1.013 (0.124)	0.823 (0.072)
20 Apr–26 Apr	11,260	0.916 (0.020)	0.967 (0.051)	0.920 (0.062)	0.814 (0.037)
27 Apr–3 May	9,849	0.995 (0.021)	0.906 (0.042)	1.034 (0.082)	0.932 (0.064)
4 May–10 May	7,194	1.033 (0.030)	0.899 (0.065)	0.786 (0.098)	0.731 (0.078)
11 May–17 May	3,902	0.945 (0.036)	1.084 (0.096)	0.647 (0.126)	0.662 (0.117)
18 May–24 May	4,256	0.828 (0.019)	1.252 (0.082)	0.588 (0.104)	0.610 (0.101)
25 May–31 May	1,871	0.992 (0.028)	0.915 (0.079)	0.440 (0.076)	0.399 (0.061)
1 Jun–7 Jun	1,022	0.866 (0.073)	0.981 (0.164)	0.645 (0.166)	0.549 (0.117)
Weighted mean		**0.953 (0.023)**	**0.955 (0.046)**	**0.873 (0.056)**	**0.777 (0.043)**
	Wild steelhead				
6 Apr–12 Apr	426	0.950 (0.086)	1.109 (0.324)	0.425 (0.136)	0.448 (0.071)
13 Apr–19 Apr	1,474	0.945 (0.041)	0.879 (0.113)	0.689 (0.108)	0.572 (0.058)
20 Apr–26 Apr	1,116	0.872 (0.045)	1.058 (0.154)	0.845 (0.158)	0.780 (0.097)
27 Apr–3 May	2,045	0.970 (0.030)	0.933 (0.068)	0.727 (0.085)	0.657 (0.063)
4 May–10 May	3,061	1.048 (0.042)	0.828 (0.093)	0.663 (0.110)	0.575 (0.074)
11 May–17 May	3,067	0.850 (0.031)	1.176 (0.107)	0.586 (0.113)	0.585 (0.102)
18 May–24 May	4,838	0.920 (0.015)	1.004 (0.048)	0.775 (0.120)	0.716 (0.106)
25 May–31 May	1,064	0.939 (0.034)	0.842 (0.094)	0.552 (0.166)	0.436 (0.123)
1 Jun–7 Jun	767	0.761 (0.064)	0.948 (0.168)	0.731 (0.236)	0.528 (0.150)
Weighted mean		**0.929 (0.018)**	**0.980 (0.034)**	**0.701 (0.032)**	**0.620 (0.034)**

For daily release groups of steelhead (hatchery and wild combined) returned or released to the tailrace of Lower Granite Dam, estimated survival probabilities were variable and had relatively poor precision. The most notable pattern is the relative decrease in estimated survival from Lower Monumental to McNary Dam tailrace from 23-31 May (Table 12; Figure 3).

Table 12. Estimated survival probabilities for daily groups of Snake River juvenile steelhead (hatchery and wild combined) detected and returned or PIT tagged and released to the tailrace of Lower Granite Dam in 2014. Daily groups pooled as needed for sufficient sample size on the dates indicated. Weighted means are of independent estimates for daily groups. Standard errors in parentheses.

		Estimated survival of steelhead daily groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
23 Mar-1 Apr	441	1.046 (0.054)	0.668 (0.100)	0.957 (0.250)	0.668 (0.151)
2 Apr	154	0.890 (0.101)	0.753 (0.205)	0.878 (0.406)	0.589 (0.232)
3-4 Apr	152	0.994 (0.123)	0.697 (0.217)	1.084 (0.590)	0.751 (0.359)
5 Apr	73	1.063 (0.184)	0.815 (0.302)	0.975 (0.639)	0.845 (0.487)
6-8 Apr	195	0.989 (0.108)	0.794 (0.218)	1.138 (0.626)	0.894 (0.441)
9 Apr	905	0.975 (0.049)	0.739 (0.096)	0.624 (0.106)	0.450 (0.058)
10 Apr	937	0.996 (0.053)	0.862 (0.138)	0.631 (0.129)	0.542 (0.076)
11-13 Apr	302	1.015 (0.102)	1.268 (0.454)	0.488 (0.197)	0.628 (0.129)
14-15 Apr	282	1.089 (0.136)	1.240 (0.569)	0.393 (0.204)	0.530 (0.146)
16 Apr	1,035	0.951 (0.050)	1.056 (0.176)	0.928 (0.209)	0.932 (0.150)
17 Apr	2,370	0.959 (0.036)	0.832 (0.088)	0.847 (0.109)	0.676 (0.056)
18-19 Apr	790	1.012 (0.083)	0.611 (0.097)	1.454 (0.349)	0.900 (0.185)
20 Apr	554	0.946 (0.059)	1.051 (0.226)	0.844 (0.238)	0.840 (0.159)
21 Apr	517	0.955 (0.073)	0.921 (0.156)	1.002 (0.239)	0.881 (0.160)
22 Apr	1,108	0.952 (0.049)	0.813 (0.100)	1.302 (0.230)	1.009 (0.139)
23 Apr	1,517	0.912 (0.050)	0.992 (0.162)	0.865 (0.165)	0.783 (0.085)
24 Apr	3,217	0.851 (0.037)	1.152 (0.134)	0.819 (0.110)	0.803 (0.062)
25 Apr	3,290	0.902 (0.040)	0.887 (0.075)	0.926 (0.112)	0.741 (0.070)
26 Apr	2,173	0.970 (0.047)	1.174 (0.212)	0.726 (0.156)	0.826 (0.091)
27 Apr	1,666	0.888 (0.038)	1.091 (0.226)	0.791 (0.202)	0.766 (0.108)
28 Apr	1,577	1.093 (0.079)	0.828 (0.153)	0.960 (0.242)	0.869 (0.156)
29 Apr	1,053	1.222 (0.142)	0.683 (0.160)	1.007 (0.326)	0.840 (0.209)
30 Apr	659	1.151 (0.172)	0.536 (0.129)	1.268 (0.425)	0.781 (0.219)

Table 12. Continued.

		Estimated survival of steelhead daily groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
1 May	2,152	0.958 (0.041)	0.999 (0.087)	0.885 (0.132)	0.848 (0.109)
2 May	2,309	0.998 (0.036)	0.921 (0.074)	0.834 (0.116)	0.767 (0.091)
3 May	2,478	0.997 (0.031)	0.859 (0.051)	1.082 (0.134)	0.927 (0.106)
4 May	389	0.985 (0.116)	1.102 (0.279)	0.598 (0.202)	0.649 (0.163)
5 May	479	0.875 (0.074)	1.074 (0.225)	1.006 (0.322)	0.946 (0.240)
6 May	1,110	1.076 (0.082)	0.929 (0.151)	0.712 (0.159)	0.711 (0.123)
7 May	2,249	1.099 (0.056)	1.027 (0.147)	0.663 (0.136)	0.748 (0.116)
8 May	2,318	1.069 (0.050)	0.804 (0.101)	0.759 (0.194)	0.652 (0.148)
9 May	2,509	0.948 (0.043)	0.830 (0.108)	0.810 (0.206)	0.638 (0.142)
10 May	1,201	1.017 (0.089)	0.713 (0.139)	1.028 (0.454)	0.745 (0.303)
11-12 May	440	0.777 (0.097)	1.583 (0.604)	0.420 (0.221)	0.517 (0.195)
13 May	1,064	1.019 (0.108)	0.713 (0.135)	1.054 (0.421)	0.766 (0.282)
14 May	1,363	0.883 (0.063)	1.709 (0.354)	0.387 (0.122)	0.584 (0.145)
15 May	1,173	0.942 (0.047)	0.894 (0.134)	0.806 (0.276)	0.679 (0.212)
16 May	1,361	0.943 (0.035)	1.203 (0.132)	0.556 (0.174)	0.630 (0.186)
17 May	1,568	0.868 (0.063)	1.006 (0.127)	0.668 (0.196)	0.584 (0.160)
18-19 May	1,063	0.860 (0.073)	1.383 (0.285)	0.982 (0.560)	1.169 (0.628)
20 May	1,579	0.914 (0.054)	0.956 (0.105)	0.942 (0.333)	0.823 (0.281)
21 May	2,236	0.857 (0.025)	1.060 (0.091)	0.775 (0.190)	0.704 (0.162)
22 May	1,699	0.921 (0.019)	0.958 (0.064)	1.069 (0.333)	0.942 (0.288)
23 May	1,758	0.942 (0.020)	1.265 (0.107)	0.358 (0.066)	0.426 (0.069)
24 May	759	1.028 (0.045)	0.866 (0.091)	0.720 (0.267)	0.640 (0.230)
25 May	194	0.940 (0.064)	1.097 (0.297)	0.245 (0.138)	0.253 (0.125)
26 May	308	0.907 (0.048)	0.968 (0.169)	0.437 (0.186)	0.384 (0.151)
27 May	170	0.999 (0.081)	0.766 (0.206)	0.286 (0.124)	0.219 (0.078)
28 May	852	0.920 (0.033)	0.881 (0.109)	0.679 (0.254)	0.550 (0.196)
29 May	509	1.079 (0.074)	0.701 (0.107)	0.425 (0.123)	0.321 (0.082)
30-31 May	902	1.034 (0.050)	0.958 (0.137)	0.472 (0.129)	0.468 (0.112)
Weighted mean		**0.953 (0.009)**	**0.947 (0.024)**	**0.836 (0.032)**	**0.740 (0.021)**

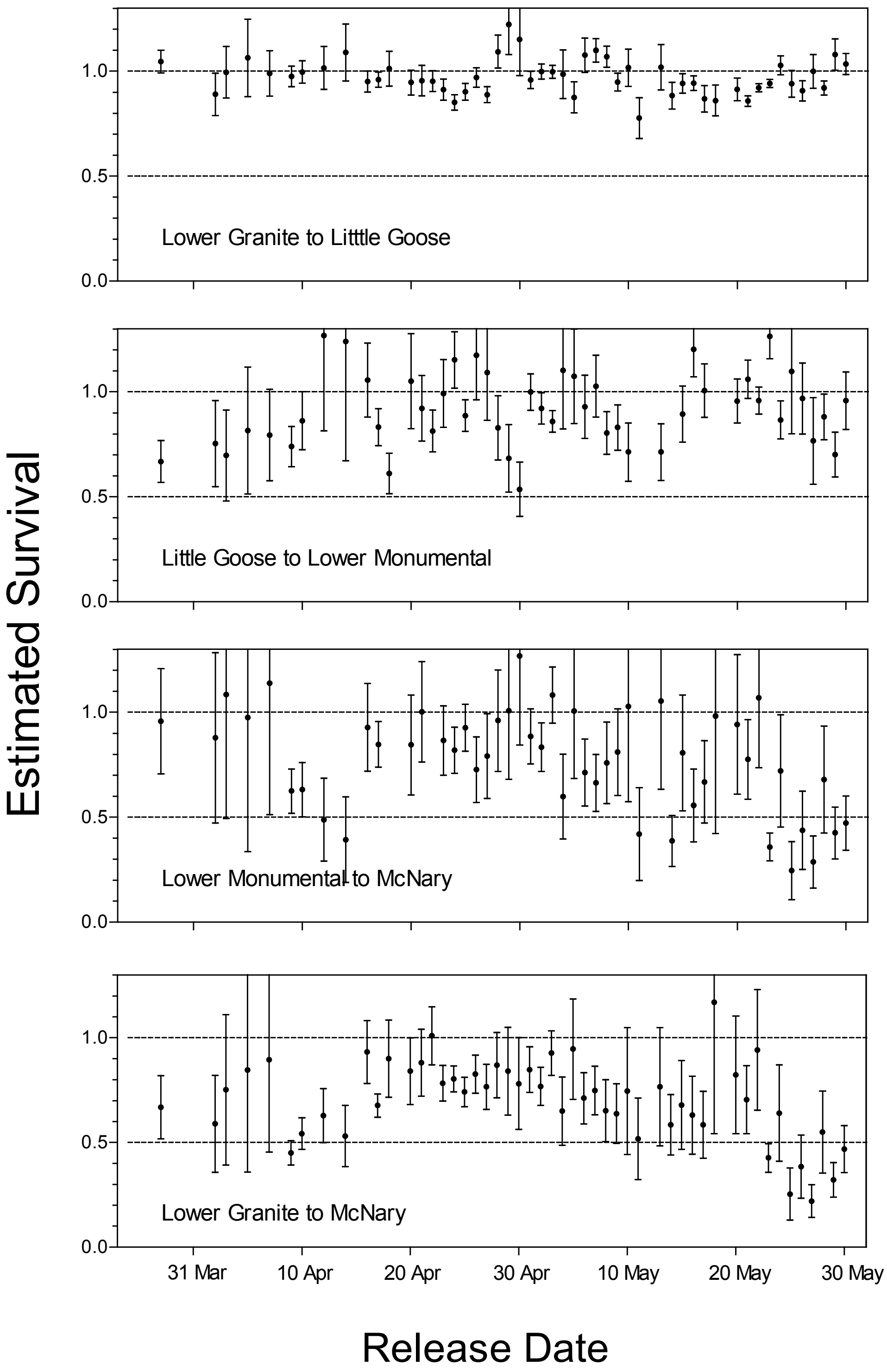

Figure 3. Estimated survival probabilities through various reaches versus release date at Lower Granite Dam for daily release groups of Snake River steelhead (hatchery and wild combined), 2014. Bars extend one standard error above and below point estimates.

Detection Probabilities—For weekly groups of steelhead, estimated detection probabilities were low at all of the Snake and Columbia River dams, with Little Goose Dam having the highest estimates (Tables 13-15). Detection probability estimates were generally higher for wild fish than for hatchery fish (Table 15).

Table 13. Estimated detection probabilities for juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of Lower Granite Dam, 2014. Weekly estimates from pooled daily groups. Standard errors in parentheses.

Estimated detection probability of steelhead from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
30 Mar–5 Apr	765	0.529 (0.031)	0.238 (0.032)	0.186 (0.036)
6 Apr–12 Apr	2,221	0.459 (0.019)	0.159 (0.016)	0.189 (0.020)
13 Apr–19 Apr	4,595	0.370 (0.012)	0.098 (0.008)	0.172 (0.013)
20 Apr–26 Apr	12,181	0.270 (0.007)	0.117 (0.006)	0.147 (0.007)
27 Apr–3 May	11,894	0.324 (0.007)	0.200 (0.008)	0.115 (0.007)
4 May–10 May	10,255	0.326 (0.009)	0.137 (0.008)	0.096 (0.009)
11 May–17 May	6,969	0.303 (0.010)	0.201 (0.013)	0.063 (0.009)
18 May–24 May	9,094	0.465 (0.008)	0.320 (0.013)	0.061 (0.007)
25 May–31 May	2,935	0.530 (0.015)	0.326 (0.023)	0.108 (0.017)
1 Jun–7 Jun	1,789	0.271 (0.020)	0.194 (0.023)	0.113 (0.022)

Table 14. Estimated detection probabilities for weekly groups of juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of McNary Dam, 2014. Standard errors in parentheses.

Estimated detection probability of steelhead from McNary Dam (SE)			
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
20 Apr–26 Apr	1,003	0.120 (0.028)	0.092 (0.062)
27 Apr–3 May	3,982	0.130 (0.014)	0.101 (0.030)
4 May–10 May	3,469	0.101 (0.015)	0.122 (0.034)
11 May–17 May	2,490	0.090 (0.017)	0.074 (0.036)
18 May–24 May	847	0.102 (0.031)	0.085 (0.058)
25 May–31 May	572	0.087 (0.034)	0.085 (0.081)

Table 15. Estimated detection probabilities for juvenile Snake River hatchery and wild steelhead from the tailrace at Lower Granite Dam, 2014. Daily groups pooled weekly. Standard errors in parentheses.

Estimated detection probability of steelhead from Lower Granite Dam				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery steelhead		
30 Mar–5 Apr	641	0.537 (0.033)	0.237 (0.033)	0.182 (0.038)
6 Apr–12 Apr	1,795	0.472 (0.021)	0.175 (0.019)	0.163 (0.021)
13 Apr–19 Apr	3,121	0.341 (0.015)	0.093 (0.010)	0.136 (0.014)
20 Apr–26 Apr	11,118	0.260 (0.007)	0.117 (0.006)	0.140 (0.007)
27 Apr–3 May	9,849	0.301 (0.008)	0.187 (0.009)	0.095 (0.007)
4 May–10 May	7,194	0.306 (0.010)	0.140 (0.010)	0.080 (0.009)
11 May–17 May	3,902	0.283 (0.013)	0.190 (0.016)	0.054 (0.011)
18 May–24 May	4,256	0.420 (0.012)	0.268 (0.018)	0.057 (0.010)
25 May–31 May	1,871	0.514 (0.019)	0.308 (0.027)	0.117 (0.021)
1 Jun–7 Jun	1,022	0.243 (0.025)	0.174 (0.028)	0.110 (0.027)
		Wild steelhead		
6 Apr–12 Apr	426	0.398 (0.043)	0.092 (0.029)	0.318 (0.059)
13 Apr–19 Apr	1,474	0.435 (0.023)	0.111 (0.016)	0.280 (0.032)
20 Apr–26 Apr	1,063	0.359 (0.024)	0.116 (0.019)	0.230 (0.032)
27 Apr–3 May	2,045	0.418 (0.017)	0.258 (0.020)	0.231 (0.025)
4 May–10 May	3,061	0.376 (0.017)	0.129 (0.015)	0.139 (0.020)
11 May–17 May	3,067	0.326 (0.015)	0.216 (0.020)	0.074 (0.014)
18 May–24 May	4,838	0.500 (0.011)	0.362 (0.018)	0.065 (0.010)
25 May–31 May	1,064	0.560 (0.025)	0.365 (0.042)	0.089 (0.028)
1 Jun–7 Jun	767	0.310 (0.032)	0.225 (0.039)	0.118 (0.037)

Survival and Detection from Hatcheries and Smolt Traps

Snake River Hatchery Release Groups—For PIT-tagged hatchery yearling Chinook, sockeye salmon, and steelhead, we estimated survival probabilities from release at Snake River Basin hatcheries to the tailrace of Lower Granite Dam and to dams further downstream. These estimates varied among hatcheries and release locations (Appendix Tables B1-B3), as did estimated detection probabilities among detection sites (Appendix Tables B4-B6).

For yearling Chinook salmon, estimated survival to Lower Granite Dam ranged from 0.816 (se 0.009) for Dworshak Hatchery fish released from Dworshak Hatchery to 0.264 (0.005) for Lookingglass Hatchery fish released to Catherine Creek Pond. For steelhead, estimated survival to Lower Granite Dam ranged from 1.017 (0.033) for Magic Valley Hatchery fish released to the Little Salmon River to 0.616 (0.014) for Dworshak Hatchery fish released into Lolo Creek on the Clearwater River. For sockeye salmon released at Redfish Lake Creek Trap in spring, estimated survival to Lower Granite Dam ranged from 0.528 (0.017) for Sawtooth Hatchery fish to 0.468 (0.092) for Oxbow Hatchery fish.

Snake River Smolt Trap Release Groups—For wild and hatchery juvenile salmonids PIT tagged and released from Snake River Basin smolt traps, estimated probabilities of survival were generally inversely related to distance of the trap from Lower Granite Dam (Appendix Table B7). Estimated probabilities of detection were similar among release groups of the same species and rearing type from different traps (Appendix Table B8). However, for both wild yearling Chinook salmon and steelhead, estimated detection probabilities at Snake River dams were consistently higher than those of hatchery conspecifics released from the same location (i.e., Grande Ronde, Salmon, and Snake River traps). These higher probabilities of detection could be due to fish size (Zabel et al. 2005) but could also be partly due to differences in migration timing.

Upper Columbia River Hatchery Release Groups—We estimated probabilities of survival from release at Upper Columbia River hatcheries to the tailraces of McNary Dam and dams further downstream for yearling Chinook, coho salmon, and steelhead. These estimates varied among hatcheries and release locations (Appendix Table B9), as did estimates of detection probability (Appendix Table B10).

For yearling Chinook originating above the Yakima River, estimated survival from release to McNary Dam ranged from 0.767 (0.034) for Chelan Hatchery fish released to Dryden Pond on the Wenatchee River to 0.260 (0.034) for Wells Hatchery fish released from Wells Hatchery. For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.811 (0.232) for Wells Hatchery fish released to the Methow River to 0.332 (0.043) for Wells Hatchery fish released to Twisp Acclimation Pond on the Methow River. For Upper Columbia River coho salmon originating above the Yakima River, estimated survival to McNary Dam ranged from 0.517 (0.054) for Cascade Hatchery fish released from Twisp Acclimation Pond on the Methow River, to 0.352 (0.047) for Willard Hatchery fish released to Beaver Creek on the Methow River.

Survival Between Lower Monumental and Ice Harbor Dam

At Ice Harbor Dam, a PIT-tag detection system became operational in 2005. From 2006 to 2014, detections at Ice Harbor were sufficient to estimate tailrace-to-tailrace survival from Lower Monumental to Ice Harbor and from Ice Harbor to McNary Dam (Table 16).

Table 16. Estimated survival and detection probabilities from Lower Granite to Ice Harbor Dam for Snake River yearling Chinook salmon and steelhead (hatchery and wild combined), 2014. Estimates are for weekly release groups. Standard errors in parentheses.

		Estimated survival probability		
Date at Lower Granite	Number released	Lower Monumental to Ice Harbor Dam	Ice Harbor to McNary Dam	**Detection probability Ice Harbor Dam**
		Hatchery and wild yearling Chinook salmon		
23 Mar–29 Mar	358	0.618 (0.141)	1.369 (0.367)	0.122 (0.034)
30 Mar–5 Apr	1,209	0.894 (0.132)	0.896 (0.139)	0.069 (0.012)
6 Apr–12 Apr	4,738	1.042 (0.082)	0.826 (0.069)	0.055 (0.006)
13 Apr–19 Apr	9,862	0.917 (0.049)	0.908 (0.051)	0.055 (0.004)
20 Apr–26 Apr	20,623	0.975 (0.037)	0.969 (0.037)	0.069 (0.003)
27 Apr–3 May	10,294	0.900 (0.046)	1.059 (0.059)	0.076 (0.005)
4 May–10 May	13,857	0.778 (0.066)	1.114 (0.098)	0.030 (0.003)
11 May–17 May	4,039	0.877 (0.074)	0.905 (0.106)	0.106 (0.010)
18 May–24 May	4,910	1.094 (0.087)	0.839 (0.090)	0.085 (0.008)
25 May–31 May	1,006	0.866 (0.187)	1.040 (0.279)	0.062 (0.015)
Weighted mean		**0.940 (0.027)**	**0.967 (0.029)**	**0.057 (0.006)**
		Hatchery and wild steelhead		
30 Mar–5 Apr	765	1.147 (0.346)	0.811 (0.269)	0.044 (0.015)
6 Apr–12 Apr	2,221	0.722 (0.143)	0.865 (0.171)	0.035 (0.008)
13 Apr–19 Apr	4,595	0.775 (0.108)	1.184 (0.164)	0.028 (0.005)
20 Apr–26 Apr	12,181	0.878 (0.058)	1.026 (0.066)	0.070 (0.004)
27 Apr–3 May	11,894	0.801 (0.050)	1.261 (0.098)	0.072 (0.005)
4 May–10 May	10,255	0.976 (0.083)	0.761 (0.083)	0.085 (0.007)
11 May–17 May	6,969	1.022 (0.110)	0.730 (0.116)	0.076 (0.008)
18 May–24 May	9,094	1.116 (0.079)	0.694 (0.089)	0.124 (0.009)
25 May–31 May	2,935	1.444 (0.219)	0.338 (0.067)	0.090 (0.014)
1 Jun–7 Jun	1,789	1.204 (0.228)	0.630 (0.152)	0.084 (0.016)
Weighted mean		**0.954 (0.055)**	**0.974 (0.079)**	**0.065 (0.008)**

For yearling Chinook salmon in 2014, mean estimated survival was 0.940 (SE 0.027) from Lower Monumental to Ice Harbor Dam and 0.967 (0.029) from Ice Harbor to McNary Dam. For steelhead, estimated mean survival through these same respective reaches was 0.954 (0.055) and 0.974 (0.079). Detection probabilities were lower at Ice Harbor than at most other dams (Table 16).

Travel Time and Migration Rates

Methods

We calculated travel times of yearling Chinook salmon and steelhead for the following eight reaches:

- Lower Granite Dam to Little Goose Dam (60 km)
- Little Goose Dam to Lower Monumental Dam (46 km)
- Lower Monumental Dam to McNary Dam (119 km)
- Lower Granite Dam to McNary Dam (225 km)
- Lower Granite Dam to Bonneville Dam (461 km)
- McNary Dam to John Day Dam (123 km)
- John Day Dam to Bonneville Dam (113 km)
- McNary Dam to Bonneville Dam (236 km)

Travel time between any two dams was calculated only for fish detected at both dams and was defined as the number of days between last detection at the upstream dam and first detection at the downstream dam. Generally, the last detection at an upstream dam was on a PIT-tag detector close enough to the outfall site that fish would arrive in the tailrace within minutes of detection. Thus, travel time included the time required to move through the tailrace of the upstream dam, the reservoir, and the forebay of the downstream dam. This estimate encompassed any delays associated with dam passage such as residence in the forebay, gatewells, or collection channel of the downstream dam prior to detection in the juvenile bypass system.

Migration rate through a river section was calculated as the length of the reach (km) divided by the travel time (d), which included any delay at dams as noted above. We calculated the 20th percentile, median, and 80th percentile travel time and migration rate for each group.

The true complete set of travel times for individual fish within a release group includes travel times of both detected and non-detected fish. However, travel time based on PIT-tag detections cannot be determined for a fish that traverses a reach of river without being detected at both ends of the reach. Therefore, travel time statistics are computed only from the travel times of detected fish, and thus they represent a subsample of the complete release group. Non-detected fish pass dams via turbines and spill; thus, their time to pass a dam is typically minutes to hours shorter than that of detected fish, all of which pass the dam via the juvenile bypass system.

Results

We estimated travel time for yearling Chinook salmon and juvenile steelhead from the tailrace of Lower Granite and McNary Dams to multiple downstream sites. Estimated travel time decreased over the migration season (Tables 17-22). For both species, estimated migration rates were generally highest in the lower river sections. Estimated travel times for both species from Lower Granite to Bonneville Dam were similar to those in 2009, which was a year of similar flow level and pattern (Figure 4).

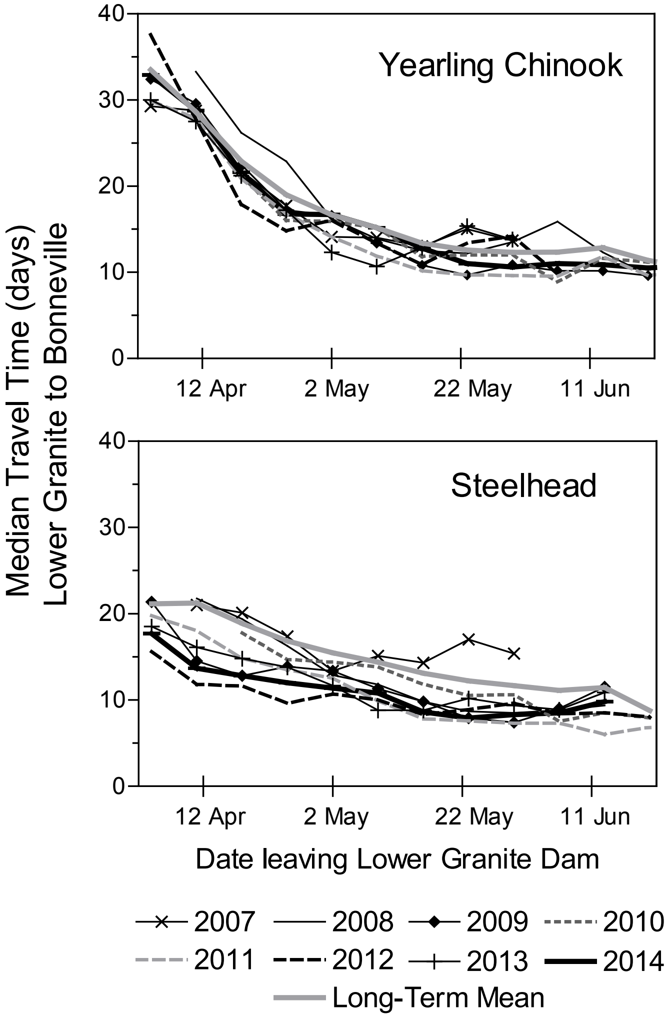

Figure 4. Median travel time (d) from Lower Granite Dam to Bonneville Dam for weekly release groups of Snake River yearling Chinook salmon and steelhead from Lower Granite Dam, 2007-2014.

For both yearling Chinook salmon and steelhead, observed decreases in travel time later in the season generally coincided with increased flow, and presumably with increased levels of smoltification (Figure 5).

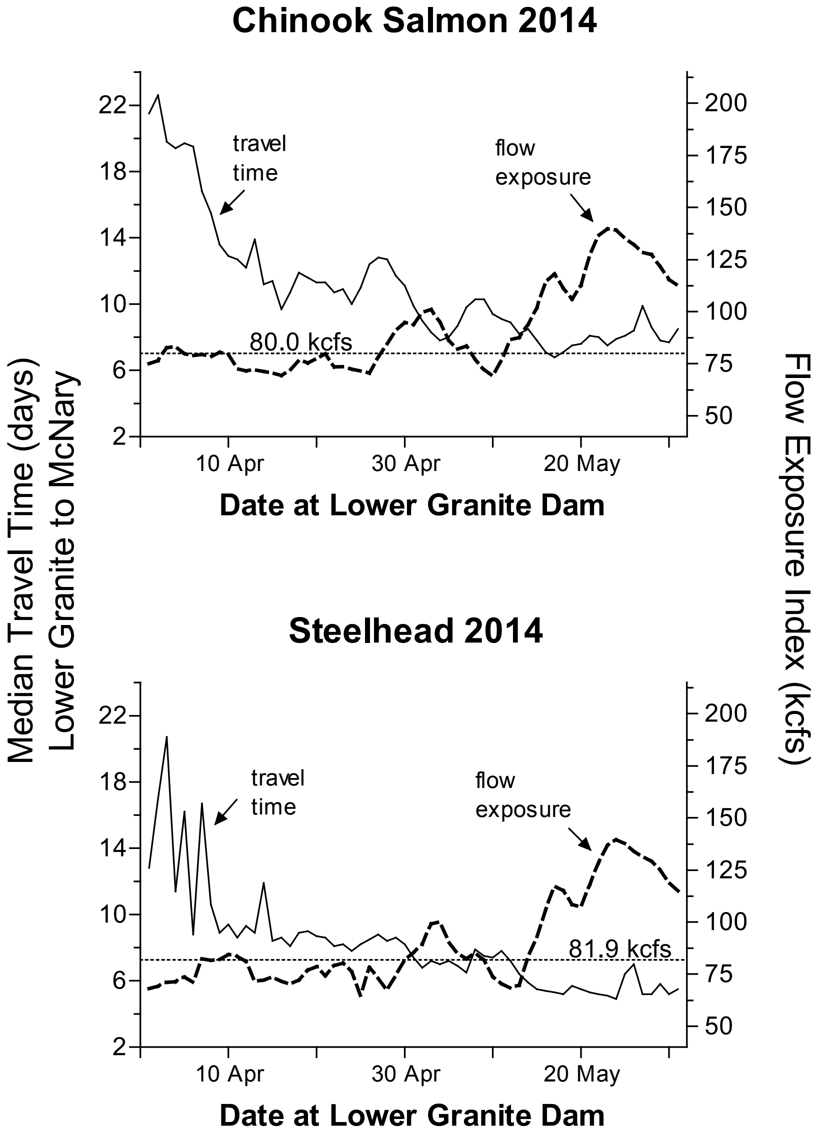

Figure 5. Travel time (d) for yearling Chinook salmon and steelhead from Lower Granite to McNary Dam and index of flow exposure at Lower Monumental Dam (kcfs) for daily groups of PIT-tagged fish during 2014 (see Appendix C). Dashed horizontal lines represent the annual average flow exposure index, weighted by the number of PIT-tagged fish in each group.

Table 17. Travel time statistics for combined hatchery and wild Snake River yearling Chinook salmon detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2014.

Travel time of yearling Chinook salmon from Lower Granite Dam (d)

Date at Lower Granite Dam	Lower Granite to Little Goose Dam				Little Goose to Lower Monumental				Lower Monumental to McNary Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
23 Mar–29 Mar	181	7.3	11.0	19.7	32	3.1	4.6	14.8	14	5.4	7.4	9.3
30 Mar–5 Apr	587	6.2	8.2	12.8	126	2.6	3.4	4.7	56	5.3	6.5	8.4
6 Apr–12 Apr	2,380	3.9	5.2	7.8	535	2.1	2.7	3.6	302	4.2	5.1	6.8
13 Apr–19 Apr	5,347	2.9	3.8	5.5	1,153	1.8	2.2	2.9	500	3.5	4.2	5.6
20 Apr–26 Apr	5,892	3.3	4.5	7.3	817	1.6	1.9	2.7	562	3.4	4.1	5.2
27 Apr–3 May	2,652	3.4	4.8	6.8	485	1.4	1.7	2.2	377	3.2	3.8	4.5
4 May–10 May	3,339	2.9	3.7	4.8	300	1.6	2.0	2.7	207	3.0	3.6	4.2
11 May–17 May	1,280	2.4	2.9	3.8	462	1.1	1.4	1.9	134	2.7	3.4	4.0
18 May–24 May	2,259	2.2	2.8	3.3	757	1.0	1.3	1.6	150	2.8	3.4	4.3
25 May–31 May	417	2.0	2.8	3.0	82	1.1	1.4	1.9	18	3.0	4.1	4.7
1 Jun–7 Jun	31	1.9	2.4	2.9	5	1.5	1.7	1.9	7	3.4	3.8	4.2
8 Jun–14 Jun	21	1.9	2.0	2.8	4	1.4	1.6	1.9	2	3.2	3.3	3.5
15 Jun–21 Jun	14	2.1	2.4	2.9	1	3.8	3.8	3.8	1	2.9	2.9	2.9

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23 Mar–29 Mar	46	19.7	23.3	40.8	13	27.1	32.9	44.7
30 Mar–5 Apr	216	15.8	20.9	29.5	59	22.4	28.8	35.3
6 Apr–12 Apr	1,046	11.0	13.5	18.2	236	18.4	21.6	27.5
13 Apr–19 Apr	2,035	8.9	10.8	15.4	509	14.7	16.8	21.4
20 Apr–26 Apr	4,109	9.0	11.0	15.0	1,052	14.1	16.7	20.9
27 Apr–3 May	2,179	8.7	10.6	13.1	536	13.2	15.2	17.3
4 May–10 May	1,942	7.5	8.8	10.7	826	11.4	12.8	14.3
11 May–17 May	340	6.7	8.0	9.7	208	9.7	11.0	12.9
18 May–24 May	406	6.5	7.7	9.3	405	9.2	10.6	12.4
25 May–31 May	90	7.0	8.2	10.1	103	9.9	11.0	12.4
1 Jun–7 Jun	39	5.9	7.0	8.5	27	9.8	10.9	12.2
8 Jun–14 Jun	22	5.8	6.6	7.7	8	9.3	10.5	10.8
15 Jun–21 Jun	16	7.5	8.6	10.4	6	10.2	10.8	12.7

Table 18. Migration rate statistics for combined hatchery and wild Snake River yearling Chinook salmon detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2014.

Migration rate of yearling Chinook salmon from Lower Granite Dam (km/d)

Date at Lower Granite Dam	Lower Granite to Little Goose Dam				Little Goose to Lower Monumental				Lower Monumental to McNary Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
23 Mar–29 Mar	181	3.0	5.5	8.2	32	3.1	9.9	14.7	14	12.8	16.2	22.0
30 Mar–5 Apr	587	4.7	7.3	9.7	126	9.9	13.6	17.9	56	14.1	18.3	22.5
6 Apr–12 Apr	2,380	7.7	11.6	15.3	535	12.7	16.9	21.6	302	17.6	23.4	28.7
13 Apr–19 Apr	5,347	10.9	15.7	20.4	1,153	15.9	21.3	25.3	500	21.4	28.2	34.1
20 Apr–26 Apr	5,892	8.2	13.4	18.3	817	17.0	24.0	28.8	562	23.1	29.0	34.8
27 Apr–3 May	2,652	8.8	12.4	17.9	485	21.2	26.9	33.6	377	26.3	31.7	36.8
4 May–10 May	3,339	12.4	16.0	20.5	300	17.2	23.5	29.5	207	28.5	32.8	40.3
11 May–17 May	1,280	15.6	20.4	24.7	462	24.6	33.1	40.7	134	29.5	35.4	43.8
18 May–24 May	2,259	18.4	21.4	26.7	757	28.8	35.9	45.5	150	27.8	35.0	42.8
25 May–31 May	417	19.8	21.1	30.0	82	24.7	34.1	43.0	18	25.5	28.7	39.0
1 Jun–7 Jun	31	20.5	25.2	31.7	5	24.3	26.4	30.7	7	28.5	31.2	34.8
8 Jun–14 Jun	21	21.1	29.4	31.9	4	24.1	29.1	31.7	2	34.4	35.6	36.8
15 Jun–21 Jun	14	20.5	24.7	28.3	1	12.2	12.2	12.2	1	41.2	41.2	41.2

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23 Mar–29 Mar	46	5.5	9.7	11.4	13	10.3	14.0	17.0
30 Mar–5 Apr	216	7.6	10.7	14.2	59	13.1	16.0	20.5
6 Apr–12 Apr	1,046	12.3	16.7	20.5	236	16.7	21.3	25.0
13 Apr–19 Apr	2,035	14.6	20.8	25.3	509	21.6	27.4	31.3
20 Apr–26 Apr	4,109	15.0	20.5	25.1	1,052	22.1	27.5	32.7
27 Apr–3 May	2,179	17.1	21.2	25.7	536	26.7	30.3	35.0
4 May–10 May	1,942	21.1	25.5	29.8	826	32.3	36.0	40.3
11 May–17 May	340	23.3	28.1	33.5	208	35.7	42.0	47.6
18 May–24 May	406	24.1	29.3	34.5	405	37.3	43.3	50.1
25 May–31 May	90	22.3	27.4	32.2	103	37.1	42.0	46.7
1 Jun–7 Jun	39	26.4	32.1	38.3	27	37.7	42.3	47.2
8 Jun–14 Jun	22	29.3	34.2	39.1	8	42.6	44.1	49.5
15 Jun–21 Jun	16	21.7	26.3	29.9	6	36.3	42.8	45.0

Table 19. Travel time and migration rate statistics for combined hatchery and wild Snake River yearling Chinook salmon detected and returned or tagged and released to the tailrace at McNary Dam, 2014.

Date at	**Hatchery and wild yearling Chinook salmon from McNary Dam**											
	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
McNary Dam	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
13 Apr–19 Apr	108	5.2	6.8	10.1	5	1.9	2.0	2.1	30	7.5	8.7	11.7
20 Apr–26 Apr	820	4.0	4.9	6.3	94	1.9	2.0	2.4	254	5.7	6.8	8.1
27 Apr–3 May	1,957	3.5	4.2	5.2	163	1.6	1.8	2.1	608	4.8	5.6	6.8
4 May–10 May	1,989	3.2	3.8	4.6	180	1.6	1.7	2.0	985	4.4	5.1	5.8
11 May–17 May	1,352	3.1	3.6	4.4	103	1.4	1.6	1.8	1,388	4.2	4.6	5.1
18 May–24 May	334	2.8	3.2	3.7	22	1.3	1.5	2.1	363	3.6	3.9	4.3
25 May–31 May	140	2.7	3.2	3.7	16	1.3	1.4	1.9	86	3.7	4.1	4.7
1 Jun–7 Jun	42	2.9	3.2	3.8	8	1.3	1.5	1.8	32	3.6	4.0	4.6
8 Jun–14 Jun	10	2.9	3.3	4.0	4	1.5	1.7	2.3	25	3.9	4.5	5.0
15 Jun–21 Jun	8	3.0	3.1	3.6	1	1.4	1.4	1.4	10	4.2	4.3	4.8
	Migration rate (km/d)											
13 Apr–19 Apr	108	12.2	18.2	23.4	5	53.6	56.2	59.2	30	20.1	27.2	31.4
20 Apr–26 Apr	820	19.5	24.9	30.6	94	47.7	55.1	59.5	254	29.0	34.8	41.3
27 Apr–3 May	1,957	23.5	29.4	35.0	163	54.6	62.1	68.9	608	35.0	42.3	48.7
4 May–10 May	1,989	26.7	32.4	38.0	180	56.2	65.7	70.6	985	41.0	46.4	53.5
11 May–17 May	1,352	28.0	34.0	40.1	103	64.2	72.0	78.5	1,388	46.0	51.5	56.6
18 May–24 May	334	33.6	38.9	44.7	22	54.9	75.8	88.3	363	55.4	61.0	64.8
25 May–31 May	140	33.2	38.7	46.1	16	60.1	81.3	84.3	86	50.6	58.1	63.4
1 Jun–7 Jun	42	31.9	37.8	42.4	8	62.4	73.4	85.6	32	51.4	59.6	64.7
8 Jun–14 Jun	10	31.1	36.9	42.9	4	48.9	67.7	75.3	25	47.2	52.7	60.2
15 Jun–21 Jun	8	34.5	39.4	40.9	1	79.6	79.6	79.6	10	49.3	54.6	56.7

Table 20. Travel time statistics for combined hatchery and wild Snake River steelhead detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2014.

Travel time of juvenile steelhead from Lower Granite Dam (d)

Date at Lower Granite Dam	Lower Granite to Little Goose Dam				Little Goose to Lower Monumental				Lower Monumental to McNary Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
30 Mar–5 Apr	415	3.0	3.9	5.1	60	2.3	3.4	11.8	16	3.6	4.2	6.1
6 Apr–12 Apr	1,014	2.2	2.9	3.6	104	1.8	2.6	6.9	32	3.0	4.0	7.0
13 Apr–19 Apr	1,648	2.5	3.0	3.8	118	1.9	2.3	3.9	55	3.1	3.6	4.8
20 Apr–26 Apr	3,032	2.1	2.9	3.4	299	1.9	3.1	6.0	126	2.8	3.3	4.1
27 Apr–3 May	3,776	2.2	3.0	3.9	600	1.2	1.8	3.5	245	2.4	2.9	3.6
4 May–10 May	3,484	2.1	2.7	3.2	378	1.5	2.0	3.2	82	2.5	2.9	3.6
11 May–17 May	1,894	1.9	2.1	2.6	455	1.0	1.3	1.9	57	2.0	2.3	2.9
18 May–24 May	3,706	1.8	1.9	2.2	1,332	0.9	1.1	1.6	127	1.8	2.1	2.6
25 May–31 May	1,513	1.6	1.8	2.2	444	1.0	1.2	1.6	45	2.0	2.4	3.3
1 Jun–7 Jun	396	1.6	1.9	2.0	79	0.9	1.1	1.4	19	2.1	2.4	3.2
8 Jun–14 Jun	132	1.8	2.0	2.2	8	1.0	1.2	1.5	6	2.5	2.6	2.7

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
30 Mar–5 Apr	85	9.8	13.6	25.5	59	14.4	17.7	23.1
6 Apr–12 Apr	204	7.2	9.2	14.2	167	11.8	13.7	17.5
13 Apr–19 Apr	569	7.5	8.4	10.6	387	11.4	12.8	15.3
20 Apr–26 Apr	1,375	7.0	8.1	10.1	992	10.8	12.0	13.9
27 Apr–3 May	1,076	6.5	7.5	9.2	739	10.0	11.4	12.9
4 May–10 May	651	6.1	7.0	8.5	521	9.9	10.8	12.2
11 May–17 May	270	5.2	5.8	6.9	441	7.8	8.6	9.6
18 May–24 May	363	4.7	5.2	6.3	516	7.4	7.9	8.9
25 May–31 May	125	4.8	5.4	6.8	206	7.5	8.3	9.3
1 Jun–7 Jun	108	4.8	5.3	6.1	188	7.8	8.5	9.7
8 Jun–14 Jun	44	5.0	5.6	6.2	48	8.9	9.8	10.8

Table 21. Migration rate statistics for combined hatchery and wild Snake River steelhead detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2014.

Migration rate of juvenile steelhead from Lower Granite Dam (km/d)												
Date at Lower Granite Dam	Lower Granite to Little Goose Dam				Little Goose to Lower Monumental				Lower Monumental to McNary Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
30 Mar–5 Apr	415	11.8	15.5	19.7	60	3.9	13.7	19.7	16	19.4	28.1	33.1
6 Apr–12 Apr	1,014	16.7	20.5	26.9	104	6.6	17.7	25.3	32	17.0	30.1	39.0
13 Apr–19 Apr	1,648	15.8	20.1	24.5	118	11.8	20.0	24.6	55	24.8	33.0	38.5
20 Apr–26 Apr	3,032	17.6	20.5	27.9	299	7.7	15.0	23.8	126	29.0	35.8	41.8
27 Apr–3 May	3,776	15.3	20.1	27.5	600	13.3	26.3	37.7	245	33.1	41.5	49.2
4 May–10 May	3,484	18.7	21.9	28.3	378	14.2	22.7	31.1	82	33.3	40.8	48.6
11 May–17 May	1,894	22.8	28.8	31.2	455	23.7	36.2	46.0	57	40.8	50.9	58.3
18 May–24 May	3,706	27.0	31.6	33.5	1,332	28.6	42.2	50.0	127	45.6	57.2	67.2
25 May–31 May	1,513	27.1	32.6	38.0	444	28.2	39.7	46.9	45	36.0	50.4	59.5
1 Jun–7 Jun	396	29.4	32.3	38.0	79	33.8	42.2	50.5	19	37.7	49.2	56.1
8 Jun–14 Jun	132	27.1	30.3	33.0	8	30.1	36.8	47.9	6	43.8	45.9	48.4

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
30 Mar–5 Apr	85	8.8	16.6	23.1	59	20.0	26.1	31.9
6 Apr–12 Apr	204	15.9	24.5	31.4	167	26.3	33.7	39.0
13 Apr–19 Apr	569	21.2	26.6	29.9	387	30.2	36.1	40.3
20 Apr–26 Apr	1,375	22.3	27.8	32.2	992	33.2	38.3	42.5
27 Apr–3 May	1,076	24.6	29.8	34.7	739	35.8	40.5	46.1
4 May–10 May	651	26.5	32.2	37.1	521	37.7	42.7	46.7
11 May–17 May	270	32.5	38.9	43.2	441	48.2	53.8	59.0
18 May–24 May	363	35.5	42.9	48.0	516	52.0	58.7	62.4
25 May–31 May	125	33.1	41.4	46.6	206	49.3	55.5	61.3
1 Jun–7 Jun	108	36.8	42.3	46.7	188	47.6	54.2	59.1
8 Jun–14 Jun	44	36.2	40.5	44.9	48	42.8	47.0	51.9

Table 22. Travel time and migration rate statistics for combined hatchery and wild Snake River steelhead detected and returned or tagged and released to the tailrace at McNary Dam, 2014.

	Hatchery and wild juvenile steelhead from McNary Dam											
	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
Date at McNary Dam	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
6 Apr–12 Apr	4	5.6	8.5	11.9	0	NA	NA	NA	11	5.5	5.8	7.8
13 Apr–19 Apr	55	4.0	4.9	8.2	7	1.6	1.7	1.8	32	4.9	5.8	6.7
20 Apr–26 Apr	152	3.2	4.1	5.8	11	1.5	1.6	1.8	115	4.5	5.0	5.7
27 Apr–3 May	535	3.1	4.0	5.8	59	1.3	1.4	1.6	456	4.3	4.7	5.4
4 May–10 May	461	3.1	3.8	5.2	33	1.3	1.5	1.6	329	3.8	4.4	4.9
11 May–17 May	185	3.0	3.5	4.6	20	1.3	1.4	1.7	233	3.8	4.4	4.8
18 May–24 May	70	2.1	2.5	3.5	8	1.1	1.2	1.4	76	3.3	3.5	3.7
25 May–31 May	60	2.3	3.1	3.6	5	1.1	1.1	1.3	58	3.4	3.7	4.3
1 Jun–7 Jun	14	2.2	2.8	4.8	4	1.2	1.4	2.8	31	3.3	3.7	4.1
8 Jun–14 Jun	13	2.8	3.2	5.6	3	1.4	1.7	1.8	44	3.8	4.5	4.8
15 Jun–21 Jun	2	3.0	3.0	3.0	1	1.3	1.3	1.3	19	3.3	3.9	4.4
	Migration rate (km/d)											
6 Apr–12 Apr	4	10.4	14.4	21.8	0	NA	NA	NA	11	30.1	40.5	43.1
13 Apr–19 Apr	55	15.1	25.2	30.6	7	61.4	68.1	69.3	32	35.0	40.8	48.0
20 Apr–26 Apr	152	21.0	30.3	38.2	11	62.8	71.1	77.4	115	41.5	47.7	52.4
27 Apr–3 May	535	21.4	30.7	39.5	59	70.6	79.0	87.6	456	43.9	50.3	54.9
4 May–10 May	461	23.7	32.1	40.2	33	68.5	77.4	85.0	329	48.3	53.2	61.3
11 May–17 May	185	26.7	35.3	40.7	20	67.3	83.1	89.0	233	48.7	53.8	61.5
18 May–24 May	70	34.9	49.0	58.0	8	80.7	96.6	101.8	76	63.8	68.4	72.0
25 May–31 May	60	34.1	39.9	54.4	5	89.7	99.1	103.7	58	55.4	63.8	69.2
1 Jun–7 Jun	14	25.7	43.5	55.2	4	41.1	79.0	94.2	31	57.8	64.5	72.2
8 Jun–14 Jun	13	22.1	38.2	44.4	3	63.5	66.9	80.7	44	49.3	52.9	62.3
15 Jun–21 Jun	2	40.3	41.0	41.6	1	89.7	89.7	89.7	19	54.1	60.8	70.9

Proportion Transported of Spring Migrants

Methods

To estimate the proportion of non-tagged fish that were transported, we proceeded through the following steps:

1. Compile daily collection counts at Lower Granite Dam from the Smolt Monitoring Program (fpc.org).

2. Use PIT-tag data to derive daily estimates of detection probability at Lower Granite Dam, following the methods of Sandford and Smith (2002). Virtually every PIT-tagged fish that enters a collection system is detected; thus, the probability of detecting a PIT-tagged fish on a given day is the de facto probability of the fish entering the collection system on that day.

3. For each day, divide the daily collection count by the detection probability estimate for that day to get an estimate of the total number of fish (tagged and untagged) that passed Lower Granite Dam on that day. This also gives rise to daily estimates of the total number of fish in the Lower Granite Dam collection system and the number of fish that passed via other routes (i.e., “non-detected” or “non-bypassed”).

4. For each daily group of PIT-tagged fish leaving Lower Granite Dam (i.e. detected and returned to the river), tabulate the number that were next detected at Little Goose Dam (i.e. next entered a collection system) and the number that passed Little Goose undetected and next entered a collection system at Lower Monumental Dam.

   Translate these counts into Lower Granite "equivalents" (an “equivalent” is a count at a downstream dam that is adjusted upward to account for mortality that occurred between release and that downstream site, i.e., the number of fish that had to have left Lower Granite Dam in order to realize the downstream counts at Little Goose and Lower Monumental Dam).

5. Assume that for the group of untagged fish arriving at Lower Granite Dam on a given day, the proportion of Lower Granite equivalents first collected at Lower Granite, Little Goose, and Lower Monumental Dams is the same as that of the group of PIT-tagged fish arriving on that day. (The number of PIT-tagged fish that arrived but were not detected at Lower Granite is estimated from steps 2 and 3.)

6. For each daily group of fish arriving at Lower Granite Dam, estimate the proportion of those that entered the collection system at each collector dam and were transported from that dam.

   For groups arriving at Lower Granite Dam after the transport starting date at a collector dam, the proportion transported is 100%.

   For groups arriving at Lower Granite Dam before the transport starting date, the estimated proportion of the daily Lower Granite Dam group that is eventually transported depends on travel time distributions to downstream transport dams. These distributions determine the proportions of the group that arrive at each downstream dam after transport has started there. Travel time distributions changes throughout the season. For example, fish that arrive earlier at Lower Granite Dam tend to take longer to get to the downstream dams.

7. For each daily group of the run-at-large, calculate the product of three quantities:
   i. Estimated number of fish in the group passing Lower Granite Dam that day (step 3)
   ii. Estimated proportion of fish first entering the collection system at each dam (steps 4-5)
   iii. Estimated proportion of fish entering the collection system that were transported (step 6)

   This gives the estimated total equivalents from each group at Lower Granite Dam that were transported from each dam.

8. Sum all estimated numbers transported and divide by the total population estimate to derive the estimated percentage transported for the season.

Results

In 2014, collection for transportation began on 1 May at Lower Granite, Little Goose, and Lower Monumental Dams, and the first barge operated on 2 May at each of those collector dams. Until these dates, smolts collected at Snake River dams were bypassed back to the river. Estimated percentages of non-tagged spring/summer Chinook salmon transported during the entire 2014 season were 30.9% for wild and 38.3% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 39.9% for wild and 34.6% for hatchery smolts.

These estimates represent the proportion of smolts that arrived at Lower Granite Dam and were subsequently transported, either from Lower Granite or from one of the downstream collector dams. These estimates were very close to those of 2013, and estimates from both years were near the average for 2007-2014, which is considerably lower than the average for 1993-2006 (Figure 6; Table 23).

Before 2006, collected fish were transported throughout the season, starting from the first day on which the collection system was supplied with water. Between 2007 and 2013, collected fish were bypassed until a designated date at each dam, and the beginning date of transportation was staggered at each downstream dam (e.g., a few days later at Little Goose Dam than at Lower Granite Dam). The 2014 season was the first during which transportation began simultaneously at all three collector dams.

By the time collection for transportation began at Lower Granite Dam on 1 May 2014, about 63% of wild yearling Chinook, 39% of hatchery yearling Chinook, 48% of wild steelhead, and 50% of hatchery steelhead had already passed the dam. During general transportation operations, we estimated that approximately 73% of wild yearling Chinook and 52% of hatchery Chinook smolts that arrived at Lower Granite Dam were transported, either from Lower Granite or from another collector dam.

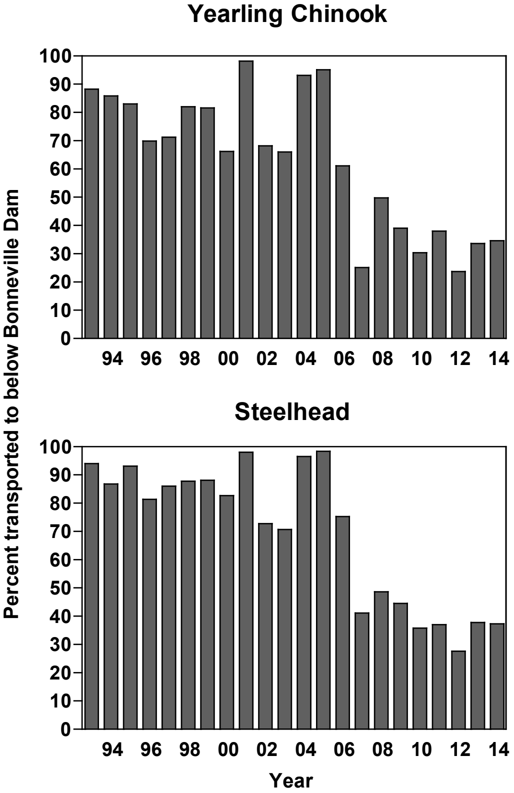

Figure 6. Estimated percent of yearling Chinook salmon and steelhead (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2014).

Table 23. Annual estimated percentages of migrating Snake River yearling Chinook salmon and steelhead that were transported (1993-2014). Estimates are shown for hatchery and wild fish separately. Arithmetic means are shown for the hatchery and wild estimates separately across years and combined within years.

	Transported fish (%)					
	Yearling Chinook Salmon			**Juvenile Steelhead**		
Year	Hatchery	Wild	Mean	Hatchery	Wild	Mean
1993	88.1	88.5	88.3	94.7	93.2	94.0
1994	84.0	87.7	85.9	82.2	91.3	86.8
1995	79.6	86.4	83.0	94.3	91.8	93.1
1996	68.7	71.0	69.9	82.9	79.8	81.4
1997	71.5	71.1	71.3	84.5	87.5	86.0
1998	81.4	82.5	82.0	87.3	88.2	87.8
1999	77.3	85.9	81.6	88.5	87.6	88.1
2000	61.9	70.4	66.2	81.5	83.9	82.7
2001	97.3	99.0	98.2	96.7	99.3	98.0
2002	64.2	72.1	68.2	70.4	75.2	72.8
2003	61.5	70.4	66.0	68.4	72.9	70.7
2004	92.9	93.2	93.1	97.3	95.7	96.5
2005	95.0	95.1	95.1	98.0	98.7	98.4
2006	62.3	59.9	61.1	76.0	74.6	75.3
2007	25.4	24.8	25.1	41.1	41.1	41.1
2008	45.3	54.3	49.8	46.6	50.5	48.6
2009	38.3	40.4	39.4	42.7	46.1	44.4
2010	22.6	38.2	30.4	34.8	36.8	35.8
2011	40.7	35.2	38.0	37.8	36.1	37.0
2012	24.7	22.7	23.7	26.7	28.4	27.6
2013	31.0	36.1	33.6	35.0	40.0	37.8
2014	38.3	30.9	34.6	34.6	39.9	37.3
Mean	**61.5**	**64.4**	**62.9**	**68.5**	**69.7**	**69.1**

We did not have sufficient data to estimate proportions separately for hatchery and wild steelhead, but for combined rear types we estimated that 63% of steelhead passing after 1 May were transported. For both species, a greater proportion of the total run passed before transportation began in 2014 than in 2013, but a greater proportion was transported after the program began. Combined with simultaneous start dates at all dams, resulting overall percentages transported in 2014 were similar to 2013.

Survival estimates presented in this report are based largely on PIT-tagged fish that remained in-river. These fish either passed through turbines or spillways (including surface passage structures), or were intentionally returned to the river after detection in bypass systems. PIT-tagged fish that were transported provide survival information up until the point where they were removed from the river, but not downstream from that point.

Therefore, when considering the implications of in-river survival probability for populations of Snake River salmonids, it is important to remember that a significant proportion of the populations at large was transported. Before 2007, well over half of the populations at large were transported annually. In recent years, the proportion has been 30-40%. Reach survival probabilities presented in this report pertain only to fish that remained in the river; survival of transported fish is affected by entirely different factors.

Comparisons of Annual Survival Estimates

Comparison Among Years

We made two comparisons of annual survival estimates from 2014 to those obtained in previous years of the NMFS survival study. First, we compared migration distance to estimated survival to Lower Granite Dam for releases of yearling Chinook from specific hatcheries. Second, we compared overall seasonal survival estimates within specific reaches across years.

Snake River Stocks

Yearling Chinook Salmon—For yearling Chinook salmon from most Snake River Basin hatcheries, estimated survival to Lower Granite Dam tailrace in 2014 was similar to that in recent years. In 2014, mean survival of fish from these hatcheries was higher than the long-term mean (Table 24). Over the years of the study, we have consistently observed an inverse relationship between distance of the release site to Lower Granite Dam and estimated survival. For yearling Chinook from Snake River hatcheries, there has been a significant negative linear correlation between migration distance and average estimated survival (Figure 7; $R^2 = 0.850$, $P = 0.003$).

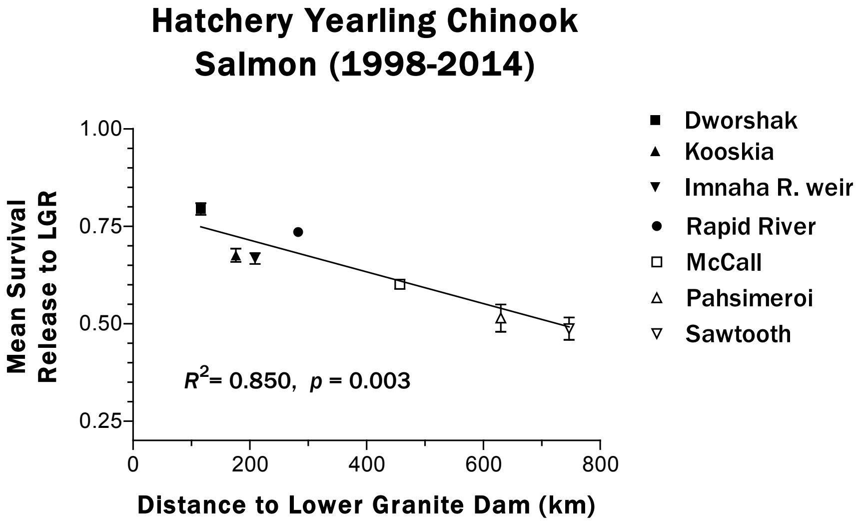

Figure 7. Estimated survival from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2014 vs. distance (km) to Lower Granite Dam. The squared correlation between survival and migration distance is also shown, along with a *P*-value for a test of the null hypothesis of zero correlation. Whiskers show standard errors.

Table 24. Estimated survival for yearling Chinook salmon from selected Snake River Basin hatcheries to the tailrace of Lower Granite Dam, 1993-2014. Distance from each hatchery to Lower Granite Dam in parentheses in header. Standard errors in parentheses following each survival estimate. Simple arithmetic means across all years are given.

	Estimated Survival of hatchery yearling Chinook salmon (SE)							
Year	Dworshak (116 km)	Kooskia (176 km)	Lookingglass* (209 km)	Rapid River (283 km)	McCall (457 km)	Pahsimeroi (630 km)	Sawtooth (747 km)	Mean
1993	0.647 (0.028)	0.689 (0.047)	0.660 (0.025)	0.670 (0.017)	0.498 (0.017)	0.456 (0.032)	0.255 (0.023)	0.554 (0.060)
1994	0.778 (0.020)	0.752 (0.053)	0.685 (0.021)	0.526 (0.024)	0.554 (0.022)	0.324 (0.028)	0.209 (0.014)	0.547 (0.081)
1995	0.838 (0.034)	0.786 (0.024)	0.617 (0.015)	0.726 (0.017)	0.522 (0.011)	0.316 (0.033)	0.230 (0.015)	0.576 (0.088)
1996	0.776 (0.017)	0.744 (0.010)	0.567 (0.014)	0.588 (0.007)	0.531 (0.007)	NA	0.121 (0.017)	0.555 (0.096)
1997	0.576 (0.017)	0.449 (0.034)	0.616 (0.017)	0.382 (0.008)	0.424 (0.008)	0.500 (0.008)	0.508 (0.037)	0.494 (0.031)
1998	0.836 (0.006)	0.652 (0.024)	0.682 (0.006)	0.660 (0.004)	0.585 (0.004)	0.428 (0.021)	0.601 (0.033)	0.635 (0.046)
1999	0.834 (0.011)	0.653 (0.031)	0.668 (0.009)	0.746 (0.006)	0.649 (0.008)	0.584 (0.035)	0.452 (0.019)	0.655 (0.045)
2000	0.841 (0.009)	0.734 (0.027)	0.688 (0.011)	0.748 (0.007)	0.689 (0.010)	0.631 (0.062)	0.546 (0.030)	0.697 (0.035)
2001	0.747 (0.002)	0.577 (0.019)	0.747 (0.003)	0.689 (0.002)	0.666 (0.002)	0.621 (0.016)	0.524 (0.023)	0.653 (0.032)
2002	0.819 (0.011)	0.787 (0.036)	0.667 (0.012)	0.755 (0.003)	0.592 (0.006)	0.678 (0.053)	0.387 (0.025)	0.669 (0.055)
2003	0.720 (0.008)	0.560 (0.043)	0.715 (0.012)	0.691 (0.007)	0.573 (0.006)	0.721 (0.230)	0.595 (0.149)	0.654 (0.028)
2004	0.821 (0.003)	0.769 (0.017)	0.613 (0.004)	0.694 (0.003)	0.561 (0.002)	0.528 (0.017)	0.547 (0.018)	0.648 (0.044)
2005	0.823 (0.003)	0.702 (0.021)	0.534 (0.004)	0.735 (0.002)	0.603 (0.003)	0.218 (0.020)	0.220 (0.020)	0.549 (0.092)
2006	0.853 (0.007)	0.716 (0.041)	0.639 (0.014)	0.764 (0.004)	0.634 (0.006)	0.262 (0.024)	0.651 (0.046)	0.645 (0.071)
2007	0.817 (0.007)	0.654 (0.015)	0.682 (0.010)	0.748 (0.004)	0.554 (0.007)	0.530 (0.038)	0.581 (0.015)	0.652 (0.040)
2008	0.737 (0.011)	0.631 (0.015)	0.694 (0.008)	0.801 (0.004)	0.578 (0.007)	0.447 (0.011)	0.336 (0.012)	0.603 (0.062)
2009	0.696 (0.007)	0.633 (0.012)	0.699 (0.009)	0.728 (0.005)	0.513 (0.005)	0.510 (0.006)	0.367 (0.007)	0.592 (0.050)
2010	0.898 (0.017)	0.744 (0.030)	0.682 (0.025)	0.786 (0.019)	0.566 (0.014)	0.384 (0.023)	0.427 (0.018)	0.641 (0.072)
2011	0.722 (0.006)	0.729 (0.014)	0.572 (0.009)	0.766 (0.006)	0.631 (0.007)	0.498 (0.005)	0.521 (0.007)	0.634 (0.041)
2012	0.743 (0.008)	0.652 (0.013)	0.689 (0.009)	0.718 (0.014)	0.571 (0.006)	0.581 (0.006)	0.473 (0.008)	0.632 (0.036)
2013	0.794 (0.015)	0.609 (0.026)	0.703 (0.019)	0.735 (0.011)	0.656 (0.011)	0.606 (0.016)	0.564 (0.011)	0.667 (0.031)
2014	0.816 (0.009)	0.595 (0.011)	0.673 (0.009)	0.757 (0.008)	0.714 (0.008)	0.794 (0.008)	0.646 (0.008)	0.714 (0.031)
Mean	**0.779 (0.016)**	**0.674 (0.018)**	**0.659 (0.011)**	**0.701 (0.020)**	**0.585 (0.014)**	**0.506 (0.033)**	**0.444 (0.033)**	**0.621 (0.012)**

* Released at Imnaha River Weir.

For combined wild and hatchery yearling Chinook salmon, mean estimated survival was 0.768 (95% CI 0.739-0.797) from Lower Granite to McNary Dam tailrace in 2014. Estimated survival from McNary to Bonneville Dam tailrace was 0.715 (0.505-0.925) for these fish (Tables 25-26; Figures 8-9). These estimates were similar to those in 2013 for both reaches. Estimated survival through the entire hydrosystem from the Snake River Trap to Bonneville Dam was 0.497 (0.349-0.645) for these fish in 2014 (Table 26). This estimate was slightly lower than the 18-year mean of 0.501 from 1997 to 2014, and lower than the 2013 estimate of 0.525, although the difference between estimates in 2013 and 2014 was not significant ($P = 0.75$).

For wild yearling Chinook salmon only, mean estimated survival in 2014 was 0.678 (95% CI 0.635-0.721) from Lower Granite to McNary Dam and 0.577 (0.432-0.722) from McNary to Bonneville Dam tailrace (Table 27). Both of these estimates were below their respective long-term averages of 0.733 and 0.662, and both were lower than the corresponding estimates from 2013. Mean estimated survival for these fish through the entire hydrosystem was 0.349 (0.258-0.440). This estimate was one of the lowest in our time series and was below the long-term average of 0.450 (0.392-0.508).

Steelhead—For combined wild and hatchery steelhead, mean estimated survival was 0.740 (95% CI 0.699-0.781) from Lower Granite to McNary Dam in 2014. Estimated survival from McNary to Bonneville Dam tailrace was 1.023 (0.851-1.200) for these fish (Tables 28-29; Figures 8-9). These estimates were both higher than the respective 18-year means for those reaches and higher than the corresponding estimates from 2013. Estimated survival through the entire hydrosystem was 0.771 (0.628-0.914) for these fish (Table 29). Again, this estimate was higher than the long-term mean of 0.457 and higher than the corresponding estimate for 2013 of 0.501. The difference between estimates in 2013 and 2014 was significant ($P = 0.01$).

For wild steelhead only, mean estimated survival in 2014 was 0.620 (0.553-0.687) from Lower Granite Dam tailrace to McNary Dam tailrace; this estimate was below the long-term average of 0.633 (Table 30). However, estimated survival from McNary to Bonneville Dam tailrace for these fish (based on a single pooled cohort) was 1.057 (0.775-1.339), which was above the average of 0.639. Estimated survival through the entire hydrosystem for wild steelhead was 0.655 (0.467-0.844), which is above the long-term average of 0.420.

Table 25. Annual weighted mean survival probability estimates for yearling Chinook salmon (hatchery and wild combined), 1995–2014 with standard errors. Shaded columns are reaches that comprise two dams and reservoirs (i.e., two projects) for which the following column gives the square root of the two–project estimate to facilitate comparison with other single-project estimates. Simple arithmetic means are given across all available years (1993-2014).

Annual survival estimates for hatchery and wild yearling Chinook salmon (SE)

Year	Trap to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	L Monumental to Ice Harbor and Ice Harbor to McNary	McNary to John Day Dam	John Day to Bonneville Dam	John Day to The Dalles and The Dalles to Bonneville Dam
1995	0.905 (0.010)	0.882 (0.004)	0.925 (0.008)	0.876 (0.038)	0.936			
1996	0.977 (0.025)	0.926 (0.006)	0.929 (0.011)	0.756 (0.033)	0.870			
1997	NA	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.893			
1998	0.925 (0.009)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)		
1999	0.940 (0.009)	0.949 (0.002)	0.925 (0.004)	0.904 (0.007)	0.951	0.853 (0.027)	0.814 (0.065)	0.902
2000	0.929 (0.014)	0.938 (0.006)	0.887 (0.009)	0.928 (0.016)	0.963	0.898 (0.054)	0.684 (0.128)	0.827
2001	0.954 (0.015)	0.945 (0.004)	0.830 (0.006)	0.708 (0.007)	0.841	0.758 (0.024)	0.645 (0.034)	0.803
2002	0.953 (0.022)	0.949 (0.006)	0.980 (0.008)	0.837 (0.013)	0.915	0.907 (0.014)	0.840 (0.079)	0.917
2003	0.993 (0.023)	0.946 (0.005)	0.916 (0.011)	0.904 (0.017)	0.951	0.893 (0.017)	0.818 (0.036)	0.904
2004	0.893 (0.009)	0.923 (0.004)	0.875 (0.012)	0.818 (0.018)	0.904	0.809 (0.028)	0.735 (0.092)	0.857
2005	0.919 (0.015)	0.919 (0.003)	0.886 (0.006)	0.903 (0.010)	0.950	0.772 (0.029)	1.028 (0.132)	1.014
2006	0.952 (0.011)	0.923 (0.003)	0.934 (0.004)	0.887 (0.008)	0.942	0.881 (0.020)	0.944 (0.030)	0.972
2007	0.943 (0.028)	0.938 (0.006)	0.957 (0.010)	0.876 (0.012)	0.936	0.920 (0.016)	0.824 (0.043)	0.908
2008	0.992 (0.018)	0.939 (0.006)	0.950 (0.011)	0.878 (0.016)	0.937	1.073 (0.058)	0.558 (0.082)	0.750
2009	0.958 (0.010)	0.940 (0.006)	0.982 (0.009)	0.855 (0.011)	0.925	0.866 (0.042)	0.821 (0.043)	0.906
2010	0.968 (0.040)	0.962 (0.011)	0.973 (0.019)	0.851 (0.017)	0.922	0.947 (0.021)	0.780 (0.039)	0.883
2011	0.943 (0.009)	0.919 (0.007)	0.966 (0.007)	0.845 (0.012)	0.919	0.893 (0.026)	0.766 (0.080)	0.875
2012	0.928 (0.012)	0.907 (0.009)	0.939 (0.010)	0.937 (0.016)	0.968	0.915 (0.023)	0.866 (0.058)	0.931
2013	0.845 (0.031)	0.922 (0.012)	0.983 (0.014)	0.904 (0.022)	0.951	0.931 (0.054)	0.823 (0.036)	0.907
2014	0.905 (0.015)	0.940 (0.007)	0.919 (0.010)	0.894 (0.017)	0.946	0.912 (0.053)	0.752 (0.104)	0.867
Mean	**0.933 (0.009)**	**0.927 (0.007)**	**0.921 (0.010)**	**0.864 (0.013)**	**0.929**	**0.885 (0.018)**	**0.794 (0.028)**	**0.889**

Table 26. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling Chinook salmon (hatchery and wild combined), 1997–2014. Standard errors in parentheses. Simple arithmetic means are given.

Annual survival estimates for hatchery and wild yearling Chinook (SE)					
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1997	NA	0.653 (0.072)	NA	NA	NA
1998	0.924 (0.011)	0.770 (0.009)	NA	NA	NA
1999	0.940 (0.009)	0.792 (0.006)	0.704 (0.058)	0.557 (0.046)	0.524 (0.043)
2000	0.929 (0.014)	0.760 (0.012)	0.640 (0.122)	0.486 (0.093)	0.452 (0.087)
2001	0.954 (0.015)	0.556 (0.009)	0.501 (0.027)	0.279 (0.016)	0.266 (0.016)
2002	0.953 (0.022)	0.757 (0.009)	0.763 (0.079)	0.578 (0.060)	0.551 (0.059)
2003	0.993 (0.023)	0.731 (0.010)	0.728 (0.030)	0.532 (0.023)	0.528 (0.026)
2004	0.893 (0.009)	0.666 (0.011)	0.594 (0.074)	0.395 (0.050)	0.353 (0.045)
2005	0.919 (0.015)	0.732 (0.009)	0.788 (0.093)	0.577 (0.068)	0.530 (0.063)
2006	0.952 (0.011)	0.764 (0.007)	0.842 (0.021)	0.643 (0.017)	0.612 (0.018)
2007	0.943 (0.028)	0.783 (0.006)	0.763 (0.044)	0.597 (0.035)	0.563 (0.037)
2008	0.992 (0.018)	0.782 (0.011)	0.594 (0.066)	0.465 (0.052)	0.460 (0.052)
2009	0.958 (0.010)	0.787 (0.007)	0.705 (0.031)	0.555 (0.025)	0.531 (0.025)
2010	0.968 (0.040)	0.772 (0.012)	0.738 (0.039)	0.569 (0.032)	0.551 (0.038)
2011	0.943 (0.009)	0.746 (0.010)	0.687 (0.065)	0.513 (0.049)	0.483 (0.046)
2012	0.928 (0.012)	0.790 (0.016)	0.802 (0.051)	0.634 (0.042)	0.588 (0.040)
2013	0.845 (0.031)	0.781 (0.016)	0.796 (0.064)	0.622 (0.052)	0.525 (0.048)
2014	0.905 (0.015)	0.768 (0.015)	0.715 (0.107)	0.549 (0.083)	0.497 (0.075)
Mean	**0.933 (0.009)**	**0.738 (0.014)**	**0.710 (0.023)**	**0.534 (0.023)**	**0.501 (0.022)**

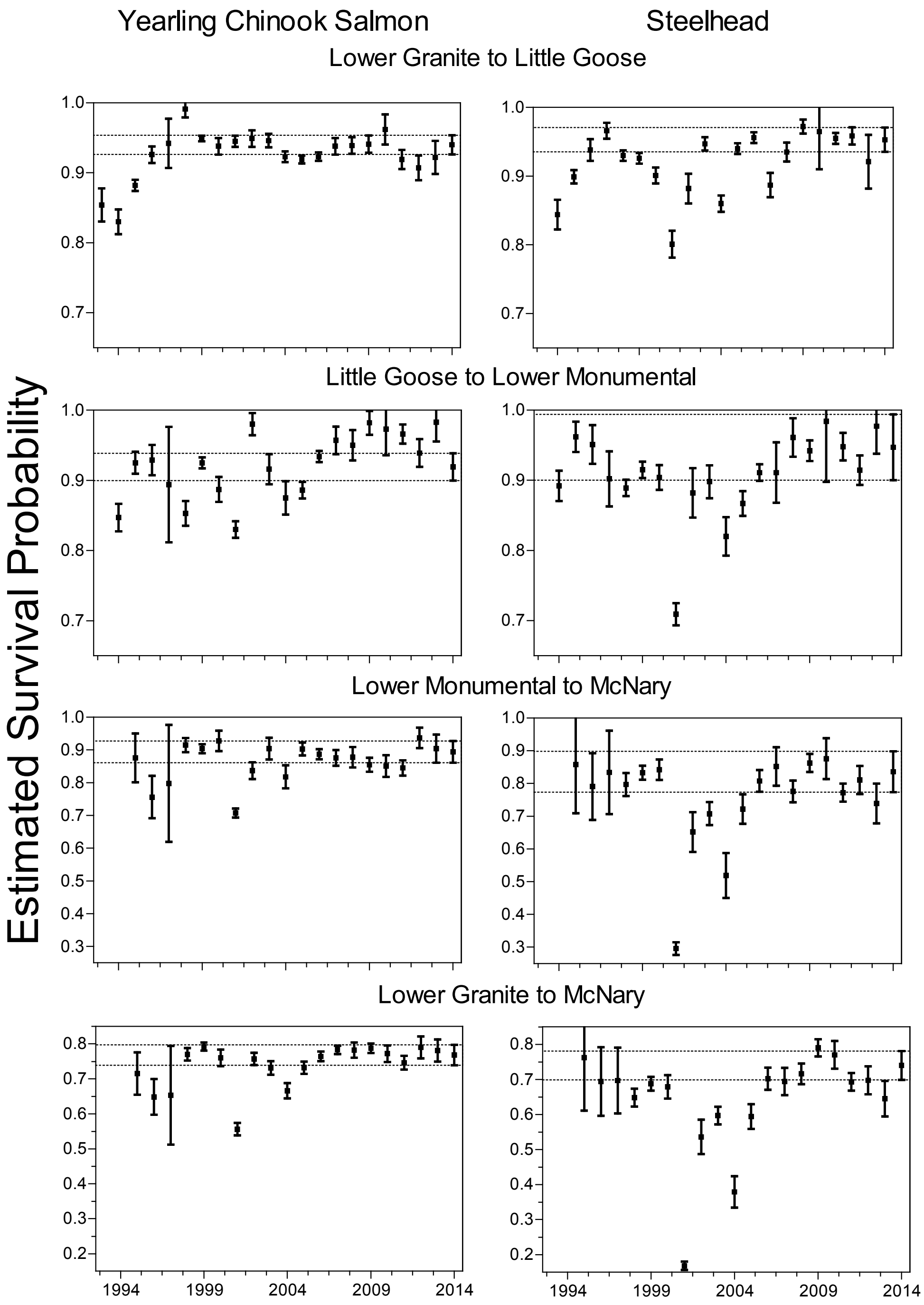

Figure 8. Annual average survival estimates for PIT-tagged yearling Chinook salmon and steelhead (hatchery and wild combined) through Snake River reaches, 1993-2014. Estimates are from tailrace to tailrace. Vertical bars represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2014 estimates.

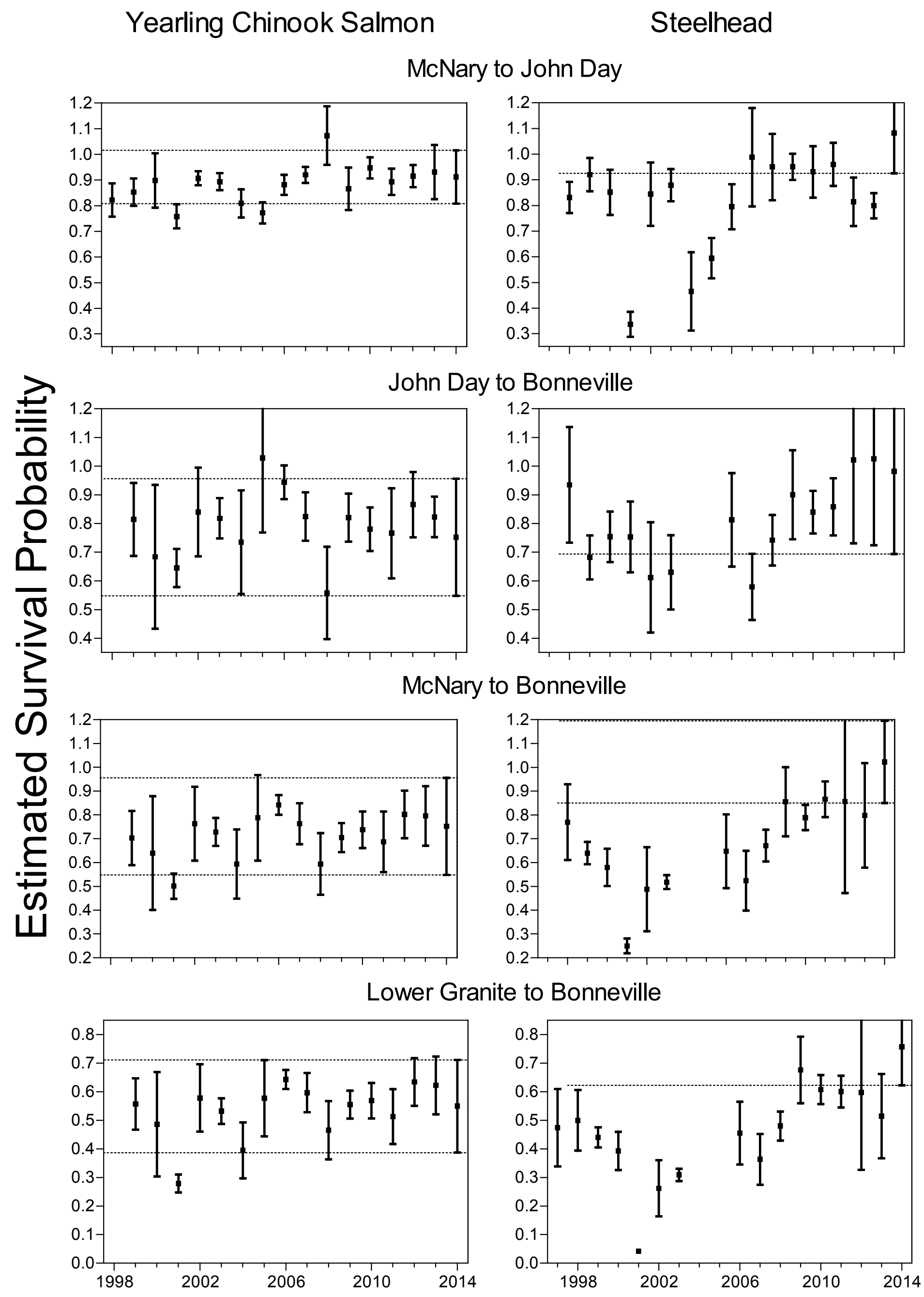

Figure 9. Annual average survival estimates for PIT-tagged Snake River yearling Chinook salmon and steelhead (hatchery and wild combined) through Columbia River reaches and from Lower Granite Dam to Bonneville Dam, 1993-2014. Estimates are from tailrace to tailrace. Vertical bars represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2014 estimates.

Table 27. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling Chinook salmon (wild only) 1999–2014. Standard errors in parentheses. Simple arithmetic means are given.

Annual survival estimates for wild yearling Chinook					
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1999	0.951 (0.011)	0.791 (0.014)	0.620 (0.099)	0.490 (0.079)	0.466 (0.075)
2000	0.955 (0.023)	0.775 (0.014)	0.575 (0.156)	0.446 (0.121)	0.425 (0.116)
2001	0.921 (0.058)	0.525 (0.034)	0.437 (0.041)	0.230 (0.026)	0.211 (0.028)
2002	0.985 (0.038)	0.768 (0.026)	0.469 (0.120)	0.360 (0.093)	0.355 (0.092)
2003	0.943 (0.033)	0.729 (0.020)	0.757 (0.059)	0.552 (0.046)	0.520 (0.047)
2004	0.862 (0.013)	0.667 (0.023)	0.566 (0.164)	0.377 (0.110)	0.325 (0.095)
2005	0.964 (0.034)	0.661 (0.017)	0.681 (0.243)	0.450 (0.161)	0.434 (0.156)
2006	0.929 (0.019)	0.754 (0.010)	0.827 (0.085)	0.623 (0.064)	0.579 (0.061)
2007	0.903 (0.062)	0.773 (0.013)	0.780 (0.088)	0.603 (0.069)	0.544 (0.072)
2008	0.955 (0.036)	0.786 (0.020)	0.607 (0.127)	0.477 (0.101)	0.456 (0.098)
2009	0.940 (0.012)	0.765 (0.018)	0.606 (0.068)	0.464 (0.053)	0.436 (0.050)
2010	0.821 (0.047)	0.744 (0.021)	0.612 (0.063)	0.455 (0.049)	0.374 (0.045)
2011	0.954 (0.010)	0.743 (0.015)	0.955 (0.197)	0.710 (0.147)	0.677 (0.140)
2012	0.942 (0.013)	0.798 (0.020)	0.831 (0.065)	0.663 (0.054)	0.625 (0.052)
2013	0.791 (0.045)	0.778 (0.018)	0.685 (0.092)	0.553 (0.073)	0.422 (0.062)
2014	0.892 (0.017)	0.678 (0.022)	0.577 (0.074)	0.391 (0.052)	0.349 (0.047)
Mean	**0.919 (0.013)**	**0.733 (0.018)**	**0.662 (0.035)**	**0.490 (0.031)**	**0.450 (0.030)**

Table 28. Annual weighted means of survival probability estimates for steelhead (hatchery and wild combined), 1995–2014. Standard errors in parentheses. Shaded columns are reaches that comprise two dams and reservoirs (i.e., two projects); the following column gives the square root of the two–project estimate to facilitate comparison with other single-project estimates. Simple arithmetic means across all available years (1993–2014) are given.

Annual survival estimates for hatchery and wild steelhead

Year	Trap to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	L Monumental to Ice Harbor and Ice Harbor to McNary	McNary to John Day Dam	John Day to Bonneville Dam	John Day to The Dalles and The Dalles to Bonneville Dam
1995	0.945 (0.008)	0.899 (0.005)	0.962 (0.011)	0.858 (0.076)	0.926			
1996	0.951 (0.015)	0.938 (0.008)	0.951 (0.014)	0.791 (0.052)	0.889			
1997	0.964 (0.015)	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.913			
1998	0.924 (0.009)	0.930 (0.004)	0.889 (0.006)	0.797 (0.018)	0.893	0.831 (0.031)	0.935 (0.103)	0.967
1999	0.908 (0.011)	0.926 (0.004)	0.915 (0.006)	0.833 (0.011)	0.913	0.920 (0.033)	0.682 (0.039)	0.826
2000	0.964 (0.013)	0.901 (0.006)	0.904 (0.009)	0.842 (0.016)	0.918	0.851 (0.045)	0.754 (0.045)	0.868
2001	0.911 (0.007)	0.801 (0.010)	0.709 (0.008)	0.296 (0.010)	0.544	0.337 (0.025)	0.753 (0.063)	0.868
2002	0.895 (0.015)	0.882 (0.011)	0.882 (0.018)	0.652 (0.031)	0.807	0.844 (0.063)	0.612 (0.098)	0.782
2003	0.932 (0.015)	0.947 (0.005)	0.898 (0.012)	0.708 (0.018)	0.841	0.879 (0.032)	0.630 (0.066)	0.794
2004	0.948 (0.004)	0.860 (0.006)	0.820 (0.014)	0.519 (0.035)	0.720	0.465 (0.078)	NA	NA
2005	0.967 (0.004)	0.940 (0.004)	0.867 (0.009)	0.722 (0.023)	0.850	0.595 (0.040)	NA	NA
2006	0.920 (0.013)	0.956 (0.004)	0.911 (0.006)	0.808 (0.017)	0.899	0.795 (0.045)	0.813 (0.083)	0.902
2007	1.016 (0.026)	0.887 (0.009)	0.911 (0.022)	0.852 (0.030)	0.923	0.988 (0.098)	0.579 (0.059)	0.761
2008	0.995 (0.018)	0.935 (0.007)	0.961 (0.014)	0.776 (0.017)	0.881	0.950 (0.066)	0.742 (0.045)	0.861
2009	1.002 (0.011)	0.972 (0.005)	0.942 (0.008)	0.863 (0.014)	0.929	0.951 (0.026)	0.900 (0.079)	0.949
2010	1.017 (0.030)	0.965 (0.028)	0.984 (0.044)	0.876 (0.032)	0.936	0.931 (0.051)	0.840 (0.038)	0.907
2011	0.986 (0.017)	0.955 (0.004)	0.948 (0.010)	0.772 (0.014)	0.879	0.960 (0.043)	0.858 (0.051)	0.926
2012	1.001 (0.026)	0.959 (0.006)	0.914 (0.011)	0.811 (0.022)	0.901	0.814 (0.048)	1.021 (0.148)	1.010
2013	0.973 (0.032)	0.921 (0.020)	0.977 (0.020)	0.739 (0.031)	0.860	0.799 (0.025)	1.026 (0.154)	1.013
2014	1.018 (0.028)	0.953 (0.009)	0.947 (0.024)	0.836 (0.032)	0.914	1.082 (0.080)	0.982 (0.147)	0.991
Mean	**0.959 (0.009)**	**0.921 (0.010)**	**0.909 (0.013)**	**0.759 (0.031)**	**0.867**	**0.823 (0.047)**	**0.808 (0.038)**	**0.898**

Table 29. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River steelhead (hatchery and wild combined), 1997–2014. Standard errors in parentheses; simple arithmetic means are given.

Annual survival estimates for hatchery and wild steelhead					
Year	Snake River Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1997	1.020 (0.023)	0.728 (0.053)	0.651 (0.082)	0.474 (0.069)	0.484 (0.072)
1998	0.924 (0.009)	0.649 (0.013)	0.770 (0.081)	0.500 (0.054)	0.462 (0.050)
1999	0.908 (0.011)	0.688 (0.010)	0.640 (0.024)	0.440 (0.018)	0.400 (0.017)
2000	0.964 (0.013)	0.679 (0.016)	0.580 (0.040)	0.393 (0.034)	0.379 (0.033)
2001	0.911 (0.007)	0.168 (0.006)	0.250 (0.016)	0.042 (0.003)	0.038 (0.003)
2002	0.895 (0.015)	0.536 (0.025)	0.488 (0.090)	0.262 (0.050)	0.234 (0.045)
2003	0.932 (0.015)	0.597 (0.013)	0.518 (0.015)	0.309 (0.011)	0.288 (0.012)
2004	0.948 (0.004)	0.379 (0.023)	NA	NA	NA
2005	0.967 (0.004)	0.593 (0.018)	NA	NA	NA
2006	0.920 (0.013)	0.702 (0.016)	0.648 (0.079)	0.455 (0.056)	0.418 (0.052)
2007	1.016 (0.026)	0.694 (0.020)	0.524 (0.064)	0.364 (0.045)	0.369 (0.047)
2008	0.995 (0.018)	0.716 (0.015)	0.671 (0.034)	0.480 (0.027)	0.478 (0.028)
2009	1.002 (0.011)	0.790 (0.013)	0.856 (0.074)	0.676 (0.059)	0.678 (0.060)
2010	1.017 (0.030)	0.770 (0.020)	0.789 (0.027)	0.608 (0.026)	0.618 (0.032)
2011	0.986 (0.017)	0.693 (0.013)	0.866 (0.038)	0.600 (0.029)	0.592 (0.030)
2012	1.001 (0.026)	0.698 (0.020)	0.856 (0.196)	0.597 (0.138)	0.598 (0.139)
2013	0.973 (0.032)	0.645 (0.026)	0.798 (0.112)	0.515 (0.075)	0.501 (0.075)
2014	1.018 (0.028)	0.740 (0.021)	1.023 (0.088)	0.757 (0.069)	0.771 (0.073)
Mean	**0.954 (0.012)**	**0.637 (0.035)**	**0.683 (0.047)**	**0.467 (0.043)**	**0.457 (0.045)**

Table 30. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River steelhead (wild only), 1999–2014. Standard errors in parentheses; simple arithmetic means are given.

	Annual survival estimates for wild steelhead				
Year	Snake River Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1999	0.910 (0.024)	0.746 (0.019)	0.634 (0.113)	0.473 (0.085)	0.430 (0.078)
2000	0.980 (0.027)	0.714 (0.028)	0.815 (0.102)	0.582 (0.076)	0.570 (0.076)
2001	0.958 (0.011)	0.168 (0.010)	0.209 (0.046)	0.035 (0.008)	0.034 (0.008)
2002	0.899 (0.023)	0.593 (0.039)	0.574 (0.097)	0.341 (0.062)	0.306 (0.056)
2003	0.893 (0.026)	0.597 (0.022)	0.500 (0.042)	0.299 (0.027)	0.267 (0.026)
2004	0.936 (0.007)	0.383 (0.029)	NA	NA	NA
2005	0.959 (0.008)	0.562 (0.046)	NA	NA	NA
2006	0.976 (0.036)	0.745 (0.040)	0.488 (0.170)	0.363 (0.128)	0.355 (0.125)
2007	1.050 (0.056)	0.730 (0.027)	0.524 (0.064)	0.383 (0.049)	0.402 (0.056)
2008	0.951 (0.029)	0.692 (0.029)	0.713 (0.093)	0.493 (0.068)	0.469 (0.066)
2009	0.981 (0.019)	0.763 (0.029)	0.727 (0.073)	0.555 (0.060)	0.544 (0.059)
2010	1.003 (0.049)	0.773 (0.041)	0.736 (0.110)	0.569 (0.090)	0.571 (0.095)
2011	0.983 (0.037)	0.730 (0.024)	0.660 (0.136)	0.482 (0.101)	0.474 (0.100)
2012	1.107 (0.070)	0.697 (0.047)	NA	NA	NA
2013	0.921 (0.057)	0.621 (0.055)	0.671 (0.142)	0.417 (0.096)	0.384 (0.091)
2014	1.000 (0.047)	0.620 (0.034)	1.057 (0.144)	0.655 (0.096)	0.655 (0.101)
Mean	**0.969 (0.014)**	**0.633 (0.040)**	**0.639 (0.055)**	**0.434 (0.044)**	**0.420 (0.045)**

Sockeye Salmon—For pooled groups of wild and hatchery sockeye salmon originating in the Snake River basin, estimated survival in 2014 from Lower Granite to McNary Dam was 0.873 (95% CI 0.773-0.985; Table 31). This estimate was higher than in 2013 and higher than the average of 0.631 for 1996-2014. Estimated survival for these fish in 2014 from Lower Granite to Bonneville Dam was 0.713 (0.528-0.963). This estimate was much higher than the average of 0.428 (0.313-0.513) through that reach and was second only to 2006 as the highest of our time series.

Table 31. Estimated survival for sockeye salmon (hatchery and wild combined) from Lower Granite Dam tailrace to Bonneville Dam tailrace for fish originating in the Snake River and from Rock Island Dam tailrace to Bonneville Dam tailrace for fish originating in the upper Columbia River, 1996–2014. Standard errors in parentheses.

	Annual survival estimates Snake River sockeye		
Year	Lower Granite to McNary	McNary to Bonneville Dam	Lower Granite to Bonneville Dam
1996	0.283 (0.184)	NA	NA
1997	NA	NA	NA
1998	0.689 (0.157)	0.142 (0.099)	0.177 (0.090)
1999	0.655 (0.083)	0.841 (0.584)	0.548 (0.363)
2000	0.679 (0.110)	0.206 (0.110)	0.161 (0.080)
2001	0.205 (0.063)	0.105 (0.050)	0.022 (0.005)
2002	0.524 (0.062)	0.684 (0.432)	0.342 (0.212)
2003	0.669 (0.054)	0.551 (0.144)	0.405 (0.098)
2004	0.741 (0.254)	NA	NA
2005	0.388 (0.078)	NA	NA
2006	0.630 (0.083)	1.113 (0.652)	0.820 (0.454)
2007	0.679 (0.066)	0.259 (0.084)	0.272 (0.073)
2008	0.763 (0.103)	0.544 (0.262)	0.404 (0.179)
2009	0.749 (0.032)	0.765 (0.101)	0.573 (0.073)
2010	0.723 (0.039)	0.752 (0.098)	0.544 (0.077)
2011	0.659 (0.033)	NA	NA
2012	0.762 (0.032)	0.619 (0.084)	0.472 (0.062)
2013	0.691 (0.043)	0.776 (0.106)	0.536 (0.066)
2014	0.873 (0.054)	0.817 (0.115)	0.713 (0.110)
Mean	**0.631 (0.041)**	**0.584 (0.081)**	**0.428 (0.059)**

Table 31. Continued.

	Annual survival estimates upper Columbia River sockeye		
	Rock Island to McNary Dam	McNary to Bonneville Dam	Rock Island to Bonneville Dam
1996	NA	NA	NA
1997	0.397 (0.119)	NA	NA
1998	0.624 (0.058)	1.655 (1.617)	1.033 (1.003)
1999	0.559 (0.029)	0.683 (0.177)	0.382 (0.097)
2000	0.487 (0.114)	0.894 (0.867)	0.435 (0.410)
2001	0.657 (0.117)	NA	NA
2002	0.531 (0.044)	0.286 (0.110)	0.152 (0.057)
2003	NA	NA	NA
2004	0.648 (0.114)	1.246 (1.218)	0.808 (0.777)
2005	0.720 (0.140)	0.226 (0.209)	0.163 (0.147)
2006	0.793 (0.062)	0.767 (0.243)	0.608 (0.187)
2007	0.625 (0.046)	0.642 (0.296)	0.401 (0.183)
2008	0.644 (0.094)	0.679 (0.363)	0.437 (0.225)
2009	0.853 (0.076)	0.958 (0.405)	0.817 (0.338)
2010	0.778 (0.063)	0.627 (0.152)	0.488 (0.111)
2011	0.742 (0.088)	0.691 (0.676)	0.513 (0.498)
2012	0.945 (0.085)	0.840 (0.405)	0.794 (0.376)
2013	0.741 (0.068)	0.658 (0.217)	0.487 (0.155)
2014	0.428 (0.056)	0.565 (0.269)	0.242 (0.111)
Mean	**0.657 (0.036)**	**0.761 (0.090)**	**0.517 (0.066)**

Upper Columbia River Stocks

Sockeye Salmon—For Upper Columbia River sockeye salmon captured, tagged, and released to the tailrace of Rock Island Dam in 2014, estimated survival to McNary tailrace was 0.428 (95% CI 0.332-0.553; Table 31). This estimate is the second lowest (to 1997) in our time series for this reach (1997-2014), and is below the 2013 estimate of 0.741 and the long-term average of 0.657. Estimated survival of sockeye from Rock Island to Bonneville Dam was 0.242 (0.103-0.570), which is also among the lowest estimates we have seen for these fish, and below the mean of 0.517 (0.389-0.646).

Yearling Chinook Salmon—For pooled groups of yearling Chinook from Upper Columbia River hatcheries, estimated survival from McNary tailrace to Bonneville tailrace was 0.933 (0.735-1.184). This estimate was greater than the 1999-2014 average of 0.805 for that reach (Table 32), but as has often been the case for this reach, the estimate was very imprecise due to poor detection at Bonneville Dam and the pair trawl.

Table 32. Estimated survival and standard error (SE) through reaches of the lower Columbia River hydropower system for hatchery yearling Chinook salmon (1999–2014) and steelhead (2003–2014) originating in the upper Columbia River. Steelhead estimates were not possible prior to 2003. Multiple release sites were used in each year and not all release sites occurred consistently among years. Simple arithmetic means across all years are given.

	Annual survival estimates upper Columbia River			
Year	Release site to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
		Hatchery yearling Chinook salmon		
1999	0.572 (0.014)	0.896 (0.044)	0.795 (0.129)	0.712 (0.113)
2000	0.539 (0.025)	0.781 (0.094)	NA	NA
2001	0.428 (0.009)	0.881 (0.062)	NA	NA
2002	0.555 (0.003)	0.870 (0.011)	0.940 (0.048)	0.817 (0.041)
2003	0.625 (0.003)	0.900 (0.008)	0.977 (0.035)	0.879 (0.031)
2004	0.507 (0.005)	0.812 (0.019)	0.761 (0.049)	0.618 (0.038)
2005	0.545 (0.012)	0.751 (0.042)	NA	NA
2006	0.520 (0.011)	0.954 (0.051)	0.914 (0.211)	0.871 (0.198)
2007	0.584 (0.009)	0.895 (0.028)	0.816 (0.091)	0.730 (0.080)
2008	0.582 (0.019)	1.200 (0.085)	0.522 (0.114)	0.626 (0.133)
2009	0.523 (0.013)	0.847 (0.044)	1.056 (0.143)	0.895 (0.116)
2010	0.660 (0.014)	0.924 (0.040)	0.796 (0.046)	0.735 (0.037)
2011	0.534 (0.010)	1.042 (0.047)	0.612 (0.077)	0.637 (0.077)
2012	0.576 (0.012)	0.836 (0.035)	1.140 (0.142)	0.953 (0.115)
2013	0.555 (0.013)	0.965 (0.050)	1.095 (0.129)	1.056 (0.117)
2014	0.571 (0.013)	0.974 (0.047)	0.958 (0.122)	0.933 (0.114)
Mean	**0.555 (0.013)**	**0.908 (0.027)**	**0.875 (0.050)**	**0.805 (0.039)**
		Hatchery steelhead		
2003	0.471 (0.004)	0.997 (0.012)	0.874 (0.036)	0.871 (0.036)
2004	0.384 (0.005)	0.794 (0.021)	1.037 (0.112)	0.823 (0.088)
2005	0.399 (0.004)	0.815 (0.017)	0.827 (0.071)	0.674 (0.057)
2006	0.397 (0.008)	0.797 (0.026)	0.920 (0.169)	0.733 (0.134)
2007	0.426 (0.016)	0.944 (0.064)	0.622 (0.068)	0.587 (0.059)
2008	0.438 (0.015)	NA	NA	NA
2009	0.484 (0.018)	0.809 (0.048)	0.935 (0.133)	0.756 (0.105)
2010	0.512 (0.017)	0.996 (0.054)	0.628 (0.038)	0.626 (0.033)
2011	0.435 (0.012)	1.201 (0.064)	0.542 (0.101)	0.651 (0.119)
2012	0.281 (0.011)	0.862 (0.047)	1.240 (0.186)	1.069 (0.159)
2013	0.384 (0.020)	0.957 (0.071)	0.974 (0.104)	0.932 (0.099)
2014	0.468 (0.043)	0.883 (0.124)	0.807 (0.153)	0.712 (0.130)
Mean	**0.423 (0.018)**	**0.914 (0.037)**	**0.855 (0.061)**	**0.767 (0.044)**

Steelhead—For pooled groups of hatchery steelhead from Upper Columbia hatcheries, estimated survival from McNary tailrace to Bonneville tailrace in 2014 was 0.712 (0.499-1.015). This estimate was again imprecise due to poor and variable detection rates at Lower Columbia River dams (Table 32).

Comparison Among Snake and Columbia River Stocks

Estimated survival from McNary to Bonneville Dam tailrace was lower for Snake (0.715, SE 0.107) than for Upper Columbia River spring/summer Chinook in 2014 (0.929, SE 0.103; Table 33). However, because of low precision in the 2014 estimates, the difference was not statistically significant (*P* = 0.15).

For steelhead migrating in this same reach during 2014, estimated survival was slightly higher for Snake (1.023, se 0.088) than for Upper Columbia River fish (0.972, SE 0.108), but the difference was small and not statistically significant (*P* = 0.71). For sockeye salmon, estimated survival from McNary to John Day tailrace was much higher for Snake (0.817, SE 0.115) than for Upper Columbia River fish (0.636, SE 0.204), but both estimates were very imprecise and the difference was not significant (*P* = 0.44).

Table 33. Average survival estimates (with standard errors in parentheses) from McNary Dam tailrace to Bonneville Dam tailrace for various spring–migrating salmonid stocks (hatchery and wild combined) in 2014. In shaded rows, the estimate represents a weighted average of weekly estimated survival. In all other rows, all release cohorts were pooled for a single seasonal estimate. Release numbers for pooled cohorts are from points upstream of McNary Dam. All Chinook salmon are spring/summer run.

			Estimated survival (SE)		
Stock	Release location	Number released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
Snake River Chinook	McNary Dam tailrace	43,693	0.912 (0.053)	0.752 (0.104)	0.715 (0.107)
Upper Columbia Chinook	Upper Columbia sites[a]	113,114	0.939 (0.038)	0.990 (0.110)	0.929 (0.100)
Upper Columbia Chinook	Yakima River sites[b]	76,731	0.900 (0.051)	0.828 (0.189)	0.745 (0.166)
Upper Columbia Coho	Upper Columbia sites	53,370	0.895 (0.057)	1.181 (0.181)	1.057 (0.159)
Upper Columbia Coho	Yakima River sites	14,461	0.940 (0.140)	1.053 (0.393)	0.989 (0.353)
Snake River Sockeye	Snake River sites[c]	54,080	0.794 (0.085)	1.029 (0.166)	0.817 (0.115)
Upper Columbia Sockeye	Upper Columbia sites	12,949	1.316 (0.284)	0.488 (0.182)	0.636 (0.204)
Snake River Steelhead	McNary Dam Tailrace	12,363	1.082 (0.080)	0.982 (0.147)	1.023 (0.088)
Upper Columbia Steelhead	Upper Columbia sites	75,578	0.899 (0.061)	1.082 (0.124)	0.972 (0.108)

[a] Any release site on the Columbia River or its tributaries upstream from confluence with the Yakima River.

[b] Any release site on the Yakima River or its tributaries.

[c] Any release site on the Snake River or its tributaries upstream from Lower Granite Dam.

Discussion

For combined hatchery and wild Snake River yearling Chinook salmon, estimated survival through the entire hydrosystem, from the Snake River Trap to Bonneville tailrace, was 49.7% in 2014. This estimate was nearly equal to the long-term average of 50.1% but lower than the 2013 estimate of 52.5%, although the difference was not significant (*P* = 0.75; Table 27). Estimated survival in 2014 for yearling Chinook salmon between Lower Granite and McNary Dams was 3.0 percentage points higher than the long-term mean (76.8 vs. 73.8%). Between McNary and Bonneville Dams, estimated survival in 2014 was 0.5 percentage points higher than the long-term mean (71.5 vs. 71.0%). For these fish, survival through the hydropower system has remained relatively stable since 1999, with the exception of lower estimates in 2001 and 2004.

For combined hatchery and wild Snake River steelhead, estimated survival through the entire hydropower system was 77.1% in 2014. This estimate was considerably higher than the long-term mean of 45.7% and was the highest of our time series (1997-2014; Table 29). This 2014 estimate was 27.0 percentage points higher than in 2013 (50.1%), and the difference was significant (*P* = 0.01; Table 29). In the reach from McNary to Bonneville Dam, estimated mean survival was much higher than average, at 102.3 (average 68.3%). High survival in this reach contributed most to the high estimate for Snake River steelhead over the entire hydropower system. Estimated survival from Lower Granite to McNary Dam tailrace was also higher than average (74.0 vs. 64.5%), and was the fourth highest estimate in our time series for that reach.

Steelhead survival estimates of 77.1% over the entire hydrosystem and 102% in the reach from McNary to Bonneville Dam are of particular interest. Estimates in 2014 were unusually high for both McNary-to-John Day Dam and John Day-to-Bonneville Dam reaches. It is possible that these estimates accurately reflect exceptionally high survival rates during 2014 in the lower Columbia River. However, there is no obvious reason that we would expect survival to be so much higher than average in 2014. Environmental conditions were average, dam operations were similar to those in recent years, and by comparison, yearling Chinook survival was only average.

For sockeye salmon originating in the Snake River Basin, estimated survival from Lower Granite to Bonneville Dam was 71.3% in 2014. This estimate was the second highest of our time series for sockeye through that reach. In contrast, for sockeye originating in the Upper Columbia Basin, estimated survival between Rock Island and Bonneville Dam was only 24.2%. This estimate was among the lowest of our time series for sockeye in that reach.

We can only speculate why sockeye survival was high in one drainage and low in the other, especially given the average river conditions during 2014. Operations at a few Upper Columbia dams may have influenced survival there. A crack was discovered in the spillway at Wanapum Dam prior to the migration period, and repair of the crack required a reservoir drawdown of over 20 ft during the migration. This change in elevation in turn forced an increase in spill at Rock Island Dam to account for head differential. Conditions produced by these changes in operations may have contributed to reduced survival for sockeye between Rock Island and McNary Dam.

River flows and water temperatures during the 2014 spring migration were generally close to long-term averages. Spill volumes and percentages were above the long-term averages but were not higher than those in recent years. Therefore, conditions in the Snake River could be categorized as average flow and temperature with above-average spill; conditions similar to those that occurred in 2009.

The series of detection sites in the lower Columbia River had relatively low detection rates in 2014, which resulted in elevated sampling error (i.e., large standard errors) in our survival estimates. Large sampling error alone could explain a high survival estimate for steelhead in the combined McNary-to-Bonneville reach. However, computer simulations indicated that it is very unlikely that sampling error alone accounted for the pattern of exceptionally high estimates in both of these sub-reaches, even if actual survival were high in both reaches.

It is likely then, that steelhead survival estimates in the lower Columbia River reaches were biased by a combination of low detection probabilities and violations of SR model assumptions. In addition to decreasing precision, low detection probabilities can amplify the effects of some assumption violations, causing otherwise minor violations to have a disproportionately large effect on estimates. Examples of some possible model violations include differential mortality between detected and nondetected fish, and other patterns of heterogeneity among individuals in survival or detection probabilities.

Violations that arise from heterogeneity or dependence in detection probabilities induce larger bias in survival estimates when detection probabilities are lower. Varying patterns through time in dam operations at successive dams can induce patterns in detection probability estimates that lead to biased survival estimates. We are investigating the likelihood and degree of assumption violations under various conditions and will report any definitive findings.

With the addition of a temporary spillway weir (TSW) at Little Goose Dam in 2009, all eight mainstem dams encountered by migrating Snake River smolts have some form of surface-bypass structure. These include removable spillway weirs (RSWs) at

Lower Granite, Lower Monumental, and Ice Harbor Dam; TSWs at Little Goose, McNary, and John Day Dam, the ice-trash sluiceway at The Dalles Dam, and the corner collector at Bonneville Dam.

Operation of surface-bypass structures can have direct positive effects on survival, as well as indirect positive effects associated with decreased travel times. Measures of absolute survival through surface-passage structures are often similar to (i.e., not higher than) those through juvenile bypass systems or unaltered spillways. However, surface-bypass structures provide an advantage by reducing smolt delay in the forebay. For migrating smolts, less time spent in the reservoir and forebay of a dam means decreased travel time and reduced exposure to predators.

Decreased forebay delay and overall shortened travel times also potentially decrease exposure to the elevated water temperatures that may occur late in spring or early summer. In steelhead smolts, warmer water can trigger reversion to the parr stage, accompanied by cessation of migration. Zaugg and Wagner (1973) found that gill Na^+K^+-ATPase (an indicator of migratory readiness) and migratory urge declined in steelhead at water temperatures of 13°C and above.

A PIT-tagged smolt that ceases migration will not be detected at further downstream dams. Therefore, reversion to parr cannot be distinguished from mortality using PIT-tag data. If significant numbers of fish revert to parr, survival estimates will be biased downward. This may have been a factor in the low survival estimates we observed for steelhead in 2001, when longer travel times were observed late in the season and water temperatures exceeded 13°C (Zabel et al. 2002). Thus, estimated survival should be higher for populations of steelhead when travel times are reduced.

Predation is another factor that directly affects survival of migrating smolts (Collis et al. 2002). Avian piscivores are abundant along the Columbia River downstream from its confluence with the Snake River, and their populations and consumption rates are intensively monitored (Ryan et al. 2001, 2003; Roby et al. 2008, Evans et al. 2012). In Lake Wallula (McNary Dam reservoir), Crescent Island harbors the second largest Caspian tern *Hydroprogne caspia* colony in North America (about 500 breeding pairs annually on average in the last 10 years), as well as large populations of gulls *Larus* spp. Other avian piscivores in this area include the American white pelican *Pelecanus erythrorhynchos,* cormorant *Phalacrocorax auritus*, egret *Ardea alba*, and herons *A. herodias* and *Nycticorax nycticorax.*

Studies have shown that steelhead smolts are particularly susceptible to predation by birds (Hostetter et al. 2012). For example, Collis et al. (2001) found that over 15% of the PIT-tags from steelhead detected at Bonneville Dam in 1998 were later found on estuarine bird colonies, but on the same colonies they found only 2% of the PIT-tags from detected yearling Chinook salmon. As indexed by the percentages of tags detected at Lower Monumental Dam and subsequently detected on bird colonies (Table 34), the estimated proportion of PIT-tagged steelhead lost to piscivorous birds Lake Wallula was lower during 2006-2012 than during 2001-2005.

Correspondingly, steelhead survival between Lower Monumental and McNary Dams was lower during 2001-2005 and higher during 2006-2012. For both yearling Chinook salmon and steelhead detected at Lower Monumental Dam, we have observed a significant negative correlation between estimated survival to McNary Dam and percentage of PIT tags recovered on avian colonies (Figure 10).

Table 34. Percentages of PIT–tagged smolts detected at Lower Monumental Dam and subsequently detected on avian predator colonies in McNary reservoir, 1998-2012. Estimates are not adjusted for detection efficiency on individual colonies and therefore are minimum estimates of predation rates.

	Proportion of wild and hatchery smolts detected at Lower Monumental Dam and subsequently detected on Lake Wallula avian colony (%)	
Year	Yearling Chinook Salmon	Steelhead
1998	0.49	4.20
1999	0.90	4.51
2000	0.98	3.66
2001	5.59	21.06
2002	1.62	10.09
2003[a]	1.06	3.71
2004[b]	2.08	19.42
2005	1.37	9.15
2006	0.92	4.81
2007	0.80	3.59
2008	1.20	4.63
2009	1.57	3.78
2010	1.27	5.26
2011	1.03	3.37
2012	0.52	2.32

[a] Only Crescent Island Caspian tern colony sampled.

[b] Only Crescent Island and Foundation Island colonies sampled.

The smaller proportion of smolts taken by birds during 2006-2012 was due in part to an increase in the total number of smolts (tagged and untagged) remaining in the river. This higher number of inriver migrant smolts in turn resulted from increased spill, expanded use of surface passage structures at Snake River dams (all 4 dams since 2009), and delayed initiation of the smolt transportation program.

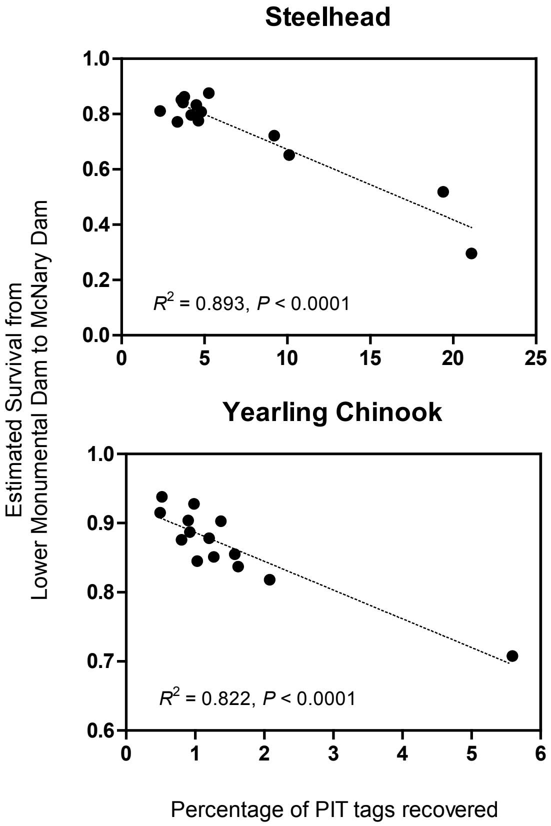

Figure 10. Estimated survival between Lower Monumental and McNary Dams vs. percentage of Lower Monumental Dam-detected PIT tags recovered on bird colonies, 1998-2012 (excluding 2003, which had incomplete recovery effort).

Piscivorous fish also contribute significantly to mortality of migrating Chinook salmon and steelhead smolts (Rieman et al. 1991). Species of reservoir-dwelling fishes that may prey heavily on migrating smolts include northern pikeminnow *Ptychocheilus oregonensis*, walleye *Sander vitreus*, and smallmouth bass *Micropterus dolomieu*. Reiman et al. (1991) found that fish predators (primarily pikeminnow) could consume nearly 14% of all smolts migrating through John Day reservoir,and more recently, salmonid smolts accounted for 15% of identifiable prey items recovered from pikeminnow stomachs in 2012 (Porter 2012).

Since 1990, the Bonneville Power Administration has funded a sport reward fishery for northern pikeminnow in the lower Columbia River under the Northern Pikeminnow Management Plan. Abundance estimates of large (>250 mm FL) pikeminnow in The Dalles and John Day reservoirs have declined steadily since the inception of the sport reward program. Over the last 5 years, abundance estimates for large fish have been only one-tenth those in 1990 (Porter 2012).

In 2014, estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams were similar to those in 2013. These similar rates were observed despite a change in relative start dates of transportation at collector dams.

In past years, transportation start dates at collector dams were staggered, starting earlier at Lower Granite Dam and progressing downstream. In 2014, collection for transportation began on 1 May at Lower Granite and Little Goose Dams and on 2 May at Lower Monumental Dam. The first barge at each dam was on 2 May. As a result, fish that were bypassed at Lower Granite Dam were more likely to arrive at a downstream site after transportation had started, and consequently a larger proportion of them were transported.

From the combined annual total of Chinook salmon passing Lower Granite Dam, we estimated that 63% of wild and 39% of hatchery fish passed before transportation began. After 1 May 2014, we estimated that 73% of wild and 52% of hatchery yearling Chinook were transported (wild fish are more likely to enter collection systems).

Less data was available to differentiate between wild and hatchery steelhead, as no distinction by origin is included in smolt sampling reports. Therefore, we were unable provide separate estimates for hatchery vs. wild steelhead with as much precision as we had for yearling Chinook. For combined wild and hatchery steelhead, we estimate that 49% passed Lower Granite Dam before transportation began and that 63% passing after 1 May were transported. Differences in estimated detection probability between wild and hatchery steelhead suggest that after collections began, the transported proportion was higher for wild than for hatchery steelhead.

In comparison to 2013, a higher proportion of both Chinook salmon and steelhead passed before transportation began, but a greater proportion was transported after the program began. For both species, this greater proportion, combined with similar transportation start dates at downstream dams, resulted in overall percentages of transported fish in 2014 that were similar to those estimated for 2013.

For survival estimates based on PIT-tag data, effective sample size is a result of both number of PIT-tagged fish migrating and detection rates during migration. Low detection rates of migrating PIT-tagged fish have become common in recent years, as management has relied increasingly on use of spill and surface-bypass structures for juvenile passage. Spill is now the primary management strategy used to increase survival of juvenile fish passing dams within the Federal Columbia River Power System.

This management strategy reduces detection rates by reducing the proportion of fish that pass dams via juvenile bypass systems. Other than the corner collector at Bonneville Dam, the juvenile bypass systems provide the only dam-passage route for which PIT-tag monitoring technology is currently available.

While smolt survival might indeed be increased by emphasizing spillway passage, the quality of information gathered to verify higher rates of survival has been reduced as a result of reduced probabilities of PIT-tag detection. Three consequences of this lost information are:

1) Reduced certainty in survival estimates, for which standard errors become larger and confidence intervals wider
2) Greater negative correlation between survival estimates in consecutive reaches. That is, there is an increased chance that estimates will be high in one reach and low in the next, or vice versa
3) Insufficient data to estimate survival at all in some cases

All three consequences are most serious in the final two reaches of the migration corridor for which we estimate smolt survival: McNary to John Day and John Day to Bonneville Dam.

Smaller effective sample sizes also heighten uncertainty in estimates of travel time and smolt-to-adult return ratios. Such uncertainty reduces the quality of predictive models, which are based on these estimates. Ultimately, this uncertainty may weaken the efficacy of management decisions informed by estimates and model predictions, hinder the development of appropriate restoration plans, and impair the ability to monitor and assess restoration plans after they are implemented.

At a given rate of PIT-tag detection, precision in survival estimates can be increased only by increasing the number of tagged fish released to the system. Unfortunately, this option would be costly and would further strain an already stressed biological resource. Therefore, assuming the emphasis on surface-bypass and spillway passage will continue, the best option for retaining or increasing precision in survival estimates would be to equip additional passage routes with PIT-tag monitoring technology.

Adding this capability will not only increase the proportions of fish detected at each dam, it will stabilize detection rates across the season. At present, fluctuations in spill and flow produce variable detection rates within each migration season. These variations can have negative consequences on the accuracy of estimates from mark-recapture models, as well as introducing bias to estimates of travel time. Detection capability in multiple routes at a dam will reduce this variation and will advance our understanding of passage via different routes throughout the migration season, producing valuable insight into fish passage behavior.

Finally, the ability to detect PIT-tagged fish in additional passage routes could increase the accuracy of survival estimates. Detection of fish passing multiple routes will reduce the possibility of bias in survival estimates that results if survival is not equal between detected and undetected fish.

For all of these reasons, we believe there is an urgent need to develop and install PIT-tag monitoring systems in passage routes other than juvenile bypass systems. In terms of their importance to survival estimates, the highest priority for new PIT-tag monitoring systems are the spillway at Bonneville Dam and the surface-passage structures Lower Granite and McNary Dams.

Because of consistently low detection rates at Bonneville Dam, the reach from John Day to Bonneville has been the weakest link in our ability to estimate survival through the entire hydropower system. At present, we rely on detections in the pair trawl system operated downstream of Bonneville Dam. However, rates of detection in the trawl are low and not likely to increase substantially in the future.

The ability to estimate survival to Bonneville Dam would be greatly improved if a detection method superior to the paired trawl could be developed for use in open water. However, in the absence of such technology, we believe that adding detection capability at Bonneville Dam should be the greatest priority.

Lower Granite and McNary Dams are important as the “starting points” for our estimates of juvenile smolt survival. Increasing the number of detections at these two dams in particular will increase precision of estimates and modeling of in-season trends and patterns. These two sites are also critical for investigations of the relationship between juvenile migration timing and downstream survival or smolt-to-adult return rates. For either assessment, the “time-stamp” provided by detection of a PIT-tag is required.

The PIT tag is a valuable research tool that yields a great deal of important information that cannot be obtained by any other tagging method. For example, the PIT-tag allows continuous monitoring of large fish groups through both their juvenile and adult migrations. It allows comparison of smolt-to-adult return ratios between different treatment groups. Therefore, it is critical that we take the necessary steps to maximize the quantity and quality of information already offered by the PIT tag at current levels of tagging.

Conclusions and Recommendations

Based on results of survival studies to date, we recommend the following:

1) Develop PIT-tag detection capability in spillways and surface structures to improve detection rates and increase certainty in estimates of juvenile salmonid survival passing Snake and Columbia River dams. High rates of spill and the use of surface-bypass structures (RSWs, TSWs) in recent years have resulted in low PIT-tag detection rates and consequently reduced precision of survival estimates.

2) Continue to coordinate survival studies with other projects to maximize the data-collection effort and minimize study effects on salmonid resources.

3) Continue development and maintenance of instream PIT-detection systems for use in tributaries in order to identify sources of mortality upstream from the Snake and Clearwater River confluence. Estimates of survival from hatcheries to Lower Granite Dam suggest that substantial mortality occurs in these areas.

4) Increase the number of PIT-tag detection facilities in the Columbia River Basin to improve survival estimation. We recommend installation of PIT-tag detection systems at The Dalles Dam and at upper Columbia River dams.

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Appendix A: Evaluation of Model Assumptions

Background

Using the Cormack-Jolly-Seber (CJS), or single-release (SR) model, the passage of a single PIT-tagged salmonid through the hydropower system is modeled as a sequence of events. Examples of such events are detection at Little Goose Dam or survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam. Each event has an associated probability of occurrence (technically, these probabilities are "conditional," as they are defined only if a certain condition is met, for example "probability of detection at Little Goose Dam *given* that the fish survived to Little Goose Dam").

The detection history is thus a record of the outcome of a series of events. (although detection history is an imperfect record of outcomes, since it cannot always distinguish between mortality and survival without detection). The SR model represents detection history data for a group of tagged fish as a multinomial distribution; each multinomial cell probability (detection history probability) is a function of the underlying survival and detection event probabilities. Three key assumptions lead to the multinomial cell probabilities used in the SR model:

A1) Fish in a single group of tagged fish have common event probabilities (each conditional detection or survival probability is common to all fish in the group).

A2) Event probabilities for each individual fish are independent from those for all other fish.

A3) Each event probability for an individual fish is conditionally independent from all other probabilities.

For a migrating PIT-tagged fish, assumption A3 implies that detection at any particular dam does not affect (or give information regarding) probabilities of subsequent events. For the tagged group as a whole, this means that detected and nondetected fish at a given dam have the same probability of survival in downstream reaches and have the same conditional probability of detection at downstream dams.

Methods

We used the methods presented by Burnham et al. (1987; pp 71-77) to assess the goodness-of-fit of the SR model to observed detection history data. In these tests, we compiled a series of contingency tables from detection history data for each group of tagged fish, and used χ^2 tests to identify systematic deviations from what was expected if the assumptions were met. We applied the tests to weekly groups of yearling Chinook salmon and steelhead (hatchery and wild combined) leaving Lower Granite and McNary Dam in 2013 (Snake River-origin fish only, i.e., the fish used for survival estimates reported in Tables 2-3 and 9-10).

If goodness-of-fit tests for a series of release groups resulted in more significant differences between observed and expected values than expected by chance, we compared observed and expected tables to determine the nature of the violation. While a consistent pattern of violations in assumption testing does not unequivocally pinpoint the cause of the violation, such patterns can be suggestive and may allow us to rule out some hypothesized causes.

Potential causes of assumption violations include

1) Inherent differences between individuals in survival or detection probability (e.g., in the propensity to be guided by bypass screens)
2) Differential mortality between the passage route that is monitored for PIT tags (juvenile collection system) and those that are not (spillways and turbines)
3) Behavioral responses to bypass and detection
4) Differences in passage timing for detected and non-detected fish if such differences result in exposure to different conditions downstream

However, inherent differences and behavioral responses cannot be distinguished using detection information alone. Conceptually, we make the distinction that inherent traits are those that characterized the fish before any hydrosystem experience, while behavioral responses occur as a result of particular hydrosystem experiences. For example, developing a preference for a particular passage route is a behavioral response, while size-related differences in passage-route selection are inherent. Of course, response to passage experience may also depend on inherent characteristics.

To describe each test we conducted, we follow the nomenclature of Burnham et al. (1987). For release groups from Lower Granite Dam, we analyzed 4-digit detection histories indicating status at Little Goose, Lower Monumental, and McNary Dams, and the final digit for detection anywhere below McNary Dam.

The first test for Lower Granite Dam groups was Burnham et al. (1987) Test 2.C2, which was based on the following contingency table:

Test 2.C2	First site detected below Little Goose		
df = 2	Lower Monumental	McNary	John Day or below
Not detected at Little Goose	n_{11}	n_{12}	n_{13}
Detected at Little Goose	n_{21}	n_{22}	n_{23}

In this table, all fish detected somewhere below Little Goose Dam were cross-classified according to their detection history at Little Goose and according to their first detection site below Little Goose. For example, n_{11} is the classification of fish not detected at Little Goose that were first detected downstream at Lower Monumental Dam.

If all SR model assumptions are met, counts of fish detected at Little Goose should be in constant proportion to those of fish not detected (i.e., n_{11}/n_{21}, n_{12}/n_{22}, and n_{13}/n_{23} should be equal). Because this table counted only fish detected below Little Goose (i.e., all fish survived passage at Goose), differential *direct* mortality between fish detected and not detected at Little Goose will not cause violations of Test 2.C2 by itself. However, differential *indirect* mortality related to Little Goose passage could cause violations if differences in mortality are not expressed until fish are below Lower Monumental Dam.

Behavioral response to guidance at Little Goose could also cause violations of Test 2.C2. For example, if fish detected at Little Goose become more likely to be detected downstream, then they will tend to have more first downstream detections at Lower Monumental. If fish detected at Little Goose become less likely to be detected downstream, they will have fewer first detections at Lower Monumental.

Inherent differences among fish could also cause violations of Test 2.C2, and would be difficult to distinguish from behavioral responses.

The second test for Lower Granite Dam groups was Test 2.C3, based on the contingency table:

Test 2.C3	First site detected below Lower Monumental	
df = 1	McNary	John Day or below
Not detected at Lower Monumental	n_{11}	n_{12}
Detected at Lower Monumental	n_{21}	n_{22}

This table and corresponding implications are similar to those of Test 2.C2. All fish that were detected somewhere below Lower Monumental are cross-classified according to their history at Lower Monumental and according to their first detection site below Lower Monumental. If the respective counts for fish first detected at McNary are not in the same proportion as those first detected at John Day or below, it could indicate behavioral response to detection at Lower Monumental, inherent differences in detectability (i.e., guidability) among tagged fish in the group, or long-term differential mortality caused by different passage routes at Lower Monumental.

The next series of tests for Lower Granite Dam groups is called Test 3. The first in the series is called Test 3.SR3, based on the contingency table:

Test 3.SR3	Detected again at McNary or below?	
df = 1	YES	NO
Detected at Lower Monumental, not detected at Little Goose	n_{11}	n_{12}
Detected at Lower Monumental, detected at Little Goose	n_{21}	n_{22}

In this table, all fish detected at Lower Monumental are cross-classified according to their status at Little Goose and whether or not they were detected again downstream from Lower Monumental. As with the Test 2 series, differential mortality in different passage routes at Little Goose will not be detected by this test if all the mortality is expressed before the fish arrive at Lower Monumental. Differences in mortality expressed below McNary could cause violations, however, as could behavioral responses (possibly somewhat harder to detect because of the conditioning on detection at Lower Monumental) or inherent differences in detectability or survival between fish detected at Little Goose and those not detected there.

The second test in the Test 3 series is Test 3.Sm3, based on the contingency table:

Test 3.Sm3	Site first detected below Lower Monumental	
df = 1	McNary	John Day
Detected at Lower Monumental, not detected at Little Goose	n_{11}	n_{12}
Detected at Lower Monumental, detected at Little Goose	n_{21}	n_{22}

This test is sensitive to the same sorts of differences as Test 3.SR3, but tends to have somewhat less power. Because the table classifies only fish detected somewhere below Lower Monumental, it is not sensitive to differences in survival between Lower Monumental and McNary.

The final test for Lower Granite Dam groups is Test 3.SR4, based on the contingency table:

Test 3.SR4	Detected at John Day or below?	
df = 1	Yes	No
Detected at McNary, not detected previously	n_{11}	n_{12}
Detected at McNary, also detected previously	n_{21}	n_{22}

This table classifies all fish detected at McNary according to whether they had been detected at least once at Little Goose and Lower Monumental and whether they were detected again below McNary. A significant test indicates that some below-McNary parameter(s) differ between fish detected upstream of McNary and those not detected. The cause of such an assumption violation could be differences in indirect survival associated with detection at Little Goose and/or Lower Monumental (mortality expressed between McNary and the estuary PIT-trawl), inherent differences in survival or detection probabilities, or behavioral responses.

We did not include any contingency table tests when any of the expected cells of the table were less than 1.0, as the test statistic does not sufficiently approximate the asymptotic χ^2 distribution in these cases. (For Test 2.C2, when expected values in the "Lower Monumental" and "McNary" columns were all greater than 1.0, but one or two of the expected values in the "John Day or below" column were less than 1.0, we collapsed the "McNary" and "John Day or below" and calculated a one-degree-of-freedom test of the resulting 2-by-2 table). We combined the two test statistics in the Test 2 series and the three in the Test 3 series and then all tests together in a single overall χ^2 test statistic.

For release groups from McNary Dam, we analyzed 3-digit detection histories indicating status at John Day Dam, Bonneville Dam, and the estuary PIT-trawl.

Only two tests are possible for 3-digit detection histories. The first of these was Test 2.C2, based on the contingency table:

Test 2.C2	First site detected below John Day	
df = 1	BON	Trawl
Not detected at John Day	n_{11}	n_{12}
Detected at John Day	n_{21}	n_{22}

The second is Test 3.SR3, based on the contingency table:

Test 3.SR3 df = 1	Detected at Trawl	
	Yes	No
Detected at Bonneville, not detected at John Day	n_{11}	n_{12}
Detected at Bonneville, detected at John Day	n_{21}	n_{22}

These tests are analogous to Tests 2.C3 and 3.SR4, respectively, for the Lower Granite Dam release groups. Potential causes of violations of the tests for McNary Dam groups are the same as those for Lower Granite Dam groups.

Results

For weekly Lower Granite Dam release groups in 2014 there were more significant ($\alpha = 0.05$) tests than expected by chance alone (5%) for both yearling Chinook salmon and steelhead (Appendix Table A1). There were 10 weekly groups of yearling Chinook salmon. For these, the overall sum of the χ^2 test statistics was significant 3 times (30%). For 10 steelhead groups, the overall test was significant 4 times (40%). Counting all individual component tests (i.e., 2.C2, 3.SR3, etc.), 7 tests of 50 (14%) were significant for yearling Chinook salmon and 8 of 50 (16%) were significant for steelhead (Appendix Tables A1-A3).

We diagnosed the patterns in the contingency tables that led to significant tests and results were similar to those we reported in past years. For weekly groups of yearling Chinook salmon and steelhead released from Lower Granite Dam, 10 of the 15 significant tests were for components of Test 2. This result provided evidence that fish had different probabilities of subsequent detection at downstream dams, depending on whether they were previously detected. Although not always consistent, fish of both species that were previously detected were typically more likely to be detected again than their cohorts that were not previously detected.

For weekly groups from McNary Dam, there were no significant contingency table test results for either yearling Chinook or steelhead (Appendix Tables A4-A6). Low detection probabilities led to reduced power of these tests to detect significant differences when present. Therefore, a lack of significant results does not necessarily indicate that assumptions were met.

Discussion

We believe that inherent differences in detectability (guidability) of fish within a release group are the most likely cause of the patterns we observed in the contingency table tests in 2014, as in previous years. Zabel et al. (2002) and Zabel et al. (2005) provided evidence of inherent differences related to length of fish at tagging, and similar observations were made in 2014 data.

Fish size probably does not explain all inherent differences, but it appeared to explain some. The relationship between length at tagging and detection probability at Little Goose Dam suggests that the heterogeneity is inherent, and not a behavioral response. Probability of detection at Little Goose Dam afforded the best insight into the relationship between fish size and detection, as Little Goose is the first dam encountered after release by fish included in these data sets (all fish included in the data set were detected at Lower Granite Dam, and Little Goose is the first dam encountered after leaving Lower Granite).

Another possibility is that changes in spill level among sequential dams were correlated with one another during passage of a cohort, and this resulted in correlated detection probabilities within subsets of the cohort.

To illustrate, suppose that spill at both Little Goose and Lower Monumental Dams is high early in the season and low late in the season. The earliest migrating fish from a cohort arrive at Little Goose Dam during high spill, and consequently have low probability of detection. These early fish will also tend to arrive at Lower Monumental during the period of high spill and low detection probability. The opposite will be true for the latest migrants from the cohort: they will encounter low spill and have high probability of detection. When the combined data for the cohort are analyzed, fish detected at Little Goose will be more likely to be detected at Lower Monumental than fish not detected at Little Goose Dam.

Although the contingency table tests described here do well at detecting some violations of CJS model assumptions, there are instances where assumptions could be violated without resulting in significant tests.

A specific example is that of acute differential post-detection mortality, where detected and non-detected fish have different rates of mortality between detection at a point of interest and at the subsequent detection point. This mortality would constitute a violation of assumption A3.

However, none of the contingency table tests described here would detect this violation because each test relies on data from fish with known fates, either at the site of interest or at sites downstream.

Detection of differential post-detection mortality requires knowledge of the fate of individual non-detected fish in the tailrace of the detection dam of interest and downstream. The fate of fish not detected at the site of interest is only known for those fish detected again downstream, and not for those never detected again. Therefore, none of the assumptions tests described here can detect differential post-detection mortality between two adjacent detection sites.

Results in previous years (e.g., Zabel et al. 2002) led us to conclude that a reasonable amount of heterogeneity in the survival and detection process occurred, but did not seriously affect the performance of estimators of survival (see also Burnham et al. 1987 on effects of small amount of heterogeneity).

Appendix Table A1. Number of tests of goodness-of-fit to the single-release model conducted for weekly release groups of yearling Chinook salmon and steelhead (hatchery and wild combined) from Lower Granite Dam, and number of significant ($\alpha = 0.05$) test results, 2014.

		Species		
Test		Chinook	Steelhead	Total
Test 2.C2	Tests (n)	10	10	20
	Significant tests (n)	4	3	7
Test 2.C3	Tests (n)	10	10	20
	Significant tests (n)	1	2	3
Test 3.SR3	Tests (n)	10	10	20
	Significant tests (n)	0	0	0
Test 3.Sm3	Tests (n)	10	10	20
	Significant tests (n)	1	2	3
Test 3.SR4	Tests (n)	10	10	20
	Significant tests (n)	1	1	2
Test 2 sum	Tests (n)	10	10	20
	Significant tests (n)	3	4	7
Test 3 sum	Tests (n)	10	10	20
	Significant tests (n)	1	1	2
Test 2 + 3	Tests (n)	10	10	20
	Significant tests (n)	3	4	7

Appendix Table A2. Results of tests of goodness of fit to the single release model for release groups of yearling Chinook salmon (hatchery and wild) from Lower Granite to McNary Dam in 2014.

	Overall		Test 2		Test 2.C2		Test 2.C3	
Release	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
23 Mar–29 Mar	8.07	0.233	1.83	0.609	0.00	1.000	1.83	0.176
30 Mar–5 Apr	5.98	0.425	3.09	0.378	2.23	0.327	0.86	0.354
6 Apr–12 Apr	23.23	**0.001**	9.40	**0.024**	9.27	**0.010**	0.13	0.721
13 Apr–19 Apr	1.87	0.931	0.54	0.910	0.25	0.882	0.29	0.590
20 Apr–26 Apr	11.45	0.075	7.20	0.066	0.62	0.734	6.58	**0.010**
27 Apr–3 May	34.50	**<0.001**	30.07	**<0.001**	29.88	**<0.001**	0.18	0.668
4 May–10 May	15.77	**0.015**	13.43	**0.004**	13.40	**0.001**	0.03	0.869
11 May–17 May	2.98	0.811	1.78	0.620	1.65	0.439	0.13	0.715
18 May–24 May	9.22	0.162	6.69	0.082	6.68	**0.035**	0.01	0.917
25 May–31 May	2.47	0.871	1.21	0.750	1.21	0.546	0.00	0.966
Total (df)	115.54 (60)	**<0.001**	75.24 (30)	**<0.001**	65.20 (20)	**<0.001**	10.04 (10)	0.437

	Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
Release	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
23 Mar–29 Mar	6.25	0.100	0.95	0.329	4.20	**0.040**	1.10	0.295
30 Mar–5 Apr	2.89	0.409	0.00	0.986	2.72	0.099	0.17	0.683
6 Apr–12 Apr	13.83	**0.003**	7.14	0.008	0.50	0.478	6.18	**0.013**
13 Apr–19 Apr	1.33	0.721	0.06	0.804	0.97	0.324	0.30	0.583
20 Apr–26 Apr	4.25	0.236	0.02	0.890	1.26	0.262	2.97	0.085
27 Apr–3 May	4.44	0.218	0.86	0.355	1.10	0.293	2.48	0.116
4 May–10 May	2.33	0.506	0.49	0.484	0.11	0.745	1.74	0.187
11 May–17 May	1.20	0.752	0.93	0.336	0.10	0.754	0.18	0.672
18 May–24 May	2.53	0.470	1.32	0.250	0.71	0.401	0.50	0.480
25 May–31 May	1.26	0.738	0.45	0.501	0.34	0.561	0.47	0.493
Total (df)	40.30 (30)	0.099	12.23 (10)	0.270	12.00 (10)	0.285	16.08 (10)	0.097

Appendix Table A3. Results of tests of goodness of fit to the single release model for release groups of juvenile steelhead (hatchery and wild) from Lower Granite to McNary Dam in 2014.

Release	Overall		Test 2		Test 2.C2		Test 2.C3	
period	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
30 Mar–5 Apr	3.72	0.715	3.62	0.305	1.79	0.408	1.83	0.176
6 Apr–12 Apr	4.43	0.619	1.81	0.614	1.81	0.405	0.00	1.000
13 Apr–19 Apr	4.58	0.599	2.40	0.493	2.40	0.302	0.01	0.939
20 Apr–26 Apr	14.44	**0.025**	12.15	**0.007**	8.24	**0.016**	3.90	**0.048**
27 Apr–3 May	61.50	**<0.001**	48.32	**<0.001**	3.09	0.213	45.23	**<0.001**
4 May–10 May	5.48	0.484	4.94	0.176	4.67	0.097	0.28	0.598
11 May–17 May	16.64	**0.011**	12.90	**0.005**	12.39	**0.002**	0.51	0.474
18 May–24 May	42.82	**<0.001**	38.23	**<0.001**	35.00	**<0.001**	3.23	0.072
25 May–31 May	10.18	0.117	7.11	0.068	5.70	0.058	1.41	0.234
1 Jun–7 Jun	5.05	0.537	3.91	0.271	3.72	0.156	0.20	0.659
Total (df)	168.83 (60)	**<0.001**	135.40 (30)	**<0.001**	78.81 (20)	**<0.001**	56.59 (10)	**<0.001**

	Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
30 Mar–5 Apr	0.09	0.993	0.01	0.922	0.06	0.808	0.02	0.881
6 Apr–12 Apr	2.62	0.454	1.28	0.258	0.03	0.854	1.31	0.253
13 Apr–19 Apr	2.18	0.537	1.97	0.160	0.17	0.682	0.03	0.854
20 Apr–26 Apr	2.30	0.513	0.57	0.450	1.47	0.225	0.26	0.614
27 Apr–3 May	13.18	**0.004**	0.39	0.530	8.31	**0.004**	4.47	**0.034**
4 May–10 May	0.53	0.911	0.02	0.877	0.45	0.505	0.07	0.799
11 May–17 May	3.74	0.291	3.05	0.081	0.32	0.570	0.37	0.541
18 May–24 May	4.59	0.204	0.04	0.847	4.41	**0.036**	0.15	0.703
25 May–31 May	3.07	0.381	0.13	0.720	2.91	0.088	0.03	0.870
1 Jun–7 Jun	1.14	0.768	0.01	0.928	0.80	0.372	0.33	0.565
Total (df)	33.43 (30)	0.304	7.47 (10)	0.680	18.93 (10)	**0.041**	7.03(10)	0.723

Appendix Table A4. Number of tests of goodness of fit to the single release model conducted for weekly release groups of yearling Chinook salmon and steelhead (hatchery and wild combined) from McNary Dam, and number of significant ($\alpha = 0.05$) test results, 2014.

	Test 2.C2		Test 3.SR3		Test 2 + 3	
Species	No.	sig.	No.	sig.	No.	sig.
Chinook	6	0	4	0	6	0
Steelhead	5	0	2	0	5	0
Total	11	0	6	0	11	0

Appendix Table A5. Results of tests of goodness of fit to the single release model for release groups of yearling Chinook salmon (hatchery and wild) from McNary to Bonneville Dam in 2014.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
20 Apr–26 Apr	0.60	0.739	0.57	0.451	0.04	0.851
27 Apr–3 May	0.17	0.917	0.03	0.855	0.14	0.709
4 May–10 May	0.24	0.888	0.03	0.868	0.21	0.647
11 May–17 May	1.77	0.413	0.91	0.341	0.86	0.353
18 May–24 May	0.00	0.959	0.00	0.959	.	.
25 May–31 May	0.08	0.776	0.08	0.776	.	.
Total (df)	2.87 (10)	0.984	1.62 (6)	0.951	1.25 (4)	0.870

Appendix Table A6. Results of tests of goodness of fit to the single release model for release groups of steelhead (hatchery and wild) from McNary to Bonneville Dam in 2014.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P* value	χ^2	*P* value	χ^2	*P* value
20 Apr–26 Apr	3.47	0.062	3.47	0.062	.	.
27 Apr–3 May	2.68	0.262	0.00	0.978	2.68	0.102
4 May–10 May	0.01	0.995	0.00	0.967	0.01	0.924
11 May–17 May	0.08	0.781	0.08	0.781	.	.
18 May–24 May	0.04	0.845	0.04	0.845	.	.
25 May–31 May	.	.	.	.	.	.
Total (df)	6.28 (7)	0.507	3.59 (5)	0.610	2.69 (2)	0.261

Appendix B: Survival and Detection from Individual Hatcheries and Traps

Appendix Table B1. Estimated survival probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2014. Estimates based on the single-release model. Standard errors in parentheses.

	Yearling Chinook salmon					
Release site	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Release to McNary Dam
			Clearwater Hatchery			
Kooskia NFH	21,877	0.771 (0.009)	0.985 (0.019)	0.941 (0.034)	1.012 (0.046)	0.724 (0.022)
Powell Pond	25,470	0.737 (0.010)	0.937 (0.020)	0.943 (0.034)	1.028 (0.045)	0.670 (0.019)
Red River Pond	17,081	0.448 (0.011)	1.008 (0.050)	0.887 (0.074)	1.067 (0.107)	0.427 (0.029)
Selway River	17,085	0.666 (0.009)	0.924 (0.021)	0.972 (0.041)	0.885 (0.047)	0.529 (0.018)
			Dworshak Hatchery			
N Fork Clearwater R	51,763	0.816 (0.009)	0.972 (0.019)	0.925 (0.031)	0.933 (0.037)	0.685 (0.017)
			Kooskia Hatchery			
Kooskia	12,249	0.595 (0.011)	0.910 (0.027)	0.999 (0.059)	0.752 (0.056)	0.406 (0.020)
			Lookingglass Hatchery			
Catherine Creek Pond	20,772	0.264 (0.005)	1.036 (0.040)	0.931 (0.070)	0.826 (0.074)	0.210 (0.012)
Grande Ronde Pond	339	0.447 (0.048)	1.111 (0.208)	1.015 (0.322)	1.344 (0.775)	0.677 (0.346)
Imnaha Weir	20,816	0.673 (0.009)	1.079 (0.031)	0.882 (0.047)	0.851 (0.056)	0.545 (0.024)
Lookingglass Hatchery	2,961	0.692 (0.019)	1.018 (0.052)	0.840 (0.074)	0.915 (0.114)	0.541 (0.054)
Lostine Pond	3,972	0.662 (0.018)	1.075 (0.053)	0.912 (0.076)	0.820 (0.101)	0.532 (0.054)
			McCall Hatchery			
Johnson Creek	2,098	0.495 (0.035)	0.797 (0.081)	1.265 (0.216)	0.748 (0.172)	0.374 (0.064)
Knox Bridge	51,898	0.714 (0.008)	0.992 (0.023)	1.010 (0.041)	0.810 (0.036)	0.579 (0.015)
			Pahsimeroi Hatchery			
Pahsimeroi Pond	22,366	0.794 (0.008)	0.973 (0.020)	0.904 (0.034)	1.005 (0.046)	0.702 (0.021)
			Rapid River Hatchery			
Rapid River Hatchery	51,672	0.757 (0.008)	1.056 (0.024)	0.887 (0.033)	0.904 (0.041)	0.641 (0.020)
			Sawtooth Hatchery			
Sawtooth Hatchery	19,972	0.646 (0.008)	1.068 (0.029)	0.923 (0.046)	0.952 (0.058)	0.607 (0.024)
Yankee Fork	2,385	0.382 (0.027)	1.013 (0.136)	0.777 (0.145)	1.283 (0.506)	0.386 (0.140)

Appendix Table B2. Estimated survival probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2014. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile steelhead					
Release site	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Release to McNary Dam
			Clearwater Hatchery			
S Fork Clearwater R	2,595	0.870 (0.033)	0.925 (0.053)	1.018 (0.121)	0.858 (0.126)	0.703 (0.066)
Meadow Creek	13,987	0.860 (0.015)	0.959 (0.028)	0.990 (0.060)	0.788 (0.060)	0.644 (0.030)
Newsome Creek	1,496	0.855 (0.054)	0.937 (0.109)	1.722 (0.594)	0.531 (0.209)	0.732 (0.142)
			Dworshak Hatchery			
Clearwater R	16,778	0.851 (0.011)	1.048 (0.024)	1.058 (0.060)	0.735 (0.055)	0.694 (0.034)
Lolo Creek	7,707	0.616 (0.014)	0.964 (0.044)	1.061 (0.108)	0.634 (0.093)	0.399 (0.043)
S Fork Clearwater R	7,704	0.802 (0.014)	1.035 (0.030)	0.889 (0.051)	0.935 (0.076)	0.690 (0.043)
			Hagerman Hatchery			
East Fork Salmon R	8,451	0.665 (0.017)	0.873 (0.046)	1.080 (0.130)	0.575 (0.124)	0.361 (0.065)
Sawtooth Hatchery	8,530	0.786 (0.022)	0.887 (0.043)	1.036 (0.103)	0.947 (0.126)	0.684 (0.064)
			Irrigon Hatchery			
Big Canyon Facility	8,658	0.897 (0.025)	0.888 (0.043)	1.145 (0.118)	0.682 (0.104)	0.622 (0.070)
Little Sheep Facility	21,897	0.792 (0.011)	0.965 (0.026)	1.008 (0.054)	0.746 (0.068)	0.575 (0.042)
Wallowa Hatchery	13,566	0.788 (0.018)	0.980 (0.042)	0.997 (0.091)	0.664 (0.078)	0.511 (0.040)
			Lyons Ferry Hatchery			
Cottonwood Pond	6,000	0.777 (0.019)	1.002 (0.052)	1.046 (0.126)	0.845 (0.131)	0.688 (0.070)

Appendix Table B2. Continued.

		Juvenile steelhead				
Release site	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Release to McNary Dam
			Magic Valley Hatchery			
Little Salmon R	4,393	1.017 (0.033)	0.782 (0.042)	1.278 (0.160)	0.673 (0.108)	0.684 (0.070)
Pahsimeroi R Trap	11,374	0.799 (0.020)	0.962 (0.044)	1.064 (0.097)	0.714 (0.093)	0.584 (0.057)
Salmon R (rkm 347)	1,895	0.849 (0.042)	1.030 (0.095)	0.980 (0.191)	1.090 (0.304)	0.935 (0.194)
Salmon R (rkm 385)	1,898	0.826 (0.036)	1.034 (0.087)	0.743 (0.106)	1.139 (0.233)	0.722 (0.116)
Salmon R (rkm 476)	1,896	0.892 (0.044)	1.113 (0.113)	1.078 (0.229)	0.469 (0.109)	0.502 (0.060)
Squaw Creek, Salmon R	1,894	0.770 (0.045)	0.916 (0.097)	2.018 (0.751)	0.609 (0.326)	0.868 (0.326)
Yankee Fork	11,374	0.686 (0.015)	0.908 (0.036)	1.181 (0.110)	0.555 (0.093)	0.409 (0.057)
			Niagara Springs Hatchery			
Hells Canyon Dam	8,571	0.742 (0.012)	1.054 (0.034)	1.020 (0.075)	0.766 (0.082)	0.611 (0.049)
Little Salmon R	5,086	0.964 (0.035)	0.926 (0.063)	1.159 (0.145)	0.752 (0.137)	0.778 (0.108)
Pahsimeroi R Trap	8,967	0.944 (0.024)	0.902 (0.041)	0.953 (0.088)	0.991 (0.122)	0.804 (0.069)

Appendix Table B3. Estimated survival probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2014. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile sockeye salmon							
Release site	Release date	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam	Release to McNary Dam
				Oxbow Hatchery				
Redfish Lake Cr Trap	8 May 14	2,045	0.468 (0.092)	0.736 (0.211)	1.411 (0.496)	0.452 (0.186)	0.469 (0.167)	0.219 (0.066)
				Sawtooth Hatchery				
Redfish Lake Cr Trap	8-9 May 14	49,881	0.528 (0.017)	0.931 (0.060)	0.963 (0.072)	0.889 (0.067)	0.797 (0.051)	0.421 (0.022)

Appendix Table B4. Estimated detection probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2014. Estimates based on the single-release model. Standard errors in parentheses.

	Yearling Chinook salmon				
Release site	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Clearwater Hatchery			
Kooskia NFH	21,877	0.278 (0.005)	0.266 (0.006)	0.156 (0.006)	0.249 (0.008)
Powell Pond	25,470	0.294 (0.006)	0.296 (0.007)	0.166 (0.007)	0.269 (0.010)
Red River Pond	17,081	0.242 (0.004)	0.258 (0.005)	0.154 (0.006)	0.259 (0.008)
Selway River	17,085	0.266 (0.008)	0.213 (0.010)	0.146 (0.011)	0.170 (0.012)
		Dworshak Hatchery			
N Fork Clearwater R	51,763	0.221 (0.003)	0.239 (0.004)	0.146 (0.005)	0.199 (0.005)
		Kooskia Hatchery			
Kooskia	12,249	0.298 (0.007)	0.347 (0.010)	0.177 (0.011)	0.268 (0.014)
		Lookingglass Hatchery			
Catherine Cr Pond	20,772	0.366 (0.009)	0.302 (0.012)	0.181 (0.013)	0.267 (0.017)
Grande Ronde Pond	339	0.350 (0.050)	0.236 (0.051)	0.168 (0.054)	0.103 (0.057)
Imnaha Weir	20,816	0.355 (0.006)	0.279 (0.008)	0.181 (0.009)	0.228 (0.011)
Lookingglass Hatch	2,961	0.372 (0.014)	0.293 (0.016)	0.172 (0.016)	0.209 (0.023)
Lostine Pond	3,972	0.322 (0.012)	0.257 (0.014)	0.174 (0.014)	0.169 (0.019)
		McCall Hatchery			
Johnson Creek	2,098	0.219 (0.019)	0.239 (0.023)	0.112 (0.020)	0.177 (0.033)
Knox Bridge	51,898	0.278 (0.004)	0.212 (0.005)	0.135 (0.005)	0.216 (0.006)
		Pahsimeroi Hatchery			
Pahsimeroi Pond	22,366	0.318 (0.005)	0.255 (0.006)	0.143 (0.006)	0.250 (0.008)
		Rapid River Hatchery			
Rapid River Hatch	51,672	0.294 (0.004)	0.225 (0.005)	0.158 (0.005)	0.184 (0.006)
		Sawtooth Hatchery			
Sawtooth Hatchery	19,972	0.360 (0.006)	0.245 (0.007)	0.164 (0.008)	0.230 (0.010)
Yankee Fork	2,385	0.322 (0.026)	0.290 (0.034)	0.320 (0.049)	0.078 (0.030)

Appendix Table B5. Estimated detection probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2014. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile steelhead				
Release site	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Clearwater Hatchery			
Meadow Creek	13,987	0.238 (0.006)	0.282 (0.008)	0.114 (0.007)	0.151 (0.008)
Newsome Creek	1,496	0.246 (0.020)	0.213 (0.024)	0.062 (0.021)	0.101 (0.022)
S.F. Clearwater R	2,595	0.213 (0.012)	0.318 (0.017)	0.111 (0.014)	0.157 (0.017)
		Dworshak Hatchery			
Clearwater R	16,778	0.287 (0.005)	0.278 (0.007)	0.140 (0.008)	0.105 (0.006)
Lolo Creek	7,707	0.364 (0.010)	0.317 (0.014)	0.181 (0.018)	0.107 (0.013)
S.F. Clearwater R	7,704	0.292 (0.008)	0.341 (0.010)	0.165 (0.010)	0.148 (0.010)
		Hagerman Hatchery			
East Fork Salmon R	8,451	0.387 (0.012)	0.366 (0.017)	0.205 (0.024)	0.067 (0.013)
Sawtooth Hatchery	8,530	0.245 (0.008)	0.275 (0.012)	0.119 (0.012)	0.102 (0.010)
		Irrigon Hatchery			
Big Canyon Facility	8,658	0.242 (0.008)	0.291 (0.012)	0.147 (0.014)	0.075 (0.010)
Little Sheep Facility	21,897	0.317 (0.006)	0.332 (0.008)	0.202 (0.010)	0.085 (0.007)
Wallowa Hatchery	13,566	0.247 (0.007)	0.235 (0.009)	0.120 (0.010)	0.091 (0.008)
		Lyons Ferry Hatchery			
Cottonwood Pond	6,000	0.299 (0.010)	0.220 (0.012)	0.118 (0.014)	0.087 (0.010)
		Magic Valley Hatchery			
Little Salmon R	4,393	0.256 (0.010)	0.305 (0.014)	0.119 (0.015)	0.119 (0.014)
Pahsimeroi R Trap	11,374	0.283 (0.008)	0.320 (0.012)	0.164 (0.014)	0.108 (0.012)
Salmon R (rkm 347)	1,895	0.252 (0.016)	0.264 (0.023)	0.124 (0.024)	0.085 (0.019)
Salmon R (rkm 385)	1,898	0.281 (0.016)	0.280 (0.023)	0.184 (0.025)	0.122 (0.022)
Salmon R (rkm 476)	1,896	0.247 (0.016)	0.200 (0.020)	0.098 (0.020)	0.166 (0.023)
Sqaw Creek, Salmon R	1,894	0.308 (0.021)	0.346 (0.030)	0.090 (0.033)	0.057 (0.023)
Yankee Fork	11,374	0.354 (0.009)	0.388 (0.013)	0.216 (0.019)	0.081 (0.012)
		Niagara Springs Hatchery			
Hells Canyon Dam	8,571	0.364 (0.008)	0.352 (0.012)	0.158 (0.012)	0.112 (0.010)
Little Salmon R	5,086	0.258 (0.011)	0.261 (0.015)	0.161 (0.018)	0.090 (0.014)
Pahsimeroi Trap	8,967	0.240 (0.008)	0.244 (0.010)	0.116 (0.010)	0.103 (0.010)

Appendix Table B6. Estimated detection probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2014. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile sockeye salmon					
Release site	Release date	Number released	Lower Granite	Little Goose	Lower Monumental	McNary
			Oxbow Hatchery			
Redfish L Cr Trap	8 May 2013	2,045	0.080 (0.018)	0.086 (0.021)	0.076 (0.023)	0.075 (0.025)
			Sawtooth Hatchery			
Redfish L Cr Trap	8 May 2013	49,881	0.158 (0.006)	0.086 (0.005)	0.142 (0.008)	0.113 (0.006)

Appendix Table B7. Estimated survival probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2014. Estimates based on the single-release model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Trap	Release dates	Number released	Release to LGR	LGR to LGO	LGO to LMO	LMO to MCN	Release to MCN
				Wild Chinook Salmon			
American River	20 Mar-31 May	339	0.378 (0.142)	0.638 (0.404)	NA	NA	NA
Catherine Creek	19 Feb-20 May	746	0.336 (0.026)	0.893 (0.088)	1.113 (0.184)	1.016 (0.280)	0.339 (0.080)
Crooked Fork Cr	25 Mar-2 May	208	0.380 (0.052)	1.583 (0.647)	0.561 (0.358)	NA	NA
Crooked River	19 Mar-31 May	486	0.388 (0.049)	0.717 (0.128)	1.466 (0.557)	0.446 (0.208)	0.182 (0.048)
Elgin (G. Ronde)	26 Feb-31 May	529	0.669 (0.032)	0.986 (0.067)	0.908 (0.105)	0.816 (0.173)	0.489 (0.093)
Grande Ronde	06 Mar-18 May	4,169	0.910 (0.011)	0.958 (0.020)	0.947 (0.040)	0.936 (0.063)	0.773 (0.043)
Imnaha	01 Feb-31 May	6,217	0.829 (0.010)	0.973 (0.021)	0.902 (0.038)	0.802 (0.052)	0.584 (0.030)
Johnson Creek	01 Mar-21 May	675	0.504 (0.028)	0.963 (0.071)	0.882 (0.115)	0.740 (0.155)	0.317 (0.057)
Knox Bridge	14 Mar-22 Apr	242	0.512 (0.063)	0.794 (0.151)	1.118 (0.558)	0.646 (0.642)	0.294 (0.243)
Lemhi River	12 Mar-30 May	934	0.723 (0.032)	1.001 (0.082)	0.795 (0.116)	1.156 (0.270)	0.665 (0.127)
Lookingglass Cr	03 Feb-30 May	271	0.407 (0.043)	0.909 (0.115)	1.156 (0.283)	0.581 (0.198)	0.248 (0.064)
Lostine River	12 Feb-23 May	1,145	0.521 (0.021)	1.052 (0.064)	1.037 (0.138)	0.932 (0.223)	0.530 (0.108)
Marsh Creek	22 Mar-31 May	1,631	0.490 (0.021)	0.982 (0.071)	1.003 (0.157)	1.235 (0.404)	0.596 (0.172)
Minam River	03 Mar-16 May	1,103	0.583 (0.024)	1.014 (0.068)	0.919 (0.127)	0.983 (0.265)	0.534 (0.127)
Pahsimeroi	27 Feb-31 May	859	0.505 (0.026)	0.967 (0.062)	1.065 (0.157)	0.760 (0.149)	0.395 (0.056)
Salmon	04 Mar-15 Apr	8,200	0.846 (0.008)	0.943 (0.013)	0.908 (0.025)	0.822 (0.034)	0.595 (0.019)
Sawtooth	22 Mar-26 May	2,190	0.605 (0.020)	0.952 (0.056)	0.872 (0.097)	0.864 (0.147)	0.434 (0.059)
Snake	07 Mar-08 May	1,963	0.892 (0.017)	0.959 (0.032)	0.909 (0.057)	0.846 (0.083)	0.658 (0.053)
U. Grande Ronde	05 Mar-31 May	360	0.290 (0.038)	0.802 (0.116)	0.825 (0.191)	0.680 (0.308)	0.131 (0.054)
				Wild Sockeye Salmon			
Redfish Lake Cr	11 Mar-31 May	1,307	0.501 (0.022)	1.006 (0.064)	0.837 (0.091)	1.125 (0.322)	0.474 (0.129)

Appendix Table B7. Continued.

Trap	Release dates	Number released	Rel to LGR	LGR to LGO	LGO to LMO	LMO to MCN	Rel to MCN
			Wild Steelhead				
Asotin Creek	28 Feb-31 May	735	0.686 (0.031)	1.068 (0.099)	1.492 (0.531)	0.467 (0.234)	0.511 (0.177)
Catherine Creek	19 Feb-31 May	397	0.288 (0.084)	0.590 (0.255)	NA	NA	NA
Crooked Fork Cr	28 Mar-02 May	377	0.540 (0.044)	1.443 (0.289)	1.326 (0.836)	0.514 (0.414)	0.531 (0.264)
Crooked River	22 Mar-30 May	199	0.566 (0.065)	0.964 (0.186)	1.294 (0.700)	0.372 (0.247)	0.262 (0.087)
Elgin (G. Ronde)	26 Feb-31 May	464	0.486 (0.055)	0.833 (0.142)	NA	NA	NA
Grande Ronde	06 Mar-21 May	792	0.888 (0.048)	1.070 (0.118)	0.820 (0.174)	0.894 (0.394)	0.696 (0.274)
Imnaha River	27 Feb-28 May	1,348	0.866 (0.034)	0.920 (0.068)	1.057 (0.201)	0.601 (0.184)	0.506 (0.123)
Minam River	03 Mar-29 May	620	0.360 (0.050)	0.737 (0.164)	0.614 (0.217)	1.790 (1.722)	0.292 (0.266)
Salmon River	07 Mar-21 Apr	244	0.990 (0.102)	0.879 (0.142)	2.175 (1.425)	0.335 (0.244)	0.635 (0.208)
Sawtooth River	28 Mar-25 May	208	0.353 (0.080)	0.619 (0.177)	0.935 (0.286)	NA	NA
Snake River	07 Mar-08 May	1,157	1.000 (0.047)	1.015 (0.086)	1.070 (0.236)	0.434 (0.109)	0.471 (0.062)
Upper Grande Ronde	05 Mar-31 May	287	0.281 (0.050)	1.530 (0.584)	0.353 (0.196)	0.976 (0.883)	0.148 (0.121)
			Hatchery Chinook Salmon				
Grande Ronde	17 Mar-03 May	1,401	0.899 (0.033)	0.995 (0.067)	0.893 (0.096)	0.878 (0.128)	0.701 (0.080)
Salmon	18 Mar-21 Apr	3,002	0.810 (0.024)	0.980 (0.051)	0.869 (0.069)	0.942 (0.096)	0.650 (0.051)
Snake	07 Mar-08 May	1,921	0.925 (0.025)	1.004 (0.048)	0.969 (0.077)	0.868 (0.100)	0.781 (0.071)
			Hatchery Steelhead				
Grande Ronde	30 Mar-21 May	3,286	0.919 (0.027)	0.935 (0.049)	1.144 (0.119)	0.596 (0.103)	0.586 (0.084)
Salmon	09 Apr-21 May	788	0.888 (0.055)	1.108 (0.139)	0.610 (0.116)	1.023 (0.237)	0.614 (0.109)
Snake	25 Mar-15 May	2,864	0.991 (0.038)	0.910 (0.052)	1.102 (0.114)	0.605 (0.091)	0.602 (0.070)

Appendix Table B8. Estimated detection probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2014. Estimates based on the single-release model. Standard errors in parentheses.

Trap	Release dates	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Wild Chinook Salmon			
American River	20 Mar-31 May	339	0.250 (0.100)	0.284 (0.136)	NA	NA
Catherine Creek	19 Feb-20 May	746	0.387 (0.038)	0.403 (0.045)	0.237 (0.046)	0.208 (0.055)
Crooked Fork Cr	25 Mar-2 May	208	0.443 (0.073)	0.248 (0.107)	0.302 (0.151)	NA
Crooked River	19 Mar-31 May	486	0.365 (0.054)	0.522 (0.068)	0.208 (0.085)	0.389 (0.115)
Elgin (G. Ronde)	26 Feb-31 May	529	0.424 (0.031)	0.449 (0.037)	0.352 (0.045)	0.195 (0.044)
Grande Ronde	06 Mar-18 May	4,169	0.443 (0.010)	0.506 (0.012)	0.285 (0.014)	0.274 (0.018)
Imnaha	01 Feb-31 May	6,217	0.462 (0.008)	0.455 (0.011)	0.289 (0.013)	0.249 (0.015)
Johnson Creek	01 Mar-21 May	675	0.450 (0.032)	0.450 (0.039)	0.322 (0.046)	0.257 (0.054)
Knox Bridge	14 Mar-22 Apr	242	0.419 (0.063)	0.551 (0.088)	0.319 (0.162)	0.125 (0.117)
Lemhi River	12 Mar-30 May	934	0.392 (0.024)	0.412 (0.034)	0.284 (0.042)	0.205 (0.044)
Lookingglass Cr	03 Feb-30 May	271	0.390 (0.055)	0.503 (0.069)	0.294 (0.083)	0.222 (0.080)
Lostine River	12 Feb-23 May	1,145	0.436 (0.024)	0.421 (0.030)	0.259 (0.036)	0.167 (0.038)
Marsh Creek	22 Mar-31 May	1,631	0.432 (0.023)	0.457 (0.033)	0.282 (0.045)	0.111 (0.035)
Minam River	03 Mar-16 May	1,103	0.451 (0.024)	0.446 (0.033)	0.277 (0.040)	0.126 (0.034)
Pahsimeroi	27 Feb-31 May	859	0.381 (0.027)	0.510 (0.036)	0.197 (0.034)	0.333 (0.053)
Salmon	04 Mar-15 Apr	8,200	0.444 (0.007)	0.542 (0.008)	0.308 (0.010)	0.334 (0.013)
Sawtooth	22 Mar-26 May	2,190	0.419 (0.018)	0.438 (0.026)	0.294 (0.033)	0.219 (0.034)
Snake	07 Mar-08 May	1,963	0.434 (0.014)	0.494 (0.018)	0.325 (0.022)	0.308 (0.029)
Upper Grande Ronde	05 Mar-31 May	360	0.335 (0.058)	0.614 (0.076)	0.384 (0.099)	0.176 (0.089)
			Wild Sockeye Salmon			
Redfish Lake Cr	11 Mar-31 May	1,307	0.399 (0.023)	0.396 (0.029)	0.346 (0.038)	0.104 (0.031)

Appendix Table B8. Continued.

Trap	Release dates	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Wild Steelhead			
Asotin Creek	28 Feb-31 May	735	0.466 (0.028)	0.447 (0.043)	0.134 (0.048)	0.182 (0.067)
Catherine Creek	19 Feb-31 May	397	0.253 (0.082)	0.325 (0.113)	NA	NA
Crooked Fork Cr	28 Mar-02 May	377	0.373 (0.042)	0.282 (0.060)	0.119 (0.073)	0.143 (0.076)
Crooked River	22 Mar-30 May	199	0.400 (0.060)	0.412 (0.081)	0.209 (0.115)	0.235 (0.103)
Elgin (Grande Ronde)	26 Feb-31 May	464	0.306 (0.044)	0.344 (0.057)	0.064 (0.043)	0.036 (0.035)
Grande Ronde	06 Mar-21 May	792	0.350 (0.026)	0.321 (0.035)	0.246 (0.050)	0.087 (0.037)
Imnaha	27 Feb-28 May	1,348	0.378 (0.020)	0.442 (0.030)	0.189 (0.036)	0.145 (0.039)
Minam River	03 Mar-29 May	620	0.314 (0.051)	0.398 (0.077)	0.315 (0.105)	0.071 (0.069)
Salmon	07 Mar-21 Apr	244	0.252 (0.038)	0.404 (0.059)	0.045 (0.031)	0.222 (0.080)
Sawtooth	28 Mar-25 May	208	0.326 (0.086)	0.614 (0.100)	0.351 (0.134)	NA
Snake	07 Mar-08 May	1,157	0.275 (0.018)	0.343 (0.027)	0.101 (0.023)	0.250 (0.038)
Upper Grande Ronde	05 Mar-31 May	287	0.298 (0.068)	0.238 (0.093)	0.233 (0.115)	0.122 (0.110)
			Hatchery Chinook Salmon			
Grande Ronde	17 Mar-03 May	1,401	0.330 (0.018)	0.267 (0.020)	0.173 (0.019)	0.216 (0.028)
Salmon	18 Mar-21 Apr	3,002	0.309 (0.013)	0.241 (0.014)	0.157 (0.013)	0.231 (0.020)
Snake	07 Mar-08 May	1,921	0.331 (0.014)	0.300 (0.016)	0.191 (0.016)	0.236 (0.024)
			Hatchery Steelhead			
Grande Ronde	30 Mar-21 May	3,286	0.304 (0.012)	0.279 (0.015)	0.145 (0.015)	0.084 (0.014)
Salmon	09 Apr-21 May	788	0.293 (0.025)	0.211 (0.028)	0.124 (0.024)	0.152 (0.031)
Snake	25 Mar-15 May	2,864	0.289 (0.014)	0.270 (0.017)	0.122 (0.015)	0.112 (0.017)

Appendix Table B9. Estimated survival probabilities for PIT-tagged yearling Chinook, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2014. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Yearling Chinook Salmon			
Chelan						
Chelan River	9,943	0.592 (0.034)	0.834 (0.093)	1.388 (0.518)	1.158 (0.424)	0.685 (0.248)
Dryden Accl. Pond	19,911	0.767 (0.034)	0.932 (0.087)	1.142 (0.268)	1.064 (0.239)	0.816 (0.179)
Cle Elum						
Clark Flat Pond	16,000	0.388 (0.017)	0.874 (0.080)	1.562 (0.766)	1.365 (0.663)	0.529 (0.256)
Easton Pond	11,997	0.286 (0.015)	0.793 (0.082)	0.742 (0.287)	0.589 (0.223)	0.168 (0.063)
Jack Creek Pond	12,000	0.280 (0.014)	1.054 (0.140)	0.401 (0.158)	0.423 (0.160)	0.118 (0.044)
East Bank						
Chiwawa Pond	5,061	0.477 (0.043)	1.067 (0.207)	2.891 (2.888)	3.085 (3.048)	1.471 (1.448)
Entiat						
Entiat Hatchery	9,897	0.497 (0.040)	1.096 (0.176)	0.608 (0.207)	0.666 (0.213)	0.331 (0.102)
Leavenworth						
Leavenworth NFH	14,977	0.573 (0.023)	0.977 (0.085)	0.733 (0.175)	0.716 (0.164)	0.410 (0.093)
Methow						
Methow Hatchery	10,460	0.360 (0.038)	0.949 (0.187)	0.976 (0.361)	0.926 (0.320)	0.334 (0.110)
Wells						
Wells Hatchery	5,973	0.260 (0.034)	0.567 (0.130)	NA	NA	NA
Winthrop						
Winthrop NFH	4,991	0.649 (0.072)	0.848 (0.186)	1.286 (0.661)	1.091 (0.535)	0.708 (0.338)

Appendix Table B9. Continued.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Steelhead			
Wells						
Methow River	1,970	0.811 (0.232)	0.738 (0.298)	3.641 (3.719)	2.686 (2.745)	2.180 (2.139)
Okanogan River	15,068	0.514 (0.056)	0.885 (0.144)	1.626 (0.510)	1.439 (0.445)	0.739 (0.214)
Twisp Acclimation Pond	4,962	0.332 (0.043)	0.766 (0.136)	1.092 (0.396)	0.837 (0.305)	0.278 (0.095)
Wells Hatchery	5,257	0.726 (0.092)	1.412 (0.352)	0.846 (0.355)	1.195 (0.456)	0.868 (0.312)
Winthrop						
Winthrop NFH	29,319	0.468 (0.043)	0.882 (0.124)	0.807 (0.153)	0.712 (0.130)	0.333 (0.053)
			Coho Salmon			
Cascade						
Gold Creek	5,924	0.511 (0.058)	0.813 (0.146)	0.687 (0.237)	0.559 (0.188)	0.286 (0.090)
Leavenworth NFH	5,940	0.429 (0.044)	1.050 (0.198)	0.906 (0.368)	0.951 (0.369)	0.408 (0.153)
Twisp Acclimation Pond	5,912	0.517 (0.054)	0.881 (0.140)	1.894 (1.053)	1.668 (0.922)	0.862 (0.468)
Winthrop Back Channel	5,935	0.409 (0.046)	1.047 (0.208)	1.372 (0.768)	1.436 (0.785)	0.587 (0.315)
Eagle						
Naches River	5,052	0.372 (0.045)	0.910 (0.223)	1.173 (0.594)	1.067 (0.507)	0.397 (0.183)
Yakima R (rkm 256)	2,502	0.184 (0.050)	0.904 (0.524)	1.198 (1.271)	1.083 (1.046)	0.200 (0.185)
Yakima R (rkm 325)	2,586	0.239 (0.098)	0.738 (0.565)	0.362 (0.376)	0.267 (0.242)	0.064 (0.052)
Leavenworth						
Leavenworth NFH	5,843	0.413 (0.054)	1.012 (0.220)	0.853 (0.418)	0.862 (0.410)	0.356 (0.163)
Willard						
Beaver Pond	5,982	0.352 (0.047)	0.848 (0.174)	0.821 (0.376)	0.696 (0.313)	0.245 (0.106)
Coulter Pond	5,878	0.424 (0.062)	0.863 (0.187)	3.105 (2.186)	2.680 (1.877)	1.136 (0.778)
Leavenworth NFH	5,971	0.364 (0.043)	0.773 (0.133)	1.179 (0.502)	0.911 (0.385)	0.332 (0.135)

Appendix Table B9. Continued.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Coho Salmon			
Winthrop						
Winthrop NFH	5,985	0.510 (0.062)	0.813 (0.163)	1.182 (0.484)	0.962 (0.381)	0.490 (0.185)
Yakima						
Natches River	2,821	0.311 (0.034)	0.911 (0.205)	1.338 (1.291)	1.219 (1.158)	0.379 (0.358)
Roza Dam	1,500	0.369 (0.072)	0.608 (0.244)	NA	NA	NA

Appendix Table B10. Estimated detection probabilities for PIT-tagged yearling Chinook salmon, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2014. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Yearling Chinook Salmon		
Chelan				
Chelan River	9,943	0.167 (0.011)	0.144 (0.015)	0.074 (0.027)
Dryden Accl. Pond	19,911	0.143 (0.007)	0.096 (0.008)	0.062 (0.014)
Cle Elum				
Clark Flat Pond	16,000	0.216 (0.010)	0.208 (0.018)	0.056 (0.027)
Easton Pond	11,997	0.239 (0.014)	0.267 (0.026)	0.132 (0.050)
Jack Creek Pond	12,000	0.247 (0.014)	0.211 (0.027)	0.136 (0.052)
East Bank				
Chiwawa Pond	5,061	0.161 (0.016)	0.120 (0.022)	0.026 (0.026)
Entiat				
Entiat Hatchery	9,897	0.125 (0.011)	0.095 (0.014)	0.119 (0.037)
Leavenworth				
Leavenworth NFH	14,977	0.195 (0.009)	0.156 (0.013)	0.114 (0.026)
Methow				
Methow Hatchery	10,460	0.105 (0.012)	0.065 (0.012)	0.112 (0.037)
Wells				
Wells Hatchery	5,973	0.175 (0.024)	0.149 (0.031)	NA
Winthrop				
Winthrop NFH	4,991	0.123 (0.015)	0.077 (0.015)	0.073 (0.035)
		Steelhead		
Methow River	1,970	0.045 (0.014)	0.064 (0.020)	0.029 (0.029)
Okanogan River	15,068	0.053 (0.006)	0.063 (0.008)	0.066 (0.019)
Twisp Accl. Pond	4,962	0.097 (0.014)	0.176 (0.024)	0.156 (0.054)
Wells Hatchery	5,257	0.074 (0.010)	0.046 (0.010)	0.074 (0.027)
Winthrop				
Winthrop NFH	29,319	0.048 (0.005)	0.051 (0.006)	0.131 (0.021)

Appendix Table B10. Continued

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Coho Salmon		
Cascade				
Gold Creek	5,924	0.085 (0.011)	0.076 (0.012)	0.292 (0.093)
Leavenworth NFH	5,940	0.116 (0.013)	0.083 (0.014)	0.144 (0.054)
Twisp Accl. Pond	5,912	0.083 (0.010)	0.084 (0.011)	0.111 (0.061)
Winthrop Back Channel	5,935	0.091 (0.012)	0.060 (0.011)	0.132 (0.071)
Eagle				
Naches River	5,052	0.125 (0.017)	0.056 (0.013)	0.140 (0.065)
Yakima R (rkm 256)	2,502	0.122 (0.036)	0.046 (0.026)	0.125 (0.117)
Yakima R (rkm 325)	2,586	0.069 (0.030)	0.037 (0.026)	0.333 (0.272)
Leavenworth				
Leavenworth NFH	5,843	0.086 (0.013)	0.082 (0.015)	0.149 (0.069)
Willard				
Beaver Pond	5,982	0.084 (0.013)	0.076 (0.014)	0.252 (0.109)
Coulter Pond	5,878	0.067 (0.011)	0.074 (0.013)	0.055 (0.038)
Leavenworth NFH	5,971	0.098 (0.013)	0.129 (0.018)	0.161 (0.066)
Winthrop				
Winthrop NFH	5,985	0.089 (0.012)	0.073 (0.013)	0.131 (0.050)
Yakima				
Natches River	2,821	0.234 (0.028)	0.161 (0.035)	0.100 (0.095)
Roza Dam	1,500	0.210 (0.044)	0.167 (0.062)	NA

Appendix C: Environmental Conditions and Salmonid Passage Timing

Methods

We obtained data on daily flow, temperature, and spill at Snake River dams and daily smolt passage index at Lower Granite Dam (yearling Chinook salmon and steelhead; hatchery and wild combined) in 2014 from the Columbia River DART website[1] on 8 September, 2014. We created plots to compare daily measures of flow, temperature, and spill at Little Goose Dam from 2014 to those from 2007-2013. We calculated long-term daily averages in flow, temperature, and spill as the mean daily value for 1993-2014. We created plots and calculated passage proportions to compare daily estimates of proportion of smolts passing Lower Granite Dam in 2014 to those of 2011-2013.

In addition, for each daily group of PIT-tagged yearling Chinook salmon and steelhead from Lower Granite Dam we calculated an index of Snake River flow exposure. For each daily group, the index was equal to the average daily flow at Lower Monumental Dam during the period between the 25th and 75th percentiles of PIT-tag detection at Lower Monumental Dam for the daily group. We then investigated the relationship between this index and estimates of travel time from Lower Granite Dam tailrace to McNary Dam tailrace (results shown in Figure 5 of the main text).

Results

In general, conditions in the Snake River during the 2014 spring migration could be categorized as average flow and temperature with above average spill percentages. These conditions are similar to those that occurred in 2009.

Mean flow volume at Little Goose Dam in 2014 during the main migration period (1 April-15 June) was 90.1 kcfs, which was very close to the 1993-2014 mean of 91.9 kcfs. Daily flow volumes varied around the long-term daily means through much of the season, with a general increasing trend with day until late May when flow began to decrease (Appendix Figure C1). Mean water temperature at Little Goose Dam in 2014

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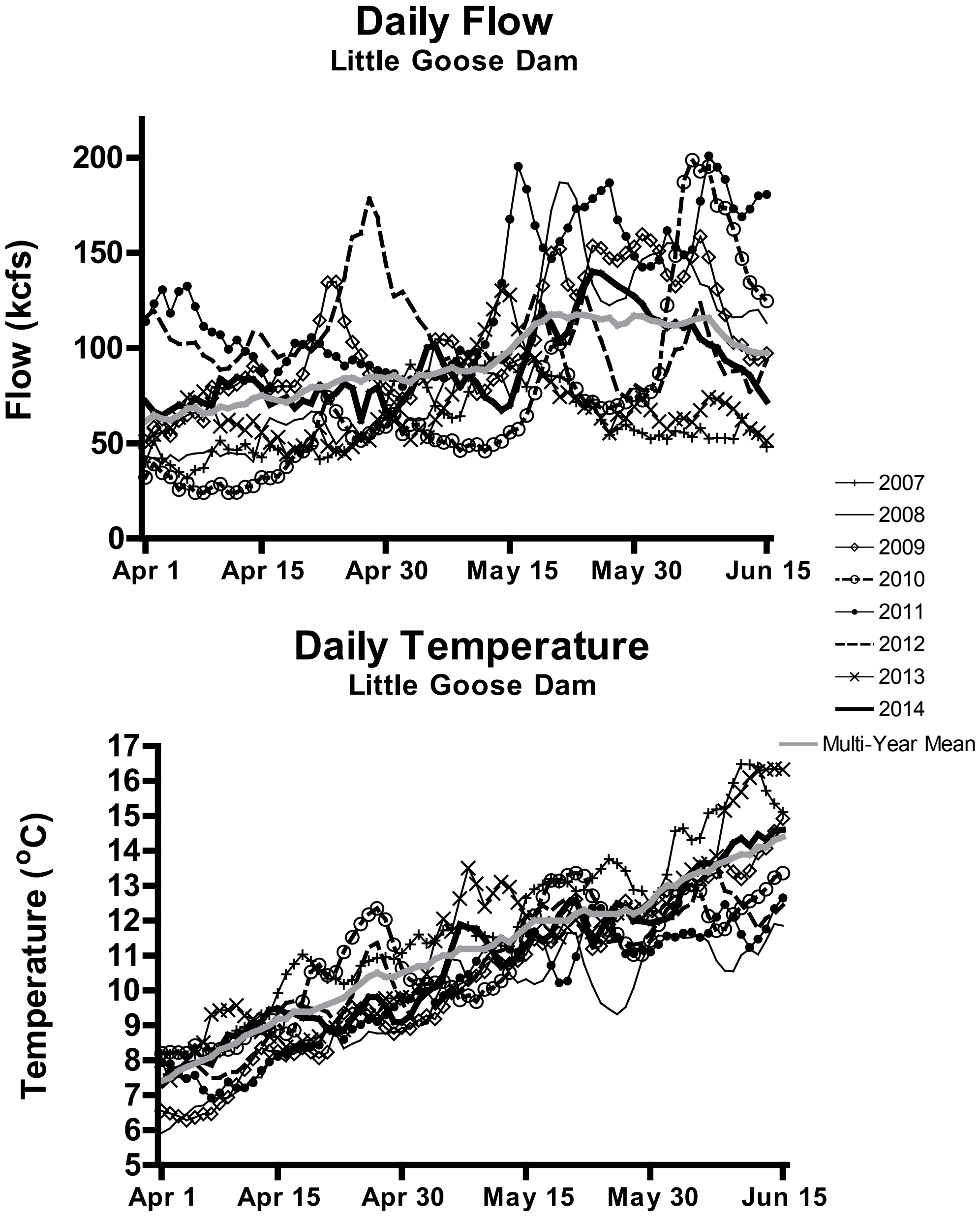
[1] www.cbr.washington.edu/dart

during the migration period was 10.9 °C, which is slightly below the long-term mean of 11.1°C. Daily water temperatures followed the long-term daily means fairly closely with some fluctuations (Appendix Figure C1).

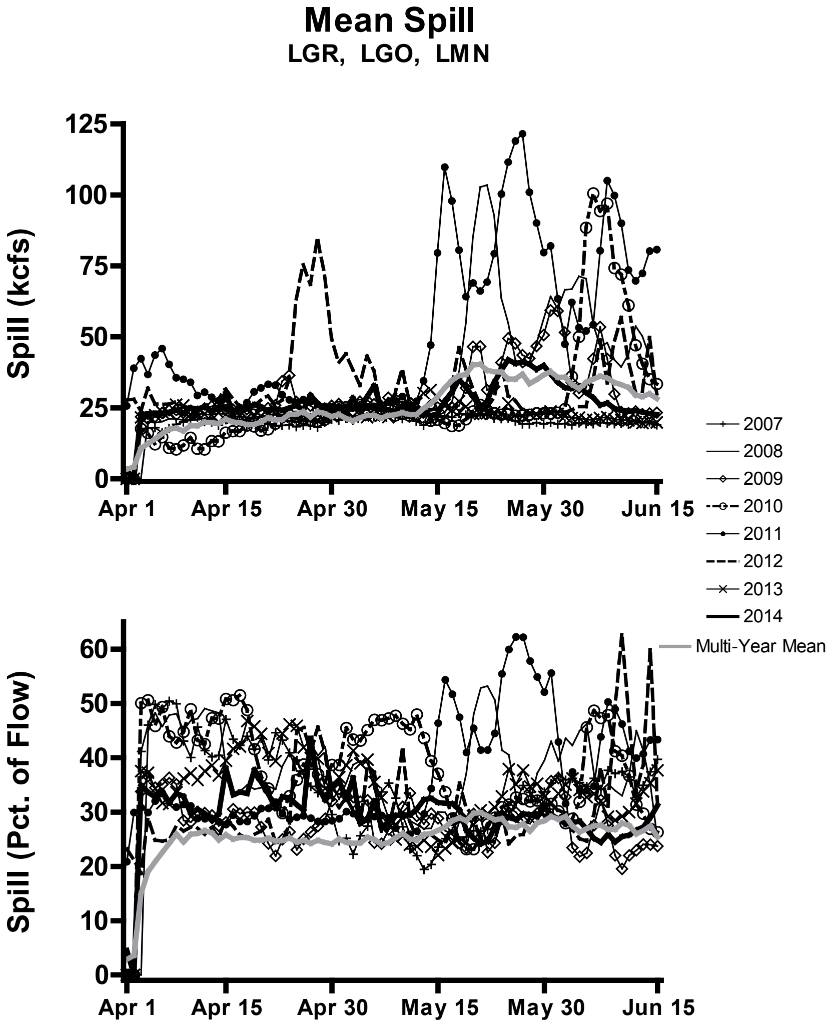


Daily Flow
Little Goose Dam

Daily Temperature
Little Goose Dam

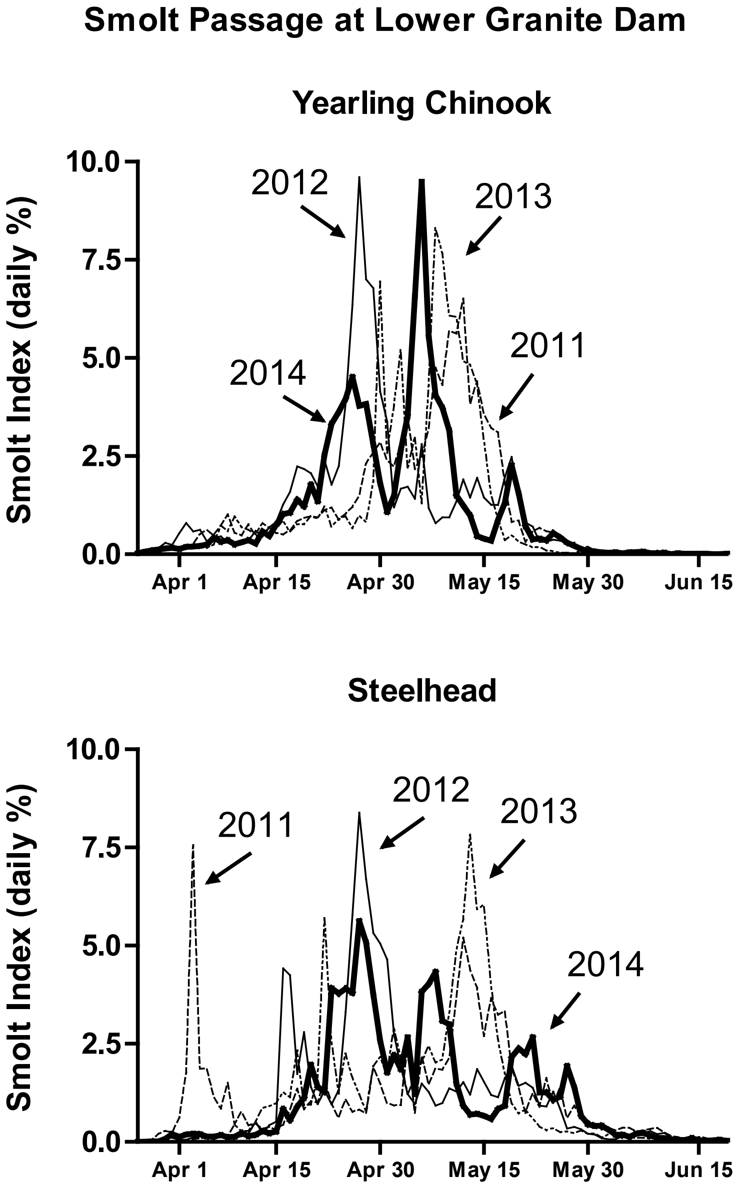
Appendix Figure C1. Daily Snake River flow (kcfs) and temperature (°C) measured at Little Goose Dam from April through mid-June, 2007-2014, including daily long-term means (1993-2014).

Mean spill volume at the Snake River dams during the 2014 migration was 26.8 kcfs, which was a little above the long-term mean of 26.0 kcfs. Daily spill volumes remained near the long-term daily means throughout the main migration period (Appendix Figure C2). Mean spill as a percentage of flow at the Snake River dams during the 2014 migration was 29.7%, which was above the long-term mean of 25.3%. Daily mean spill percentages in 2014 were above the long-term daily means for the majority of the migration (Appendix Figure C2).



Appendix Figure C2. Daily mean spill (top = kcfs; bottom = percentage of total flow) averaged across Lower Granite, Little Goose and Lower Monumental dams from April through mid-June, 2007-2014, including daily long-term means (1993-2014).

Flow gradually increased in pulses through May, reaching a peak near the end of the month. Spikes in smolt passage for both yearling Chinook salmon and steelhead at Lower Granite Dam in 2014 (Appendix Figure C3) did not closely track these pulses in flow (Appendix Figure C1).



Appendix Figure C3. Daily smolt passage index of yearling Chinook salmon and steelhead passing Lower Granite Dam, 2011-2014.