Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2017

Daniel L. Widener, James R. Faulkner, Steven G. Smith, Tiffani M. Marsh,
and Richard W. Zabel

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Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

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Executive Summary

In 2017, we completed the 25th year of a study to estimate survival and travel time of juvenile Pacific salmon *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 21,470 hatchery steelhead *O. mykiss*, 19,003 wild steelhead, and 14,247 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 yearling Chinook and steelhead tagged by other researchers upstream from Lower Granite Dam and at other hatcheries and traps 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 corner collector and 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 2017 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 2017, we estimated reach survival and travel time for hatchery and wild yearling Chinook salmon, hatchery sockeye *O. nerka*, hatchery coho salmon *O. kisutch*, and hatchery and wild steelhead. During most of the 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 Dam.

Hatchery and wild fish were combined in some analyses. For PIT-tagged fish detected or released at Lower Granite Dam, overall percentages by origin were 61% hatchery and 39% wild for yearling Chinook and 72% hatchery and 28% 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 87.6% of the overall yearling Chinook salmon run in 2017 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 between dams were calculated from tailrace to tailrace. Estimates of average survival and associated standard errors (SE) are listed by reach in Table E for groups of combined wild and hatchery yearling Chinook salmon and steelhead.

Table E. Average survival estimates by reach for groups of combined hatchery and wild yearling Chinook salmon and steelhead during 2017 (standard errors in parentheses).

	Yearling Chinook salmon (SE)	Steelhead (SE)
Snake River Trap to Lower Granite Dam	NA	NA
Lower Granite to Little Goose Dam	0.916 (0.009)	0.962 (0.008)
Little Goose to Lower Monumental Dam	0.908 (0.013)	0.943 (0.015)
Lower Monumental to McNary Dam[a]	0.912 (0.024)	0.849 (0.022)
Lower Monumental to Ice Harbor	0.980 (0.032)	1.004 (0.040)
Ice Harbor to McNary	0.923 (0.036)	0.876 (0.040)
McNary to John Day Dam	0.720 (0.041)	0.941 (0.020)
John Day to Bonneville Dam[b]	0.871 (0.200)	0.643 (0.040)
Snake River Trap to Bonneville Dam[c]	NA	NA

[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.

We were not able to estimate survival from the Snake River Trap to Bonneville Dam in 2017 because high flows throughout the migration season precluded operation of the trap. Instead, we estimated average survival from Lower Granite to Bonneville Dam (seven hydroelectric projects). These estimates were the product of average survival estimates through the two reaches from Lower Granite to McNary and from McNary to Bonneville Dam (Table E). For groups of combined wild and hatchery Snake River fish, estimated survival from Lower Granite to Bonneville Dam was 0.478 (95% CI 0.249-0.707) for yearling Chinook and 0.459 (0.400-0.518) for steelhead.

We estimated survival for hatchery fish originating upstream from the confluence of the Columbia and Yakima Rivers. For yearling Chinook salmon, estimated survival to McNary Dam ranged from 0.735 (0.062) for Chelan Hatchery fish released to the Chelan River to 0.248 (0.016) for Cle Elum Hatchery fish released to Jack Creek Pond. For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.575 (0.108) for Wells Hatchery fish released from Similkameen Pond on the Similkameen River to 0.209 (0.056) for East Bank Hatchery fish released to the Wenatchee River.

For smolts that arrived at Lower Granite Dam, we estimated that 19.7% of yearling Chinook (wild and hatchery combined) and 22.1% of steelhead were transported from a Snake River collector dam. These estimates were among the lowest on record (1993-2017); only estimates in 2015 were lower.

Low proportions of transported smolts resulted in part from timing of the transportation program in 2017. We estimated that 70% of the wild yearling Chinook and 53% of the hatchery yearling Chinook population had passed Lower Granite Dam before transportation began on 1 May. For steelhead, we estimated that 60% of the wild and 63% of the hatchery population had passed Lower Granite Dam by the time transportation began. After transportation began, the proportion of fish that entered juvenile collection facilities was also lower than average because a large proportion of flow was spilled at multiple dams, each of which used surface-passage structures to encourage spillway passage. As a result, fewer smolts were guided into the juvenile bypass systems of dams with facilities for collection and transport.

In addition to estimates of survival, we calculated travel time for yearling Chinook salmon and steelhead over individual reaches between dams and over combined reaches between Lower Granite Dam and Bonneville Dam (461 km). For both species, median travel time through the entire hydropower system was shorter than the long-term average for the entire migration season. This divergence from the average was largest in April and declined toward the end of May.

The estimated proportion of PIT-tagged fish detected as they passed monitoring sites was higher in 2017 than in 2016 at Lower Monumental Dam and John Day Dam, but substantially lower at other dams. Detection probabilities were especially low at McNary and Bonneville Dams; the detection probability estimates in 2017 at those two dams are the lowest on record.

These low detection probabilities were likely caused by the combination of high flow and high spill in 2017. However, the impact of flow on detection probability appeared to trend in opposite directions at some dams when compared to recent low flow years. Detection probability improved with higher flows at Lower Monumental and John Day Dam, but declined with higher flows at Little Goose, McNary, and Bonneville Dam.

In recent years, high levels of spill have been used to boost juvenile salmonid survival through the hydropower system. Starting in 2018, planned spill levels will increase again, to the maximum levels allowed under the gas cap. This additional spill will further reduce the proportion of fish passing dams via the bypass systems, which will result in lower detection probabilities.

Lower detection probabilities greatly reduce the precision with which we can estimate survival using PIT tag data. In light of these planned operations that will reduce detection probabilities below the current low levels, we believe the need is now more urgent than ever before to develop PIT-tag detection capability through passage routes other than the juvenile bypass systems. Specifically, the region should continue to place high priority on development and installation of PIT-monitoring systems for normal spill bays as well as for surface-passage structures.

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 collected from annual efforts to PIT-tag juvenile salmon.

Contents

Introduction

Accurate and precise estimates of survival are critical for recovery of depressed stocks of Pacific salmon *Oncorhynchus* spp. Pacific salmon stocks migrate through reservoirs, dams, and free-flowing sections of the Snake and Columbia River. To develop recovery strategies that will optimize survival of migrating smolts, resource managers need information on the magnitude, locations, and causes of juvenile mortality. Such knowledge is necessary for recovery strategies applied under present passage conditions as well as for those applied under conditions projected for the future (Williams and Matthews 1995; Williams et al. 2001, Crawford and Rumsey 2011).

From 1993 through 2017, the National Marine Fisheries Service (NMFS) has estimated survival for these stocks as they pass Snake and Columbia 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. 2007-2017). These annual survival estimates are based on data from detections of juvenile salmonids marked with passive integrated transponder (PIT) tags (Prentice et al. 1990a). Here we report results for smolts that migrated in spring 2017, the 25th year of the study. Research objectives in 2017 were:

1) Estimate reach survival and travel time in the Snake and Columbia Rivers throughout the yearling Chinook salmon and steelhead migration
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

To estimate survival and detection probabilities for groups of PIT-tagged Pacific salmon smolts *Oncorhynchus* spp., we used the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965; Skalski 1998; Skalski et al. 1998; Muir et al. 2001a). Background information and underlying statistical theory pertaining to the SR model is detailed by Iwamoto et al. (1994).

During the 2017 migration season, survival estimates were based on detections of fish released from Lower Granite Dam, from hatcheries and traps in the Snake River Basin, and from hatcheries and dams in the Upper Columbia River. A large number of PIT-tagged yearling Chinook salmon *O. tshawytscha* used in this analysis were released in the Snake River upstream from Lower Granite Dam for the multi-agency Comparative Survival Study (McCann et al. 2017).

Tagged study fish were detected at dams with monitoring facilities if they were diverted into the juvenile bypass systems at those dams (Figure 1). The following eight sites were equipped with automated PIT-tag monitoring systems (Figure 1; Prentice et al. 1990a,b,c):

- Lower Granite Dam (rkm 695)
- Little Goose Dam (rkm 635)
- Lower Monumental Dam (rkm 589)
- Ice Harbor Dam (rkm 538)
- McNary Dam (rkm 470)
- John Day Dam (rkm 347)
- Bonneville Dam (rkm 234)
- Pair-trawl system (rkm 65-84)

The farthest downstream detection site was in the Columbia River estuary, where NMFS operated a pair-trawl detection system (Ledgerwood et al. 2004). Since spring 2006, a PIT-tag detection system has been operated in the corner collector at Bonneville Dam Second Powerhouse. Using the SR model, detection at the last downstream site (pair-trawl system) is required for an estimate of survival probability to the second-to-last downstream detection site (Bonneville Dam). In 2017, detection probabilities at Bonneville Dam and in the pair trawl were low, but sufficient to estimate survival from John Day to Bonneville tailrace for most stocks.

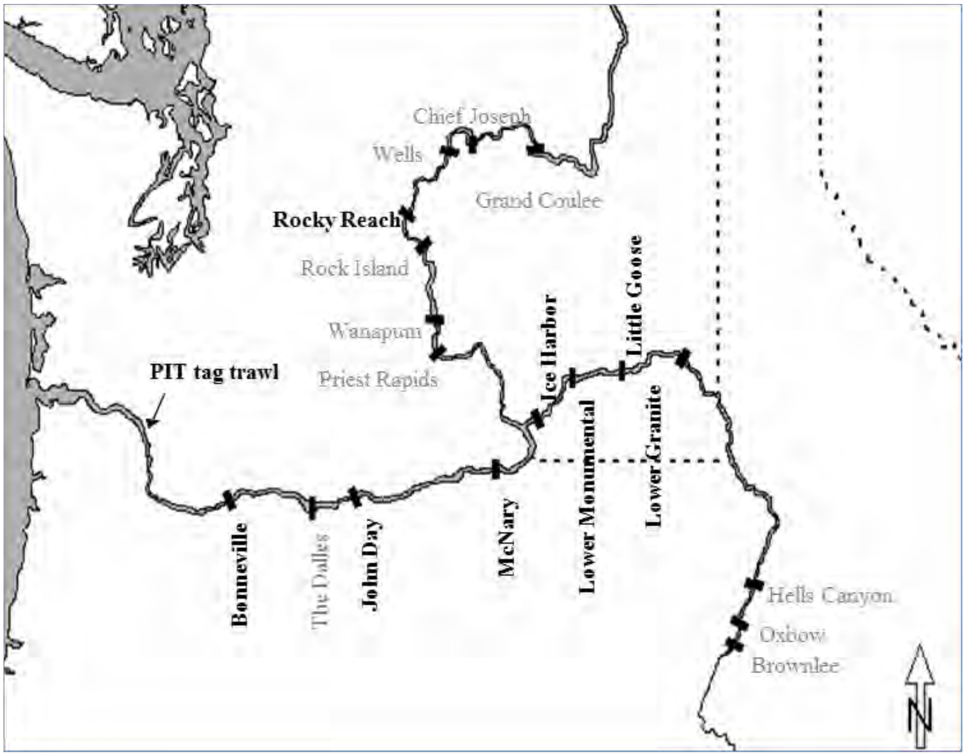


Figure 1. Study area showing the eight sites with PIT-tag detection capability in boldface, including seven dams and the PIT-tag trawl in the Columbia River estuary. Dams with names in gray do not have detection facilities.

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 estimate survival in the following seven reaches, with all estimates between dams spanning the reach from tailrace to tailrace:

- 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, detection rates were low again in 2017. A PIT-tag detection system was first operated in the Ice Harbor juvenile bypass facility in 2005. However, because of high levels of spill that year, too few smolts were detected there to partition survival between Lower Monumental and McNary Dams. From 2006 to 2017, detections at Ice Harbor have been sufficient to partition survival through this reach. However, low detection rates at Lower Monumental and Ice Harbor have often resulted in 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 2017, we collected hatchery and wild steelhead *O. mykiss* 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 ensure adequate detection numbers for estimates during these periods.

No hatchery yearling Chinook salmon were tagged specifically for this study because sufficient numbers of these fish were tagged and released from Snake River Basin hatcheries and traps by other researchers. 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" according to date of detection at the dam. At Lower Granite Dam, each daily group of fish detected and returned to the river was combined with fish tagged and released from the dam on the same date. Daily release groups were then pooled into weekly groups.

We estimated survival for both daily and weekly groups in individual reaches between Lower Granite and McNary Dam. However, for fish released at the beginning and end of the season, some daily groups were too small, even when pooled, to form weekly groups of sufficient sample size for reliable estimates of either survival or travel time. These fish were excluded from analyses that used weekly release groups.

At Lower Granite Dam, we PIT tagged and released 21,470 hatchery steelhead, 19,003 wild steelhead, and 14,247 wild yearling Chinook salmon from 5 April through 17 June 2017 (Table 1). From these numbers, total mortalities were 18, 4, and 26 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 52,733 yearling Chinook salmon (32,388 hatchery origin, 20,344 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 73,925 steelhead (53,311 hatchery origin and 20,614 wild) were tagged and released or detected and returned to the tailrace of Lower Granite Dam.

We estimated that 87.6% of the overall run of yearling Chinook salmon in 2017 was of hatchery origin. This estimate was based on counts of the run at large (both tagged and non-tagged 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. In the combined PIT-tagged groups used to estimate survival, estimated proportions of hatchery fish were 61% for yearling Chinook salmon and 72% for steelhead.

Table 1. Number by date of PIT–tagged hatchery and wild steelhead, and wild yearling Chinook salmon released at Lower Granite Dam for survival estimates in 2017. 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
5-Apr	855	-	-	254	-	-	887	2	-
6-Apr	652	-	1	356	-	-	1,342	4	-
12-Apr	702	-	-	457	1	-	1,271	1	-
13-Apr	699	-	1	143	-	-	927	2	-
19-Apr	875	-	-	209	-	-	768	-	-
20-Apr	876	-	-	182	-	-	470	2	-
26-Apr	1,760	-	-	322	-	-	1,047	4	-
27-Apr	1,763	1	-	417	-	-	767	3	2
2-May	876	1	-	465	-	-	453	2	-
3-May	646	1	-	155	-	-	212	-	-
4-May	797	3	1	219	-	-	412	-	-
5-May	799	1	-	305	-	1	250	-	-
6-May	556	1	-	289	-	-	244	-	-
9-May	666	2	-	812	-	-	169	-	-
10-May	659	2	-	953	2	-	348	-	-
11-May	664	1	-	867	-	-	540	1	-
12-May	664	-	1	429	-	-	652	1	-
13-May	662	1	-	605	-	-	505	-	-
16-May	498	-	1	1,070	-	-	303	1	-
17-May	502	1	-	983	-	-	284	-	-
18-May	499	1	-	785	-	-	261	-	-
19-May	505	-	-	879	-	-	396	-	1
20-May	440	-	-	1,138	-	1	509	-	-
23-May	351	-	-	711	-	1	197	1	-
24-May	353	-	1	752	-	2	155	-	-
25-May	352	-	-	1,038	-	-	203	1	-
26-May	517	-	-	1,313	1	-	361	1	-
27-May	182	-	-	424	-	-	147	-	-
31-May	263	-	-	214	-	1	53	-	-
1-Jun	264	-	1	229	-	1	51	-	-
2-Jun	261	1	1	322	-	-	50	-	-
3-Jun	262	-	-	338	-	-	13	-	-
6-Jun	148	1	-	130	-	-	-	-	-
7-Jun	150	-	-	94	-	-	-	-	-
8-Jun	149	-	1	175	-	-	-	-	-
9-Jun	150	-	-	194	-	-	-	-	-
10-Jun	50	-	-	152	-	-	-	-	-
13-Jun	100	-	-	169	-	1	-	-	-
14-Jun	100	-	-	146	-	-	-	-	-
15-Jun	99	-	-	119	-	-	-	-	-
16-Jun	104	-	-	104	-	-	-	-	-
17-Jun	-	-	-	85	-	-	-	-	-
	21,470	18	9	19,003	4	8	14,247	26	3

Releases from McNary Dam—For tagged yearling Chinook and steelhead released from locations throughout the Snake and Upper Columbia River, we created virtual daily "release groups" according to day of detection at McNary Dam. Daily release groups included only fish returned to the tailrace, and detections of daily groups were pooled into weekly groups for analyses. We estimated survival from McNary to John Day and from John Day to Bonneville Dam for weekly groups only, as detection data in 2017 were too sparse to estimate survival for daily groups.

Releases from Hatcheries and Smolt Traps—In 2017, most hatcheries in the Snake and Upper Columbia River Basins released PIT-tagged fish as part of research independent of the NMFS survival study. We used data from hatchery releases of PIT-tagged yearling Chinook, sockeye *O. nerka*, coho *O. kisutch*, and steelhead to obtain estimates of survival and detection probability. For fish originating in the Snake River Basin, we provided estimates from release to Lower Granite Dam and to points downstream from Lower Granite Dam.   For fish originating in the Upper Columbia River Basin, we provided estimates of survival from release to McNary Dam and to points downstream from McNary Dam.

We also estimated survival to Lower Granite Dam and to points downstream for releases of PIT-tagged wild and hatchery yearling Chinook salmon and steelhead from the Salmon (White Bird), Snake, and Grand Ronde traps, and from other smolt traps throughout the Snake River Basin. In past years, we have used fish tagged and released from the Snake River trap to estimate survival through Lower Granite Dam and reservoir. However, because of high-flow conditions, the Snake River trap was not operated in 2017. Thus, a direct estimate of survival through the Lower Granite project is not available for 2017.

Data Analysis

Tagging and detection data were downloaded on 15 August 2017 from the Columbia Basin PIT Tag Information System (PTAGIS), a regional database maintained by the Pacific States Marine Fisheries Commission (PSMFC 1996-present). Data were examined for erroneous records, inconsistencies, and anomalies. Records were eliminated where appropriate, and all eliminated PIT-tag codes were recorded with the reasons for their elimination. Very few records were eliminated (<0.1%).

For each remaining PIT-tag code, we constructed a detection history, or 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).

All analyses reported here used data downloaded on 15 August 2017. It is possible that data in the PTAGIS database may be updated or corrected after this date. Thus, estimates we provide or data used for analyses in the future 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 (Appendix A).

In many cases, sample sizes were large enough that these tests had sufficient power to detect very small violations of model assumptions. Very small deviations have only marginal effects on survival estimates. Appendix A contains a detailed discussion of these tests of assumption, the extent of assumption violations, and implications of and possible reasons for these violations.

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

Estimates of survival probability under the SR model are random variables, subject to sampling variability, and the SR model does not constrain the parameter estimates below 1.0. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probability to exceed 1.0. For practical purposes, these estimates should be considered equal to 1.0 and to represent true survival probabilities that are certainly less than 1.0 by some amount.

When estimates of survival through a particular river section were available for a series of release groups of the same stock, we calculated a weighted average of these estimates over the migration season (Muir et al. 2001a). When these series extended across all or most of the season, we considered this weighted average as the seasonal average for the year. 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. 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.

Estimated survival from the Snake River trap to Bonneville Dam provides important information on survival through an extended reach containing eight hydroelectric projects. The Snake River trap is located near the head of Lower Granite reservoir, so estimated survival from the trap to Bonneville Dam essentially covers the reservoir, forebay, dam, and tailrace for each of these eight hydropower projects traversed by juvenile salmonids from the Snake River Basin. For yearling Chinook salmon and steelhead, we constructed this estimate from three components:

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

Results

Snake River Yearling Chinook Salmon

Survival Probabilities—For weekly groups of yearling Chinook salmon, we estimated survival probability from Lower Granite to multiple Snake River dams over 10 consecutive weeks during 23 March-31 May (Table 2). Mean estimated survival was 0.916 (SE 0.009) from Lower Granite to Little Goose, 0.908 (0.013) from Little Goose to Lower Monumental, and 0.912 (0.024) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.743 (0.019).

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 2017. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for daily groups. Standard errors in parentheses.

Estimated survival of yearling Chinook salmon groups 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
23–29 Mar	892	0.645 (0.044)	0.881 (0.127)	0.882 (0.182)	0.501 (0.080)
30 Mar–5 Apr	1,589	0.807 (0.024)	0.908 (0.059)	0.826 (0.083)	0.605 (0.050)
6–12 Apr	4,052	0.911 (0.015)	0.915 (0.029)	0.834 (0.048)	0.695 (0.035)
13–19 Apr	7,538	0.929 (0.013)	0.894 (0.025)	0.948 (0.046)	0.787 (0.033)
20–26 Apr	11,960	0.932 (0.014)	0.884 (0.031)	1.000 (0.064)	0.824 (0.046)
27 Apr–3 May	13,864	0.917 (0.036)	0.955 (0.066)	0.907 (0.104)	0.795 (0.078)
4 –10 May	5,885	0.985 (0.109)	0.877 (0.106)	0.878 (0.092)	0.758 (0.070)
11–17 May	3,585	0.950 (0.042)	0.918 (0.068)	0.856 (0.104)	0.746 (0.079)
18–24 May	1,886	0.976 (0.061)	0.884 (0.109)	0.712 (0.121)	0.614 (0.082)
25–31 May	1,055	0.950 (0.082)	0.872 (0.134)	1.069 (0.280)	0.886 (0.204)
Weighted mean[a]		**0.916 (0.009)**	**0.908 (0.013)**	**0.912 (0.024)**	**0.743 (0.019)**

a Weighted mean estimates for daily groups (20 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 seven consecutive weeks during 13 April-31 May (Table 3). Overall weighted mean survival was 0.720 (SE 0.041) from McNary to John Day, 0.871 (0.200) from John Day to Bonneville, and 0.643 (0.157) for the combined reach from McNary to Bonneville Dam.

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 2017. 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 groups from McNary Dam (SE)		
Date at McNary Dam	Number Released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
13–19 Apr	713	0.755 (0.115)	0.243 (0.139)	0.184 (0.101)
20–26 Apr	2,498	0.663 (0.040)	0.613 (0.280)	0.406 (0.184)
27 Apr–3 May	4,818	0.724 (0.042)	1.708 (0.824)	1.236 (0.592)
4–10 May	3,512	1.095 (0.196)	0.977 (0.692)	1.070 (0.733)
11–17 May	4,128	0.823 (0.082)	0.764 (0.513)	0.628 (0.418)
18–24 May	1,371	0.539 (0.077)	0.909 (0.595)	0.490 (0.313)
25–31 May	483	0.713 (0.184)	0.488 (0.432)	0.348 (0.295)
Weighted mean		**0.720 (0.041)**	**0.871 (0.200)**	**0.643 (0.157)**

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 0.478 (SE 0.117) from the tailrace of Lower Granite Dam to Bonneville Dam. Because of high flow conditions, the Snake River trap was not operated in 2017, and we were not able to estimate survival probability from the trap to Lower Granite Dam.

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for weekly groups of hatchery vs. wild yearling Chinook (Table 4). Weighted mean estimated survival from Lower Granite to McNary Dam was lower for wild than for hatchery groups, and weekly estimates were lower for wild than for hatchery fish for every week except 30 March-5 April.

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 2017. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival of weekly 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
			Hatchery yearling Chinook		
23–29 Mar	852	0.651 (0.048)	0.847 (0.129)	0.901 (0.195)	0.497 (0.084)
30 Mar–5 Apr	565	0.686 (0.045)	0.955 (0.158)	1.002 (0.269)	0.657 (0.144)
6–12 Apr	850	0.894 (0.050)	0.904 (0.106)	0.939 (0.174)	0.759 (0.117)
13–19 Apr	4,066	0.942 (0.022)	0.826 (0.038)	1.102 (0.086)	0.857 (0.058)
20–26 Apr	8,803	0.951 (0.020)	0.868 (0.043)	1.023 (0.088)	0.845 (0.061)
27 Apr–3 May	11,391	0.975 (0.057)	0.920 (0.090)	0.907 (0.130)	0.814 (0.096)
4–10 May	4,182	0.901 (0.117)	0.976 (0.142)	0.868 (0.110)	0.763 (0.083)
11–17 May	1,167	0.919 (0.081)	0.992 (0.149)	1.117 (0.306)	1.018 (0.250)
18–24 May	232	0.648 (0.134)	1.290 (0.675)	0.913 (0.638)	0.763 (0.382)
Weighted mean		**0.922 (0.027)**	**0.871 (0.019)**	**1.010 (0.031)**	**0.811 (0.032)**
			Wild yearling Chinook		
30 Mar–5 Apr	1,024	0.876 (0.029)	0.893 (0.063)	0.787 (0.084)	0.615 (0.055)
6–12 Apr	3,202	0.928 (0.016)	0.914 (0.030)	0.812 (0.049)	0.688 (0.037)
13–19 Apr	3,472	0.942 (0.016)	0.932 (0.032)	0.835 (0.052)	0.733 (0.040)
20–26 Apr	3,157	0.959 (0.019)	0.902 (0.043)	0.930 (0.089)	0.805 (0.069)
27 Apr–3 May	2,473	1.016 (0.050)	0.916 (0.090)	0.829 (0.160)	0.771 (0.133)
4–10 May	1,703	1.205 (0.254)	0.690 (0.154)	0.897 (0.167)	0.746 (0.127)
11–17 May	2,418	0.968 (0.050)	0.891 (0.075)	0.784 (0.105)	0.676 (0.079)
18–24 May	1,654	1.020 (0.066)	0.853 (0.108)	0.691 (0.121)	0.601 (0.083)
25–31 May	939	0.965 (0.088)	0.816 (0.127)	1.048 (0.271)	0.825 (0.187)
Weighted mean		**0.942 (0.011)**	**0.911 (0.010)**	**0.832 (0.020)**	**0.709 (0.020)**

We estimated survival probabilities for daily groups of yearling Chinook salmon (hatchery and wild combined) either detected and returned to the tailrace or PIT-tagged and released to the tailrace of Lower Granite Dam (Table 5). During late May and over other periods scattered through the season, low downstream detection rates required us to pool groups over multiple days to create sufficient sample sizes for survival probability estimates.

Statistical sampling error in these daily estimates was higher in 2017 than in 2016, which made it difficult to assess within-season trends in survival through Snake River reaches during 2017 (Table 5; Figure 2). During the 2017 migration season, estimated survival for Chinook between Lower Granite and McNary Dam appeared to be low in late March and early April before increasing to average levels by mid-April. However, survival estimates in May were highly variable from day to day, and no clear patterns in survival were evident late in the season.

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 2017. 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 daily yearling Chinook salmon 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
20–23 Mar	280	0.703 (0.096)	0.886 (0.260)	0.806 (0.353)	0.502 (0.176)
24 Mar	246	0.613 (0.075)	0.836 (0.208)	1.677 (0.792)	0.859 (0.359)
25 Mar	154	0.579 (0.085)	1.048 (0.332)	0.788 (0.349)	0.478 (0.153)
26 Mar	99	0.812 (0.144)	0.902 (0.325)	0.865 (0.462)	0.634 (0.278)
27–28 Mar	156	0.568 (0.113)	1.204 (0.996)	0.380 (0.351)	0.260 (0.096)
29 Mar	87	0.699 (0.189)	1.780 (1.615)	0.192 (0.183)	0.239 (0.079)
30 Mar	120	0.618 (0.112)	0.645 (0.216)	1.733 (1.036)	0.692 (0.380)
31 Mar	121	0.839 (0.113)	0.957 (0.416)	0.661 (0.313)	0.530 (0.122)
1-2 Apr	195	0.712 (0.064)	1.206 (0.354)	0.994 (0.552)	0.853 (0.397)
3–4 Apr	138	0.845 (0.124)	0.768 (0.204)	0.975 (0.419)	0.633 (0.242)
5 Apr	1,015	0.848 (0.029)	0.897 (0.064)	0.797 (0.088)	0.606 (0.056)
6 Apr	1,447	0.885 (0.024)	0.900 (0.053)	0.838 (0.086)	0.667 (0.059)
7 Apr	86	0.816 (0.149)	0.840 (0.300)	0.607 (0.268)	0.416 (0.139)
8–9 Apr	271	0.894 (0.070)	0.791 (0.109)	1.061 (0.253)	0.750 (0.163)
10 Apr	271	1.055 (0.118)	0.777 (0.150)	0.790 (0.209)	0.647 (0.140)
11 Apr	308	0.938 (0.065)	0.913 (0.133)	0.937 (0.239)	0.802 (0.177)
12 Apr	1,669	0.922 (0.021)	0.964 (0.040)	0.808 (0.066)	0.718 (0.053)
13 Apr	1,373	0.892 (0.026)	0.974 (0.052)	0.819 (0.082)	0.712 (0.064)
14 Apr	771	0.915 (0.041)	0.966 (0.088)	0.805 (0.120)	0.712 (0.087)
15 Apr	828	0.919 (0.036)	0.839 (0.064)	1.142 (0.159)	0.881 (0.108)
16 Apr	738	0.919 (0.043)	0.971 (0.091)	1.002 (0.165)	0.894 (0.127)
17 Apr	1,286	0.911 (0.036)	0.800 (0.059)	1.153 (0.154)	0.840 (0.100)
18 Apr	792	1.006 (0.052)	0.858 (0.101)	0.886 (0.153)	0.765 (0.103)
19 Apr	1,750	0.958 (0.026)	0.854 (0.048)	0.962 (0.098)	0.787 (0.070)
20 Apr	1,975	0.903 (0.024)	0.937 (0.054)	0.971 (0.111)	0.822 (0.084)
21 Apr	1,186	1.000 (0.044)	1.034 (0.128)	0.659 (0.116)	0.681 (0.087)
22 Apr	1,207	0.998 (0.041)	0.782 (0.076)	0.926 (0.146)	0.723 (0.093)
23–24 Apr	2,774	0.962 (0.032)	0.913 (0.077)	1.353 (0.251)	1.188 (0.199)
25 Apr	2,045	0.918 (0.040)	0.875 (0.092)	1.111 (0.215)	0.893 (0.149)
26 Apr	2,773	0.908 (0.032)	0.885 (0.072)	1.051 (0.167)	0.844 (0.118)
27 Apr	3,037	0.894 (0.043)	0.857 (0.096)	0.902 (0.164)	0.691 (0.102)

Table 5. Continued.

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
		Estimated survival of daily yearling Chinook salmon groups from Lower Granite Dam (SE)			
28 Apr	2,404	0.898 (0.084)	0.958 (0.205)	1.177 (0.433)	1.012 (0.309)
29 Apr	2,679	0.918 (0.117)	1.381 (0.363)	0.662 (0.228)	0.839 (0.211)
30 Apr	2,247	0.868 (0.116)	1.244 (0.305)	0.560 (0.188)	0.605 (0.155)
1–2 May	2,918	1.125 (0.151)	0.749 (0.122)	1.092 (0.274)	0.920 (0.215)
3–4 May	1,476	1.231 (0.474)	0.709 (0.286)	1.111 (0.356)	0.969 (0.287)
5–6 May	1,888	1.326 (0.582)	0.727 (0.333)	0.856 (0.212)	0.824 (0.172)
7 May	802	1.035 (0.336)	0.975 (0.350)	0.597 (0.137)	0.602 (0.102)
8–9 May	1,418	1.247 (0.271)	0.696 (0.162)	1.125 (0.240)	0.976 (0.192)
10 May	880	1.018 (0.148)	0.827 (0.140)	0.817 (0.170)	0.687 (0.131)
11 May	997	1.142 (0.138)	0.835 (0.129)	0.888 (0.228)	0.847 (0.201)
12 May	1,006	0.857 (0.082)	0.942 (0.132)	1.029 (0.259)	0.831 (0.191)
13 May	644	0.812 (0.067)	0.967 (0.149)	0.826 (0.191)	0.648 (0.124)
14 May	116	0.956 (0.223)	0.799 (0.361)	0.712 (0.500)	0.544 (0.318)
15–16 May	468	0.787 (0.070)	1.502 (0.445)	0.810 (0.372)	0.958 (0.343)
17 May	354	1.068 (0.128)	0.680 (0.172)	0.770 (0.252)	0.560 (0.137)
18 May	333	1.303 (0.188)	0.880 (0.314)	0.826 (0.453)	0.946 (0.418)
19 May	454	0.910 (0.098)	1.324 (0.454)	0.442 (0.175)	0.533 (0.118)
20 May	561	0.877 (0.097)	0.735 (0.141)	0.910 (0.270)	0.586 (0.150)
21–23 May	283	0.778 (0.113)	1.300 (0.377)	0.914 (0.458)	0.924 (0.399)
24 May	255	1.112 (0.368)	0.686 (0.282)	0.511 (0.185)	0.389 (0.106)
25–26 May	720	0.937 (0.092)	0.816 (0.141)	1.499 (0.550)	1.146 (0.389)
27 May	194	0.898 (0.173)	1.479 (0.627)	0.398 (0.212)	0.529 (0.196)
28–31 May	141	1.298 (0.532)	0.472 (0.264)	1.090 (0.636)	0.668 (0.308)
Weighted mean		**0.916 (0.009)**	**0.908 (0.013)**	**0.912 (0.024)**	**0.743 (0.019)**

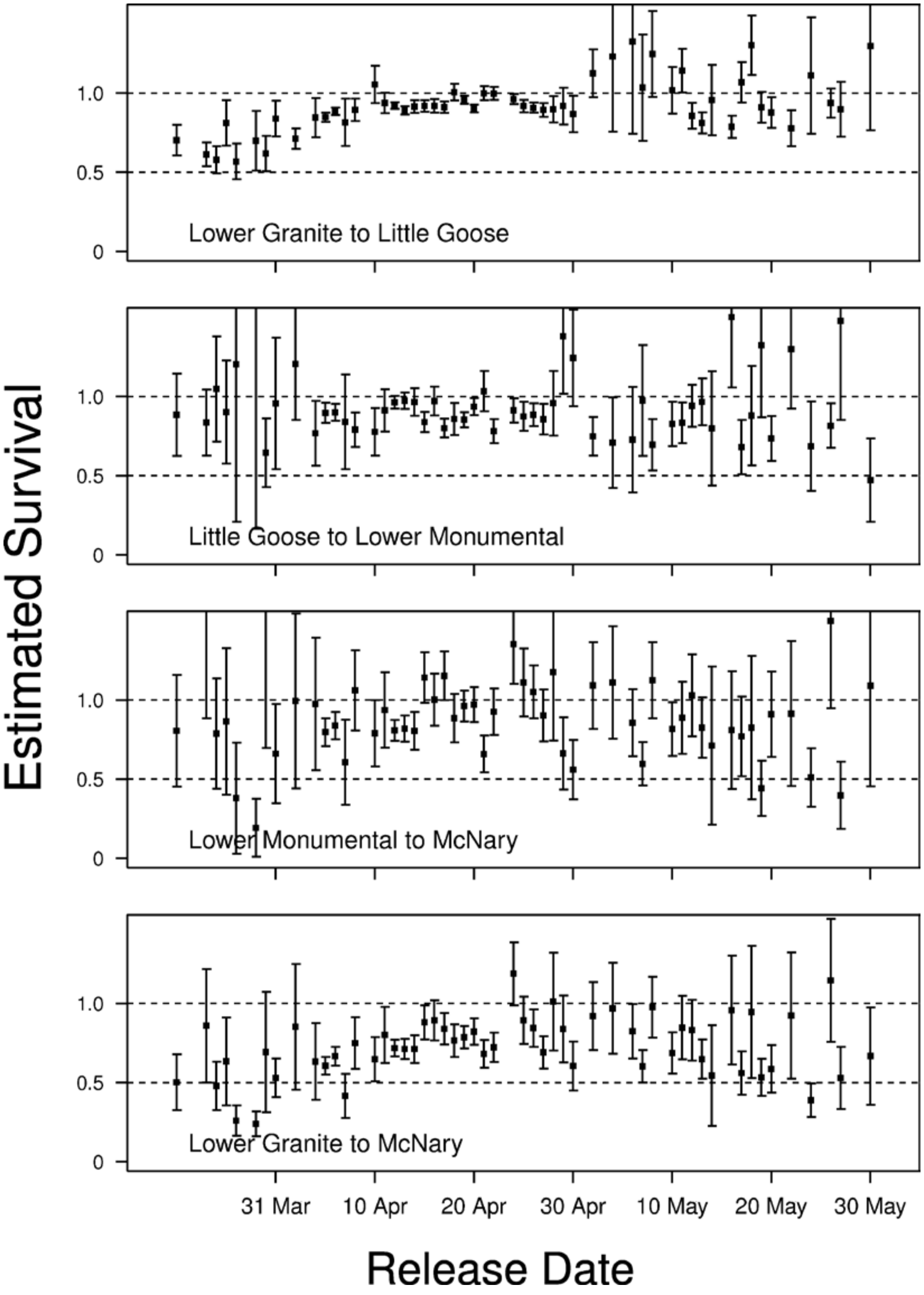


Figure 2. Estimated survival probabilities through various reaches versus release date at Lower Granite Dam for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined), 2017. Whiskers extend one standard error above and below point estimates.

Detection Probabilities—For weekly groups of yearling Chinook salmon, estimates of detection probability varied throughout the season with changing flow volumes, spill levels, and seasonal migration timing (Tables 6-8). Detection probability estimates were generally highest at Little Goose and John Day and lowest at McNary and Bonneville Dams, with the exception of one group with extremely low detection rates at Little Goose Dam. 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 2017. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
23–29 Mar	892	0.369 (0.031)	0.217 (0.033)	0.170 (0.033)
30 Mar–5 Apr	1,589	0.490 (0.019)	0.271 (0.020)	0.198 (0.021)
6–12 Apr	4,052	0.452 (0.011)	0.367 (0.013)	0.181 (0.012)
13–19 Apr	7,538	0.415 (0.008)	0.326 (0.010)	0.158 (0.008)
20–26 Apr	11,960	0.400 (0.007)	0.238 (0.009)	0.105 (0.007)
27 Apr–3 May	13,864	0.151 (0.007)	0.163 (0.010)	0.052 (0.006)
4–10 May	5,885	0.025 (0.004)	0.187 (0.011)	0.077 (0.008)
11–17 May	3,585	0.196 (0.011)	0.218 (0.015)	0.108 (0.013)
18–24 May	1,886	0.238 (0.018)	0.147 (0.018)	0.140 (0.021)
25–31 May	1,055	0.212 (0.022)	0.166 (0.024)	0.090 (0.023)

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 2017. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon groups from McNary Dam (SE)		
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
13–19 Apr	713	0.444 (0.070)	0.354 (0.198)
20–26 Apr	2,498	0.601 (0.037)	0.151 (0.069)
27 Apr–3 May	4,818	0.349 (0.022)	0.072 (0.034)
4 –10 May	3,512	0.116 (0.021)	0.050 (0.034)
11–17 May	4,128	0.240 (0.025)	0.108 (0.072)
18–24 May	1,371	0.267 (0.041)	0.160 (0.103)
25–31 May	483	0.226 (0.062)	0.259 (0.222)

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 2017. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

		Estimated detection probability of groups from Lower Granite Dam (SE)		
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery Yearling Chinook		
23–29 Mar	852	0.357 (0.032)	0.218 (0.035)	0.169 (0.034)
30 Mar–5 Apr	565	0.467 (0.038)	0.212 (0.039)	0.134 (0.035)
6–12 Apr	850	0.372 (0.027)	0.255 (0.031)	0.154 (0.028)
13–19 Apr	4,066	0.376 (0.012)	0.281 (0.014)	0.143 (0.012)
20–26 Apr	8,803	0.358 (0.009)	0.201 (0.010)	0.091 (0.008)
27 Apr–3 May	11,391	0.113 (0.007)	0.144 (0.011)	0.046 (0.006)
4–10 May	4,182	0.026 (0.004)	0.158 (0.012)	0.075 (0.009)
11–17 May	1,167	0.177 (0.020)	0.179 (0.025)	0.075 (0.020)
18–24 May	232	0.220 (0.056)	0.078 (0.042)	0.103 (0.057)
		Wild Yearling Chinook		
30 Mar–5 Apr	1,024	0.500 (0.023)	0.292 (0.024)	0.220 (0.025)
6–12 Apr	3,202	0.466 (0.012)	0.389 (0.014)	0.186 (0.013)
13–19 Apr	3,472	0.448 (0.011)	0.372 (0.014)	0.171 (0.012)
20–26 Apr	3,157	0.485 (0.013)	0.317 (0.016)	0.136 (0.014)
27 Apr–3 May	2,473	0.262 (0.016)	0.216 (0.020)	0.072 (0.014)
4–10 May	1,703	0.023 (0.006)	0.261 (0.023)	0.081 (0.016)
11–17 May	2,418	0.203 (0.013)	0.235 (0.018)	0.122 (0.016)
18–24 May	1,654	0.240 (0.019)	0.155 (0.019)	0.145 (0.023)
25–31 May	939	0.213 (0.024)	0.181 (0.027)	0.101 (0.025)

Snake River Steelhead

Survival Probabilities—For weekly groups of steelhead, we estimated probabilities of survival from Lower Granite Dam to multiple downstream dams for 13 consecutive weeks during 23 March-21 June (Table 9). Average estimated survival was 0.962 (SE 0.008) from Lower Granite to Little Goose, 0.943 (0.015) from Little Goose to Lower Monumental, and 0.849 (0.022) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, estimated survival averaged 0.759 (0.019).

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 2017. 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 groups 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
23–29 Mar	2,323	0.967 (0.019)	0.996 (0.056)	0.718 (0.075)	0.691 (0.062)
30 Mar–5 Apr	1,793	0.978 (0.034)	0.814 (0.063)	0.836 (0.152)	0.666 (0.112)
6–12 Apr	4,081	0.951 (0.017)	0.936 (0.045)	0.720 (0.079)	0.641 (0.064)
13–19 Apr	8,730	0.941 (0.016)	0.933 (0.029)	0.881 (0.058)	0.774 (0.047)
20–26 Apr	11,546	0.973 (0.015)	0.954 (0.030)	0.906 (0.057)	0.841 (0.048)
27 Apr–3 May	11,489	0.957 (0.020)	0.997 (0.042)	0.839 (0.083)	0.800 (0.073)
4–10 May	9,366	0.930 (0.094)	0.934 (0.099)	0.874 (0.082)	0.759 (0.067)
11–17 May	8,105	1.006 (0.024)	0.957 (0.039)	0.835 (0.080)	0.805 (0.073)
18–24 May	7,174	1.015 (0.028)	0.789 (0.044)	0.864 (0.093)	0.692 (0.067)
25–31 May	4,849	0.933 (0.046)	0.982 (0.078)	0.753 (0.095)	0.690 (0.076)
1–7 Jun	2,387	0.948 (0.039)	0.861 (0.085)	0.862 (0.184)	0.704 (0.137)
8–14 Jun	1,471	0.920 (0.041)	0.966 (0.109)	0.726 (0.182)	0.645 (0.148)
15–21 Jun	562	0.853 (0.087)	0.862 (0.184)	0.668 (0.220)	0.492 (0.132)
Weighted mean*		**0.962 (0.008)**	**0.943 (0.015)**	**0.849 (0.022)**	**0.759 (0.019)**

* Weighted mean of estimates for daily groups (23 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 21 April-1 June. Detection probabilities were low at McNary and Bonneville Dam and in the pair trawl detection system; thus, these estimates were very imprecise. We pooled weekly groups into 3 biweekly groups to increase precision (Table 10). Mean estimated survival from the overall pooled group was 0.941 (SE 0.020) from McNary to John Day, 0.643 (SE 0.040) from John Day to Bonneville, and 0.605 (SE 0.037) for the entire reach from McNary to Bonneville Dam. Despite biweekly pooling, precision remained very low, especially for estimates to Bonneville Dam.

Table 10. Estimated survival probabilities for biweekly groups of juvenile Snake River steelhead (hatchery and wild combined) from McNary Dam in 2017. 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 groups from McNary Dam (SE)			
Date at McNary Dam	Number released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
21 Apr–4 May	3,536	0.882 (0.056)	1.956 (1.341)	1.725 (1.178)
5–18 May	1,819	0.716 (0.088)	0.953 (0.646)	0.683 (0.455)
19 May–1 Jun	1,293	0.496 (0.064)	1.680 (1.610)	0.834 (0.792)
Overall mean[*]		**0.941 (0.020)**	**0.643 (0.040)**	**0.605 (0.037)**

[*] Estimate for overall pooled group (29 Mar–31 May)

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 0.459 (SE 0.030) from the tailrace of Lower Granite Dam to Bonneville Dam. Because of high-flow conditions, the Snake River trap was not operated in 2017, and we were not able to estimate survival probability through Lower Granite Dam.

Survival probabilities were estimated separately for weekly groups of hatchery vs. wild steelhead through individual and combined reaches (Table 11). Estimated survival differed substantially between wild and hatchery steelhead in some weeks. Average estimated survival over the combined reach between Lower Granite and McNary Dam was usually higher for hatchery than for wild steelhead released in the same week. When wild steelhead had higher estimated survival than the corresponding hatchery cohort, one or both estimates generally had poor precision.

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, 2017. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

	Estimated survival for 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
	Hatchery steelhead				
23–29 Mar	2,320	0.967 (0.019)	0.995 (0.056)	0.717 (0.075)	0.690 (0.062)
30 Mar–5 Apr	1,512	0.983 (0.038)	0.827 (0.075)	0.740 (0.144)	0.601 (0.106)
6–12 Apr	3,323	0.948 (0.020)	0.936 (0.053)	0.692 (0.087)	0.614 (0.070)
13–19 Apr	8,184	0.947 (0.017)	0.914 (0.030)	0.872 (0.059)	0.754 (0.046)
20–26 Apr	10,768	0.966 (0.016)	0.958 (0.032)	0.918 (0.062)	0.849 (0.052)
27 Apr–3 May	10,033	0.967 (0.021)	0.988 (0.044)	0.857 (0.090)	0.819 (0.080)
4–10 May	6,438	0.852 (0.099)	1.057 (0.130)	0.907 (0.119)	0.817 (0.102)
11–17 May	4,091	1.033 (0.035)	0.925 (0.052)	0.793 (0.094)	0.758 (0.084)
18–24 May	2,693	1.035 (0.045)	0.818 (0.068)	1.045 (0.188)	0.885 (0.146)
25–31 May	1,745	1.047 (0.079)	0.917 (0.108)	0.730 (0.138)	0.701 (0.117)
1–7 Jun	1,247	0.952 (0.058)	0.810 (0.108)	0.768 (0.208)	0.592 (0.145)
8–14 Jun	646	0.959 (0.063)	0.963 (0.158)	0.808 (0.289)	0.747 (0.242)
15–21 Jun	264	1.034 (0.185)	0.714 (0.237)	0.626 (0.283)	0.462 (0.165)
Weighted mean		**0.967 (0.007)**	**0.939 (0.014)**	**0.844 (0.025)**	**0.764 (0.024)**
	Wild steelhead				
30 Mar–5 Apr	281	0.951 (0.076)	0.818 (0.118)	1.429 (0.737)	1.111 (0.560)
6–12 Apr	758	0.985 (0.032)	0.931 (0.084)	0.806 (0.182)	0.738 (0.155)
13–19 Apr	546	0.892 (0.046)	1.171 (0.134)	1.085 (0.341)	1.134 (0.335)
20–26 Apr	778	1.065 (0.052)	0.909 (0.094)	0.792 (0.143)	0.768 (0.119)
27 Apr–3 May	1,456	0.874 (0.047)	1.023 (0.121)	0.734 (0.214)	0.656 (0.178)
4–10 May	2,928	1.116 (0.221)	0.725 (0.148)	0.860 (0.115)	0.696 (0.086)
11–17 May	4,014	0.980 (0.033)	0.985 (0.059)	0.915 (0.146)	0.883 (0.134)
18–24 May	4,481	0.996 (0.035)	0.781 (0.059)	0.755 (0.103)	0.587 (0.070)
25–31 May	3,104	0.870 (0.056)	1.034 (0.111)	0.761 (0.128)	0.685 (0.099)
1–7 Jun	1,140	0.946 (0.054)	0.921 (0.134)	1.000 (0.342)	0.871 (0.274)
8–14 Jun	825	0.888 (0.055)	0.962 (0.149)	0.661 (0.233)	0.565 (0.182)
15–21 Jun	298	0.745 (0.090)	0.986 (0.276)	0.703 (0.339)	0.517 (0.210)
Weighted mean		**0.961 (0.018)**	**0.942 (0.032)**	**0.830 (0.034)**	**0.723 (0.039)**

We estimated survival for daily release groups of combined hatchery and wild steelhead either detected and returned to the tailrace or released to the tailrace of Lower Granite Dam on the same day (Table 12). Precision of estimates was frequently poor, and estimates were variable from day to day, making it difficult to discern any pattern in survival across time (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 2017. 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 daily steelhead 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
23–25 Mar	966	0.968 (0.033)	0.940 (0.078)	0.810 (0.134)	0.736 (0.108)
26 Mar	633	0.996 (0.027)	1.121 (0.117)	0.635 (0.119)	0.709 (0.110)
27 Mar	408	0.958 (0.046)	1.133 (0.187)	0.543 (0.156)	0.590 (0.139)
28 Mar	178	1.027 (0.101)	0.728 (0.141)	0.921 (0.278)	0.688 (0.177)
29 Mar	138	0.876 (0.082)	0.824 (0.209)	0.824 (0.481)	0.594 (0.317)
30 Mar	153	0.793 (0.087)	1.253 (0.489)	0.608 (0.420)	0.605 (0.338)
31 Mar–1 Apr	254	0.963 (0.065)	0.743 (0.177)	0.765 (0.447)	0.547 (0.292)
2–3 Apr	101	1.203 (0.223)	0.884 (0.343)	0.533 (0.415)	0.567 (0.397)
4 Apr	52	1.158 (0.315)	0.851 (0.429)	0.432 (0.337)	0.426 (0.279)
5 Apr	1,233	0.976 (0.043)	0.790 (0.069)	0.897 (0.190)	0.691 (0.138)
6 Apr	1,212	0.945 (0.030)	0.925 (0.089)	0.664 (0.138)	0.580 (0.109)
7–8 Apr	559	0.924 (0.048)	0.953 (0.152)	0.696 (0.295)	0.613 (0.241)
9 Apr	270	0.981 (0.070)	1.084 (0.306)	0.544 (0.216)	0.579 (0.163)
10 Apr	293	0.908 (0.116)	0.926 (0.219)	0.864 (0.441)	0.726 (0.342)
11 Apr	348	1.005 (0.102)	0.796 (0.129)	1.069 (0.522)	0.856 (0.406)
12 Apr	1,399	0.960 (0.024)	0.971 (0.067)	0.732 (0.120)	0.682 (0.103)
13 Apr	1,110	0.946 (0.028)	1.003 (0.074)	0.679 (0.116)	0.645 (0.101)
14 Apr	1,059	0.940 (0.051)	0.919 (0.082)	1.261 (0.323)	1.090 (0.267)
15 Apr	1,024	0.924 (0.039)	0.915 (0.076)	1.265 (0.286)	1.069 (0.229)
16 Apr	665	0.976 (0.050)	0.851 (0.094)	1.073 (0.302)	0.892 (0.234)
17 Apr	1,306	1.099 (0.062)	0.727 (0.063)	0.734 (0.099)	0.587 (0.069)
18 Apr	1,098	0.921 (0.063)	0.940 (0.102)	0.772 (0.150)	0.668 (0.117)
19 Apr	2,468	0.882 (0.033)	0.996 (0.063)	0.903 (0.107)	0.794 (0.084)
20 Apr	2,729	0.930 (0.033)	0.965 (0.060)	0.929 (0.100)	0.833 (0.078)
21–23 Apr	3,931	0.962 (0.024)	0.961 (0.053)	1.117 (0.129)	1.032 (0.107)
24 Apr	740	1.008 (0.075)	0.964 (0.167)	0.633 (0.174)	0.615 (0.138)

Table 12. Continued.

		Estimated survival of daily steelhead 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
25 Apr	861	0.882 (0.058)	1.040 (0.141)	0.654 (0.179)	0.600 (0.146)
26 Apr	3,285	1.011 (0.027)	0.902 (0.050)	0.844 (0.105)	0.770 (0.088)
27 Apr	4,315	0.971 (0.025)	1.013 (0.056)	0.806 (0.105)	0.793 (0.096)
28 Apr	1,493	0.965 (0.043)	1.259 (0.221)	0.913 (0.348)	1.110 (0.370)
29 Apr	1,340	1.015 (0.062)	0.964 (0.167)	0.955 (0.287)	0.935 (0.225)
30 Apr–1 May	1,747	1.155 (0.193)	0.854 (0.190)	0.699 (0.218)	0.690 (0.187)
2 May	1,541	1.122 (0.105)	0.707 (0.094)	0.756 (0.271)	0.600 (0.208)
3 May	1,053	0.883 (0.070)	0.952 (0.115)	1.044 (0.472)	0.878 (0.388)
4–5 May	2,870	0.760 (0.153)	1.149 (0.245)	1.363 (0.444)	1.189 (0.378)
6–7 May	1,827	1.067 (0.349)	0.803 (0.270)	0.615 (0.134)	0.528 (0.108)
8 May	651	0.844 (0.235)	1.027 (0.324)	0.787 (0.276)	0.682 (0.217)
9 May	2,000	1.532 (0.580)	0.588 (0.226)	0.931 (0.161)	0.840 (0.134)
10 May	2,018	0.971 (0.140)	0.915 (0.139)	0.838 (0.124)	0.744 (0.105)
11 May	1,764	0.962 (0.138)	0.992 (0.156)	0.888 (0.165)	0.848 (0.148)
12 May	1,239	1.197 (0.090)	0.853 (0.085)	0.925 (0.212)	0.944 (0.208)
13 May	1,419	1.055 (0.075)	1.044 (0.128)	0.862 (0.270)	0.949 (0.281)
14–15 May	340	0.876 (0.093)	0.756 (0.160)	0.869 (0.352)	0.576 (0.210)
16 May	1,708	0.898 (0.027)	1.159 (0.108)	0.698 (0.160)	0.726 (0.153)
17 May	1,635	0.978 (0.044)	0.891 (0.075)	0.794 (0.157)	0.692 (0.128)
18 May	1,427	1.008 (0.045)	0.940 (0.121)	0.718 (0.188)	0.680 (0.158)
19 May	1,567	0.931 (0.036)	0.834 (0.100)	0.938 (0.237)	0.728 (0.165)
20 May	1,663	0.957 (0.049)	0.692 (0.085)	0.992 (0.224)	0.656 (0.129)
21–22 May	148	1.071 (0.206)	0.592 (0.191)	1.223 (0.790)	0.775 (0.465)
23 May	1,119	0.887 (0.097)	1.018 (0.160)	0.734 (0.179)	0.663 (0.142)
24 May	1,250	1.374 (0.414)	0.582 (0.185)	0.840 (0.204)	0.672 (0.150)
25 May	1,556	1.088 (0.147)	0.760 (0.128)	0.995 (0.225)	0.823 (0.167)
26 May	1,966	0.766 (0.057)	1.281 (0.167)	0.758 (0.171)	0.744 (0.147)
27 May	668	1.097 (0.105)	0.945 (0.213)	0.446 (0.146)	0.462 (0.119)
28–30 May	127	0.889 (0.132)	0.918 (0.344)	0.562 (0.318)	0.459 (0.206)
31 May	532	0.903 (0.113)	1.025 (0.206)	0.688 (0.210)	0.637 (0.166)
Weighted mean		**0.962 (0.008)**	**0.943 (0.015)**	**0.849 (0.022)**	**0.759 (0.019)**

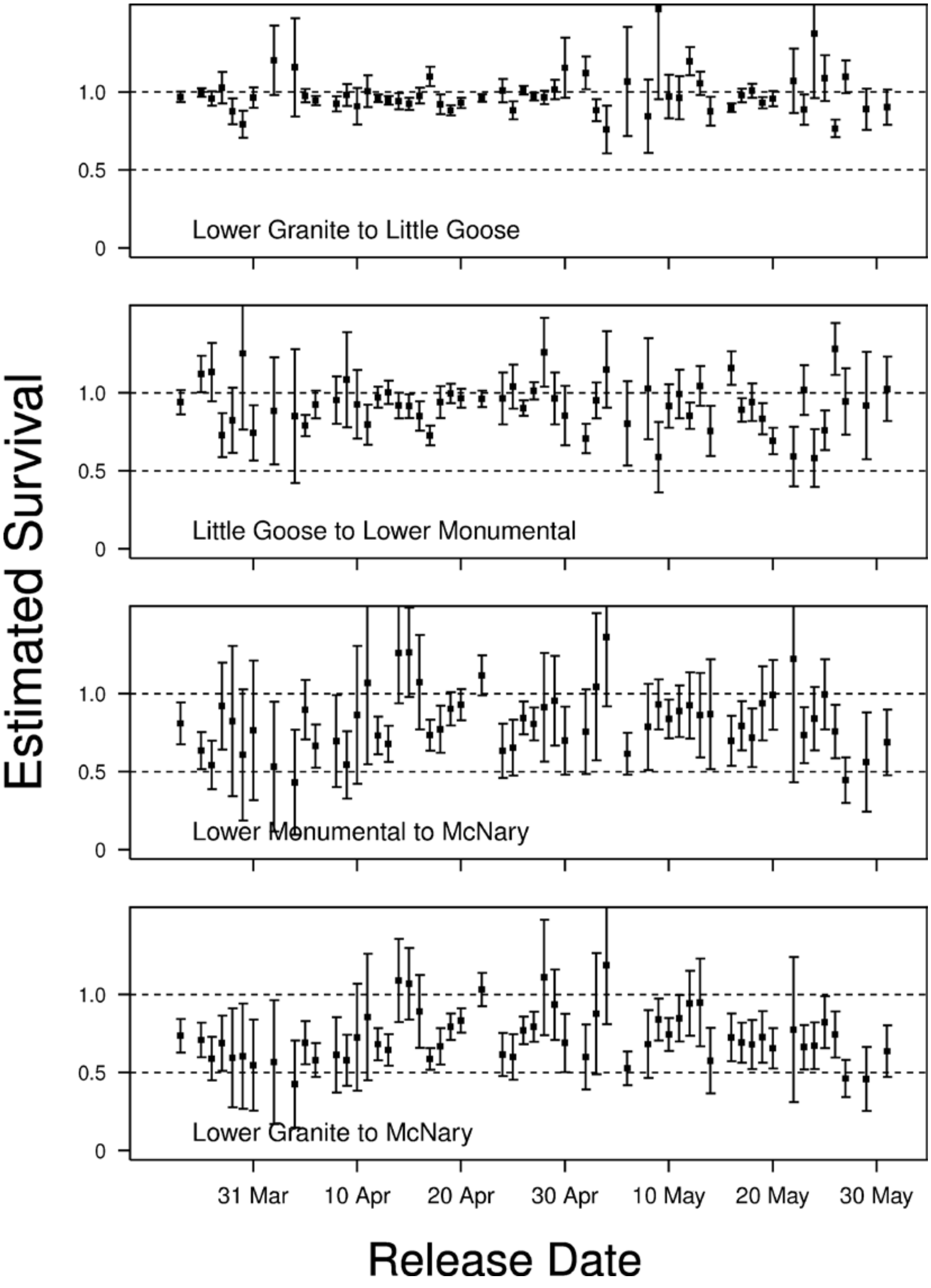


Figure 3. Estimated survival probabilities through various reaches versus release date at Lower Granite Dam for daily groups of Snake River steelhead (hatchery and wild combined), 2017. Whiskers extend one standard error above and below point estimates.

Detection Probabilities—For weekly groups of steelhead, estimated detection probabilities were very low at McNary and Bonneville Dam (Tables 13-15). Detection probability estimates were average at other dams, with the exception of Little Goose Dam, where one group had extremely low detection rates. Detection probability estimates were generally higher for wild fish than for hatchery fish released in the same week (Table 15).

Table 13. Estimated detection probabilities for juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of Lower Granite Dam, 2017. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

Estimated detection probability of steelhead groups from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
23–29 Mar	2,323	0.549 (0.015)	0.270 (0.017)	0.118 (0.013)
30 Mar–5 Apr	1,793	0.419 (0.019)	0.300 (0.024)	0.072 (0.014)
6–12 Apr	4,081	0.509 (0.012)	0.279 (0.014)	0.068 (0.008)
13–19 Apr	8,730	0.309 (0.007)	0.310 (0.010)	0.071 (0.006)
20–26 Apr	11,546	0.319 (0.007)	0.226 (0.007)	0.058 (0.004)
27 Apr–3 May	11,489	0.265 (0.007)	0.233 (0.009)	0.040 (0.004)
4–10 May	9,366	0.015 (0.002)	0.244 (0.009)	0.040 (0.004)
11–17 May	8,105	0.224 (0.007)	0.295 (0.011)	0.065 (0.007)
18–24 May	7,174	0.298 (0.010)	0.212 (0.012)	0.084 (0.009)
25–31 May	4,849	0.151 (0.009)	0.182 (0.013)	0.083 (0.010)
1–7 Jun	2,387	0.364 (0.018)	0.198 (0.020)	0.062 (0.013)
8–14 Jun	1,471	0.394 (0.022)	0.232 (0.027)	0.069 (0.018)
15–21 Jun	562	0.296 (0.036)	0.198 (0.042)	0.122 (0.038)

Table 14. Estimated detection probabilities for juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of McNary Dam, 2017. Daily groups were pooled for biweekly estimates. Standard errors in parentheses.

Estimated detection probability of steelhead groups from McNary Dam (SE)			
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
21 Apr–4 May	3,536	0.354 (0.024)	0.061 (0.042)
5–18 May	1,819	0.305 (0.039)	0.096 (0.064)
19 May–1 Jun	1,293	0.348 (0.048)	0.081 (0.078)

Table 15. Estimated detection probabilities for juvenile Snake River hatchery and wild steelhead from the tailrace at Lower Granite Dam, 2017. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

		Estimated detection probability of groups from Lower Granite Dam		
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Hatchery steelhead	
23–29 Mar	2,320	0.550 (0.015)	0.271 (0.017)	0.118 (0.013)
30 Mar–5 Apr	1,512	0.425 (0.021)	0.278 (0.026)	0.078 (0.016)
6–12 Apr	3,323	0.490 (0.014)	0.269 (0.016)	0.066 (0.010)
13–19 Apr	8,184	0.304 (0.008)	0.313 (0.010)	0.072 (0.006)
20–26 Apr	10,768	0.316 (0.007)	0.225 (0.008)	0.055 (0.004)
27 Apr–3 May	10,033	0.259 (0.007)	0.233 (0.010)	0.039 (0.004)
4–10 May	6,438	0.016 (0.002)	0.235 (0.011)	0.030 (0.004)
11–17 May	4,091	0.217 (0.010)	0.288 (0.015)	0.069 (0.009)
18–24 May	2,693	0.275 (0.015)	0.220 (0.018)	0.064 (0.012)
25–31 May	1,745	0.155 (0.014)	0.205 (0.021)	0.083 (0.016)
1–7 Jun	1,247	0.343 (0.025)	0.215 (0.028)	0.071 (0.020)
8–14 Jun	646	0.398 (0.032)	0.218 (0.037)	0.070 (0.026)
15–21 Jun	264	0.238 (0.050)	0.187 (0.059)	0.152 (0.062)
			Wild steelhead	
30 Mar–5 Apr	281	0.389 (0.043)	0.392 (0.057)	0.048 (0.027)
6–12 Apr	758	0.580 (0.026)	0.316 (0.032)	0.074 (0.019)
13–19 Apr	546	0.374 (0.029)	0.270 (0.034)	0.054 (0.019)
20–26 Apr	778	0.369 (0.025)	0.249 (0.028)	0.106 (0.021)
27 Apr–3 May	1,456	0.311 (0.021)	0.244 (0.028)	0.049 (0.015)
4–10 May	2,928	0.014 (0.003)	0.262 (0.016)	0.063 (0.009)
11–17 May	4,014	0.231 (0.010)	0.304 (0.017)	0.059 (0.010)
18–24 May	4,481	0.316 (0.013)	0.206 (0.015)	0.101 (0.013)
25–31 May	3,104	0.148 (0.012)	0.166 (0.016)	0.082 (0.013)
1–7 Jun	1,140	0.388 (0.026)	0.181 (0.027)	0.052 (0.018)
8–14 Jun	825	0.390 (0.030)	0.245 (0.038)	0.068 (0.025)
15–21 Jun	298	0.347 (0.052)	0.208 (0.059)	0.098 (0.046)

Survival and Detection from Hatcheries and Smolt Traps

Snake River Hatchery Release Groups—Survival estimates varied among stocks and among release sites for fish of the same hatchery stock (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 0.802 (SE 0.015) for Clearwater Hatchery fish released to the North Fork of the Clearwater River to 0.398 (0.032) for Lookingglass Hatchery fish released to Grande Ronde Pond on the Grande Ronde River (Appendix Table B1).

For steelhead, estimated survival to Lower Granite Dam ranged from 0.944 (0.027) for Irrigon Hatchery releases to Cottonwood Pond on the Grande Ronde River to 0.664 (0.034) for Hagerman Hatchery fish released from Sawtooth Hatchery (Appendix Table B2).

For sockeye salmon, only a single hatchery stock was released for migration year 2017. Estimated survival to Lower Granite Dam was 0.162 (0.012) for Springfield Hatchery fish released in mid-to-late April at Redfish Lake Creek Trap (Appendix Table B3).

Snake River Smolt Trap Release Groups—For tagged wild and hatchery juvenile salmonids released from Snake River Basin smolt traps, estimated survival probability to Lower Granite Dam was generally inversely related to distance between the respective traps and the dam (Appendix Table B7). Estimated detection probabilities were slightly lower than in 2016 (not shown) and similar among release groups of the same species and rearing type from different traps (Appendix Table B8).

For wild Chinook salmon, estimated detection probabilities at Snake River dams were consistently higher than those of hatchery conspecifics released from the same location (i.e., Grande Ronde and Salmon River traps). Estimated detection probabilities were higher for wild than hatchery steelhead at Lower Granite and Little Goose Dam, but lower for wild than hatchery steelhead at Lower Monumental and McNary Dam. These differences in detection probability 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 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).

We estimated survival for hatchery fish originating upstream from the confluence of the Columbia and Yakima Rivers. For yearling Chinook salmon, estimated survival to McNary Dam ranged from 0.735 (0.062) for Chelan Hatchery fish released to the Chelan River to 0.248 (0.016) for Cle Elum Hatchery fish released to Jack Creek Pond.

For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.575 (0.108) for Wells Hatchery fish released from Similkameen Pond on the Similkameen River to 0.209 (0.056) for East Bank Hatchery fish released to the Wenatchee River.

For coho salmon, estimated survival to McNary Dam ranged from 0.432 (0.066) for Willard Hatchery fish released from Winthrop Hatchery, to 0.117 (0.022) for Eagle Hatchery fish released to the Yakima River.

Survival Between Lower Monumental and Ice Harbor Dam

At Ice Harbor Dam, detections in 2017 were extremely poor and lower than at other dams (Table 16). A PIT-tag detection system became operational at Ice Harbor in 2005. In most years since then, detections have been sufficient to estimate survival from Lower Monumental to Ice Harbor and from Ice Harbor to McNary Dam.

For yearling Chinook salmon in 2017, mean estimated survival was 0.980 (SE 0.032) from Lower Monumental to Ice Harbor Dam and 0.923 (0.036) from Ice Harbor to McNary Dam. For steelhead, estimated mean survival through these same respective reaches was 1.004 (0.040) and 0.876 (0.040).

Table 16. Estimated survival and detection probabilities from Lower Monumental to Ice Harbor Dam for groups of Snake River yearling Chinook salmon and steelhead released from Lower Granite Dam (hatchery and wild combined), 2017. Daily groups were pooled for weekly estimates.

		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	892	1.287 (0.318)	0.634 (0.170)	0.081 (0.021)
30 Mar–5 Apr	1589	1.039 (0.105)	0.806 (0.097)	0.133 (0.016)
6–12 Apr	4052	0.937 (0.058)	0.890 (0.067)	0.112 (0.009)
13–19 Apr	7538	1.067 (0.065)	0.887 (0.062)	0.071 (0.005)
20–26 Apr	11960	0.918 (0.070)	1.071 (0.095)	0.046 (0.004)
27 Apr–3 May	13864	0.838 (0.093)	1.106 (0.152)	0.039 (0.004)
4–10 May	5885	0.908 (0.106)	0.959 (0.135)	0.044 (0.006)
11–17 May	3585	0.937 (0.122)	0.930 (0.148)	0.060 (0.008)
18–24 May	1886	1.174 (0.308)	0.597 (0.165)	0.032 (0.009)
25–31 May	1055	1.449 (0.511)	0.760 (0.309)	0.030 (0.011)
Weighted mean		**0.980 (0.032)**	**0.923 (0.036)**	**0.053 (0.007)**
		Hatchery and wild steelhead		
23 Mar–29 Mar	2323	0.972 (0.093)	0.781 (0.096)	0.113 (0.012)
30 Mar–5 Apr	1793	0.840 (0.106)	0.972 (0.195)	0.121 (0.017)
6–12 Apr	4081	0.958 (0.091)	0.735 (0.097)	0.088 (0.009)
13–19 Apr	8730	0.899 (0.055)	1.009 (0.083)	0.068 (0.005)
20–26 Apr	11546	0.933 (0.065)	0.995 (0.085)	0.039 (0.003)
27 Apr–3 May	11489	1.067 (0.088)	0.846 (0.100)	0.053 (0.005)
4–10 May	9366	1.019 (0.076)	0.864 (0.097)	0.060 (0.005)
11–17 May	8105	1.114 (0.080)	0.783 (0.088)	0.093 (0.007)
18–24 May	7174	1.400 (0.154)	0.604 (0.085)	0.059 (0.007)
25–31 May	4849	1.076 (0.154)	0.732 (0.126)	0.046 (0.007)
1–7 Jun	2387	1.232 (0.363)	0.716 (0.246)	0.024 (0.008)
8–14 Jun	1471	0.594 (0.155)	1.223 (0.405)	0.044 (0.013)
15–21 Jun	562	0.541 (0.169)	1.356 (0.498)	0.072 (0.026)
Weighted mean		**1.004 (0.040)**	**0.876 (0.040)**	**0.056 (0.006)**

Travel Time and Migration Rates

Methods

We calculated travel time of yearling Chinook salmon and steelhead through 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)

Between any two dams, travel time could be calculated only for individual fish that were detected at both the upstream and downstream dam. We defined travel time 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 monitor near the outfall site, which ensured that the fish would arrive in the tailrace within minutes of detection.

Thus, estimates of travel time included the time required to move through the tailrace of the upstream dam, the reservoir, and the forebay of the downstream dam. These estimates encompassed any delays associated with passage at the downstream dam such as lingering in the forebay, gatewell, or collection channel prior to detection in the juvenile bypass system.

Migration rate was calculated as length of the reach of interest (km) divided by travel time (d) and included the potential delays 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 tagged fish within a release group would include the travel time of both detected and non-detected fish. However, travel time cannot be determined for a fish that traverses a reach of river without being detected at both ends. Therefore, travel time statistics were computed only for detected fish, which represent a subsample of the complete tagged release group. Tagged fish that pass dams without being detected must have passed via turbines or spillways. Thus dam passage time for non-detected fish is typically minutes to hours shorter than that for detected fish, all of which pass the dam via the juvenile bypass system.

Results

We computed travel time statistics from the tailrace of Lower Granite and McNary Dam to multiple downstream sites for weekly groups of yearling Chinook salmon and juvenile steelhead. 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. For Chinook salmon in 2017, travel time between Lower Granite and Bonneville Dam was shorter than in all previous recorded years except 2016 (1997-2015). In late May, estimated travel time diverged even from 2016 to become the shortest on record. For steelhead, travel time between Lower Granite and Bonneville Dam was shorter through late May in 2017 than in all previous years; for the remainder of the 2017 season, steelhead travel time converged with that of 2016.

For both yearling Chinook salmon and steelhead, observed decreases in travel time later in mid April and early May generally coincided with increased flow and presumably with increased levels of smolt readiness (Figure 5).

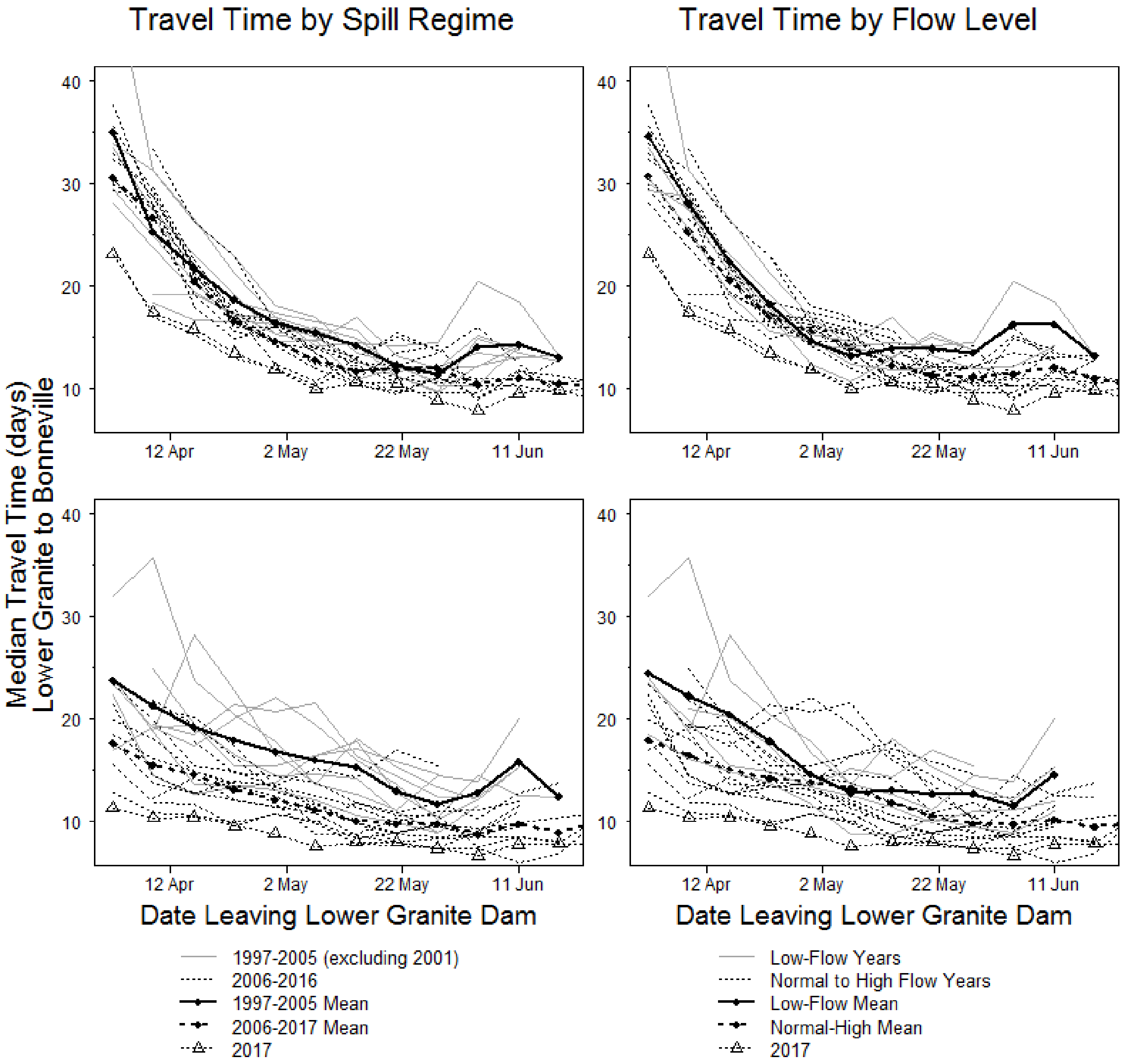
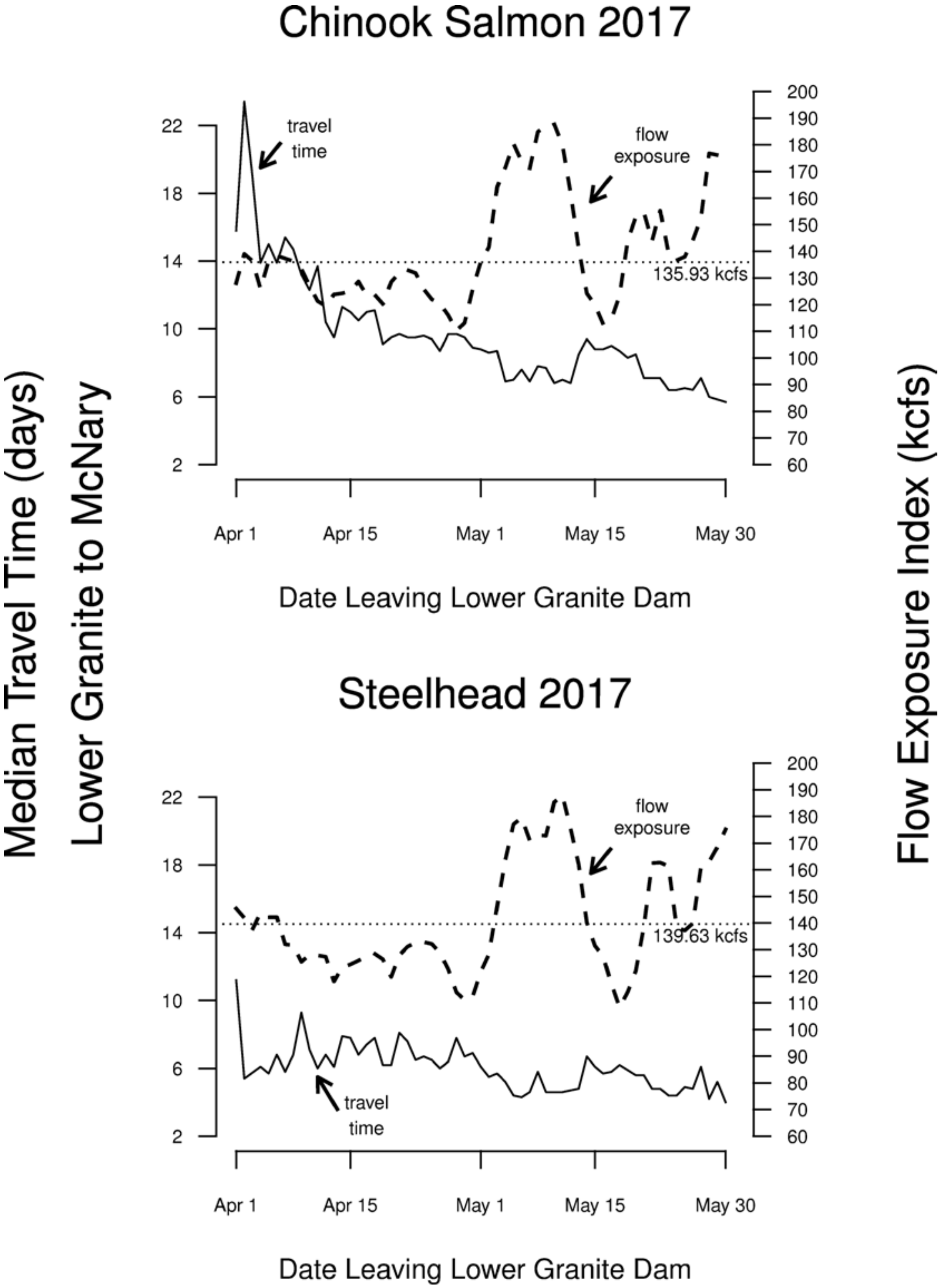


Figure 4. Median travel time (d) from Lower Granite Dam to Bonneville Dam for yearling Chinook salmon and steelhead for the period 1997-2017 (excluding 2001). Years are shown by spill regime (left) and flow level (right).



Chinook Salmon 2017

Steelhead 2017

Figure 5. Median travel time (d) from Lower Granite to McNary Dam for daily groups of PIT-tagged yearling Chinook salmon and steelhead and index of flow exposure at Lower Monumental Dam (kcfs) during 2017 (see Appendix C). Dashed horizontal lines represent the mean flow exposure index for the year, 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, 2017.

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%
23–29 Mar	212	7.3	16.7	28.9	26	1.4	2.3	3.8	11	4.1	6.1	8.5
30 Mar–5 Apr	629	4.0	5.0	10.3	126	1.6	2.1	2.9	46	4.0	5.4	9.0
6–12 Apr	1,668	3.3	4.1	6.6	489	1.3	1.7	2.3	153	3.8	5.2	7.4
13–19 Apr	2,906	3.0	4.2	6.2	594	1.3	1.6	2.2	209	3.3	4.0	5.5
20–26 Apr	4,464	2.9	3.9	5.2	702	1.2	1.5	2.0	174	3.0	3.7	5.4
27 Apr–3 May	1,915	3.0	3.9	4.9	166	1.3	1.5	1.8	53	2.8	3.6	6.0
4–10 May	146	2.8	3.3	4.8	28	0.9	1.1	1.4	59	2.4	3.2	4.3
11–17 May	666	2.2	3.0	4.1	105	1.2	1.5	1.9	52	2.6	3.5	4.7
18–24 May	438	2.9	3.0	4.0	55	1.1	1.4	1.6	19	2.9	3.2	4.2
25–31 May	213	1.9	2.1	2.9	29	1.0	1.2	1.4	13	2.6	3.2	4.5
1–7 Jun	31	1.9	2.0	2.9	3	0.8	0.9	1.1	0	NA	NA	NA
8–14 Jun	11	2.0	2.1	2.9	1	2.5	2.5	2.5	1	4.2	4.2	4.2

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	64	22.0	32.9	36.8	29	29.5	37.7	41.5
30 Mar–5 Apr	174	12.0	15.8	20.9	55	17.6	23.1	31.7
6–12 Apr	473	9.5	11.6	16.6	151	14.9	17.4	23.5
13–19 Apr	774	8.5	10.4	14.3	354	13.2	15.8	19.2
20–26 Apr	859	7.7	9.4	11.9	584	11.8	13.4	15.3
27 Apr–3 May	497	7.9	9.5	11.3	536	10.6	11.8	12.9
4–10 May	339	5.9	7.5	8.9	248	8.6	9.9	11.6
11–17 May	283	6.2	7.9	9.9	212	8.9	10.6	12.3
18–24 May	160	6.9	8.2	9.7	90	9.3	10.5	11.8
25–31 May	83	5.7	6.5	7.7	60	7.7	8.8	9.8
1–7 Jun	6	6.2	6.7	10.4	13	7.4	7.8	8.3
8–14 Jun	4	6.1	7.0	9.4	3	8.4	9.5	9.6

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, 2017.

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%
23–29 Mar	212	2.1	3.6	8.2	26	11.9	19.8	33.1	11	14.0	19.6	29.0
30 Mar–5 Apr	629	5.8	12.0	15.0	126	16.1	21.8	29.5	46	13.3	22.1	29.8
6–12 Apr	1,668	9.1	14.7	18.3	489	20.2	26.6	34.8	153	16.0	23.0	31.2
13–19 Apr	2,906	9.7	14.4	20.3	594	21.2	27.9	34.8	209	21.5	29.5	36.2
20–26 Apr	4,464	11.5	15.2	20.8	702	23.6	30.7	37.4	174	22.2	32.2	39.1
27 Apr–3 May	1,915	12.3	15.5	20.3	166	25.6	30.7	36.2	53	19.7	33.0	42.8
4–10 May	146	12.5	18.1	21.8	28	34.1	41.1	52.3	59	27.6	36.7	50.4
11–17 May	666	14.7	19.7	27.6	105	24.5	30.9	38.3	52	25.1	33.7	44.9
18–24 May	438	14.9	19.9	21.0	55	28.8	34.1	40.7	19	28.0	36.6	41.5
25–31 May	213	20.9	28.6	31.1	29	32.9	38.7	44.7	13	26.7	36.7	45.9
1–7 Jun	31	20.9	29.6	32.1	3	41.4	51.7	61.3	0	NA	NA	NA
8–14 Jun	11	20.9	28.7	30.3	1	18.3	18.3	18.3	1	28.3	28.3	28.3

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	64	6.1	6.8	10.3	29	11.1	12.2	15.6
30 Mar–5 Apr	174	10.8	14.2	19.2	55	14.5	19.9	26.2
6–12 Apr	473	13.5	19.4	23.6	151	19.6	26.5	30.9
13–19 Apr	774	15.7	21.5	26.5	354	23.9	29.1	34.9
20–26 Apr	859	18.8	23.8	29.4	584	30.2	34.3	39.1
27 Apr–3 May	497	19.8	23.7	28.6	536	35.8	39.2	43.3
4–10 May	339	25.2	30.2	38.0	248	39.7	46.7	53.9
11–17 May	283	22.8	28.6	36.3	212	37.4	43.6	51.7
18–24 May	160	23.1	27.5	32.5	90	38.9	43.9	49.7
25–31 May	83	29.2	34.7	39.8	60	46.8	52.7	59.9
1–7 Jun	6	21.6	33.6	36.5	13	55.3	59.0	62.1
8–14 Jun	4	23.9	32.3	36.9	3	48.2	48.6	54.6

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, 2017.

	Hatchery and wild yearling Chinook salmon from McNary Dam											
Date at	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)											
6–12 Apr	31	4.2	5.0	6.9	2	1.7	1.7	1.8	3	6.0	6.4	6.5
13–19 Apr	239	4.0	5.2	7.0	21	1.5	1.6	1.9	46	5.5	6.7	8.4
20–26 Apr	995	3.1	3.9	5.0	94	1.5	1.7	2.0	153	4.7	5.3	6.8
27 Apr–3 May	1,217	3.0	3.5	4.4	140	1.4	1.6	1.8	426	4.4	4.8	5.6
4–10 May	446	2.6	3.1	4.0	24	1.2	1.2	1.5	186	3.5	3.7	4.3
11–17 May	816	2.5	3.0	3.9	68	1.2	1.3	1.5	279	3.5	3.8	4.5
18–24 May	197	2.3	3.1	3.9	29	1.3	1.4	1.5	107	3.5	3.8	4.7
25–31 May	78	2.1	2.9	3.8	8	1.1	1.2	1.2	43	3.2	3.6	4.0
1–7 Jun	13	2.0	2.3	3.1	1	1.2	1.2	1.2	15	2.9	3.6	3.8
8–14 Jun	4	2.3	2.8	3.4	1	1.2	1.2	1.2	1	3.7	3.7	3.7
	Migration rate (km/d)											
6–12 Apr	31	17.8	24.8	29.5	2	64.6	64.9	65.7	3	36.1	36.6	39.3
13–19 Apr	239	17.6	23.5	30.5	21	59.5	68.5	73.4	46	28.1	35.1	43.2
20–26 Apr	995	24.6	31.7	39.4	94	57.4	64.9	76.9	153	34.6	44.7	50.3
27 Apr–3 May	1,217	28.2	35.5	41.4	140	62.1	71.1	78.5	426	41.9	49.0	54.1
4–10 May	446	30.4	39.9	46.8	24	74.3	91.9	96.6	186	54.8	63.1	68.0
11–17 May	816	31.9	41.1	48.2	68	75.3	88.3	95.0	279	52.7	61.8	66.5
18–24 May	197	31.6	39.0	53.0	29	75.8	83.1	89.0	107	50.6	62.3	67.2
25–31 May	78	32.7	42.1	57.2	8	91.9	97.4	106.6	43	58.6	65.2	72.8
1–7 Jun	13	39.9	53.5	60.6	1	93.4	93.4	93.4	15	62.8	64.7	82.2
8–14 Jun	4	36.1	43.9	53.0	1	96.6	96.6	96.6	1	63.3	63.3	63.3

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, 2017.

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%
23–29 Mar	1,233	1.8	2.2	3.3	319	1.0	1.8	4.2	41	2.4	4.0	10.1
30 Mar–5 Apr	735	1.8	2.1	3.3	151	1.1	1.6	4.1	23	2.0	2.8	5.2
6–12 Apr	1,975	1.8	2.0	2.8	433	1.1	1.7	3.2	54	2.1	2.9	5.8
13–19 Apr	2,539	1.8	2.4	3.2	568	1.1	1.7	3.1	124	2.3	3.0	5.0
20–26 Apr	3,588	1.9	2.2	2.9	575	1.1	1.6	2.6	97	2.1	3.0	4.5
27 Apr–3 May	2,910	1.9	2.1	2.9	509	1.2	1.7	2.6	59	2.3	3.1	5.2
4–10 May	129	1.7	2.2	3.6	33	0.8	1.4	1.9	85	1.6	2.0	2.4
11–17 May	1,825	1.6	1.8	2.1	505	1.1	1.3	2.0	128	2.0	2.5	3.1
18–24 May	2,174	1.9	1.9	2.2	314	1.1	1.4	2.0	78	2.0	2.2	2.7
25–31 May	682	1.6	1.8	2.1	133	0.9	1.1	1.6	54	1.6	2.0	2.3
1–7 Jun	825	1.3	1.4	1.6	136	0.7	0.8	1.1	29	1.7	1.9	2.3
8–14 Jun	533	1.3	1.5	1.8	105	0.7	0.9	1.2	18	1.9	2.1	2.6
15–21 Jun	142	1.5	1.8	2.0	20	1.0	1.2	1.6	4	1.7	1.9	2.3

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	180	5.8	10.3	19.9	34	8.5	18.3	30.7
30 Mar–5 Apr	79	4.8	5.9	12.9	37	8.8	11.3	27.0
6–12 Apr	161	5.1	6.8	12.9	192	8.5	10.3	16.3
13–19 Apr	408	5.5	7.0	10.8	578	8.7	10.4	13.9
20–26 Apr	493	5.3	6.5	9.5	1,088	8.5	9.5	11.3
27 Apr–3 May	324	5.4	6.5	9.3	714	8.3	8.8	10.5
4–10 May	281	4.1	4.6	5.6	523	6.7	7.5	8.5
11–17 May	415	4.4	5.4	6.7	395	7.2	7.9	10.3
18–24 May	405	4.9	5.5	6.5	358	7.3	7.9	8.8
25–31 May	272	4.2	4.6	5.3	196	6.7	7.3	8.2
1–7 Jun	102	3.6	4.2	4.9	120	6.3	6.6	7.5
8–14 Jun	64	4.0	4.4	5.2	96	6.8	7.7	8.4
15–21 Jun	32	4.9	5.2	5.5	54	7.2	7.8	8.7

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, 2017.

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%
23–29 Mar	1,233	18.3	26.7	33.5	319	10.9	25.4	45.1	41	11.8	30.1	49.0
30 Mar–5 Apr	735	18.1	28.8	34.3	151	11.2	29.3	43.4	23	22.8	41.8	59.8
6–12 Apr	1,975	21.4	29.7	33.9	433	14.2	27.7	42.6	54	20.7	41.6	55.3
13–19 Apr	2,539	18.6	25.2	32.8	568	14.9	27.1	40.0	124	23.8	39.5	52.4
20–26 Apr	3,588	20.5	27.6	32.3	575	17.7	29.5	40.4	97	26.3	39.3	56.7
27 Apr–3 May	2,910	20.5	28.3	31.9	509	17.6	27.4	38.7	59	23.1	38.6	52.7
4–10 May	129	16.6	27.0	34.5	33	24.1	33.8	54.1	85	50.0	58.3	73.5
11–17 May	1,825	28.0	33.0	37.5	505	23.5	36.2	43.8	128	38.0	48.2	60.7
18–24 May	2,174	26.9	30.9	32.3	314	23.4	33.6	43.0	78	44.4	54.6	61.0
25–31 May	682	28.8	32.6	38.7	133	29.1	43.0	52.9	54	51.3	60.1	72.1
1–7 Jun	825	37.5	42.0	45.8	136	43.0	59.0	68.7	29	51.5	61.3	71.7
8–14 Jun	533	33.7	40.0	45.5	105	39.0	48.9	65.7	18	46.3	55.9	62.6
15–21 Jun	142	29.4	33.9	39.2	20	28.8	39.7	48.4	4	51.3	63.0	70.0

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	180	11.3	21.8	38.6	34	15.0	25.2	54.4
30 Mar–5 Apr	79	17.4	37.9	46.4	37	17.0	40.7	52.1
6–12 Apr	161	17.5	33.1	44.4	192	28.3	44.6	54.1
13–19 Apr	408	20.8	32.4	40.9	578	33.1	44.3	53.1
20–26 Apr	493	23.6	34.6	42.7	1,088	40.9	48.4	54.4
27 Apr–3 May	324	24.1	34.5	41.4	714	44.0	52.3	55.3
4–10 May	281	40.3	48.8	55.0	523	54.0	61.7	68.4
11–17 May	415	33.4	41.9	50.8	395	44.8	58.1	63.9
18–24 May	405	34.6	40.9	46.2	358	52.2	58.7	63.4
25–31 May	272	42.1	49.3	54.0	196	56.2	63.2	68.7
1–7 Jun	102	46.0	53.6	62.3	120	61.5	69.6	73.2
8–14 Jun	64	43.1	50.7	56.0	96	54.9	59.9	67.9
15–21 Jun	32	41.3	43.7	46.2	54	53.0	59.4	63.6

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, 2017.

	Hatchery and wild juvenile steelhead from McNary Dam											
Date at	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)						
30 Mar–5 Apr	130	1.8	2.0	2.8	3	2.5	4.4	18.5	10	2.7	7.8	20.4
6–12 Apr	62	1.9	2.9	5.8	2	1.9	2.7	3.5	7	2.9	3.5	5.9
13–19 Apr	166	2.0	3.0	7.8	12	1.2	1.2	1.3	34	3.1	3.4	4.5
20–26 Apr	524	2.0	2.8	5.9	58	1.1	1.2	1.3	126	2.7	3.5	5.6
27 Apr–3 May	567	2.0	2.7	5.0	72	1.1	1.2	1.3	245	2.7	3.3	3.9
4–10 May	172	1.5	2.5	4.3	19	1.0	1.1	1.1	67	2.3	2.8	3.4
11–17 May	250	1.3	2.0	3.9	20	1.0	1.1	1.1	51	2.3	2.5	3.7
18–24 May	94	1.2	2.0	3.0	10	1.0	1.1	1.2	36	2.3	2.7	3.3
25–31 May	125	1.1	1.5	2.7	18	1.0	1.0	1.1	52	1.8	2.4	2.7
1–7 Jun	50	1.2	1.5	2.5	9	0.9	1.0	1.0	27	1.9	2.3	3.1
8–14 Jun	17	1.4	1.6	1.9	2	1.1	1.2	1.3	4	2.5	2.6	2.7
15–21 Jun	8	1.0	1.4	3.0	1	1.2	1.2	1.2	5	2.5	2.6	3.0
						Migration rate (km/d)						
30 Mar–5 Apr	130	43.5	62.1	69.1	3	6.1	25.9	45.9	10	11.6	30.2	87.4
6–12 Apr	62	21.1	43.0	64.1	2	31.8	41.9	60.8	7	39.8	66.5	81.7
13–19 Apr	166	15.9	40.5	61.2	12	87.6	90.4	94.2	34	52.9	69.8	76.4
20–26 Apr	524	20.9	43.3	61.2	58	88.3	97.4	102.7	126	42.2	68.4	87.4
27 Apr–3 May	567	24.7	45.9	61.2	72	85.0	90.4	98.3	245	61.1	71.3	88.7
4–10 May	172	28.5	49.6	80.4	19	100.0	107.6	115.3	67	69.0	85.2	101.3
11–17 May	250	31.5	60.6	95.3	20	102.7	107.6	110.8	51	63.1	95.5	102.2
18–24 May	94	40.6	63.1	102.5	10	91.9	101.8	109.7	36	71.7	88.7	100.9
25–31 May	125	46.2	81.5	112.8	18	105.6	110.8	117.7	52	87.4	99.6	128.3
1–7 Jun	50	48.6	81.5	100.8	9	109.7	113.0	127.0	27	76.4	101.7	125.5
8–14 Jun	17	64.4	78.3	90.4	2	88.3	96.6	105.6	4	88.7	91.1	94.8
15–21 Jun	8	40.9	91.1	120.6	1	97.4	97.4	97.4	5	79.5	91.5	96.3

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 transportation starting date at a collector dam, the proportion transported is 100%.

   For groups arriving at Lower Granite Dam before the transportation starting date, the estimated proportion of the daily Lower Granite Dam group that is eventually transported depends on travel time distributions to downstream transportation dams. These distributions determine the proportions of the group that arrive at each downstream dam after transportation has started there. Travel time distributions change 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 proportion transported for the season.

Results

In 2017, 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 these 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 2017 season were 17.8% for wild and 21.6% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 23.3% for wild and 20.9% 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. Estimates for 2017 were among the lowest recorded in our time series of estimates; only in 2015 were estimates lower (1993-2017; 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, and this approach continued in 2017.

By the time collection for transportation began at Lower Granite Dam on 1 May 2017, about 70% of wild yearling Chinook and 53% of hatchery yearling Chinook had already passed the dam. During general transportation operations, we estimated that for yearling Chinook salmon, approximately 51% of wild and 36% of hatchery smolts that arrived at Lower Granite Dam were transported, either from Lower Granite or from a downstream collector dam. The difference in proportion of transported fish between rear-types is due to a difference in the probability of entering the collection system.

By the time collection for transportation began at Lower Granite Dam on 1 May 2017, about 60% of wild steelhead and 63% of hatchery steelhead had already passed the dam. During general transportation operations, we estimated that for steelhead, approximately 53% of wild and 49% of hatchery smolts that arrived at Lower Granite Dam were transported, either from Lower Granite or from a downstream collector dam.

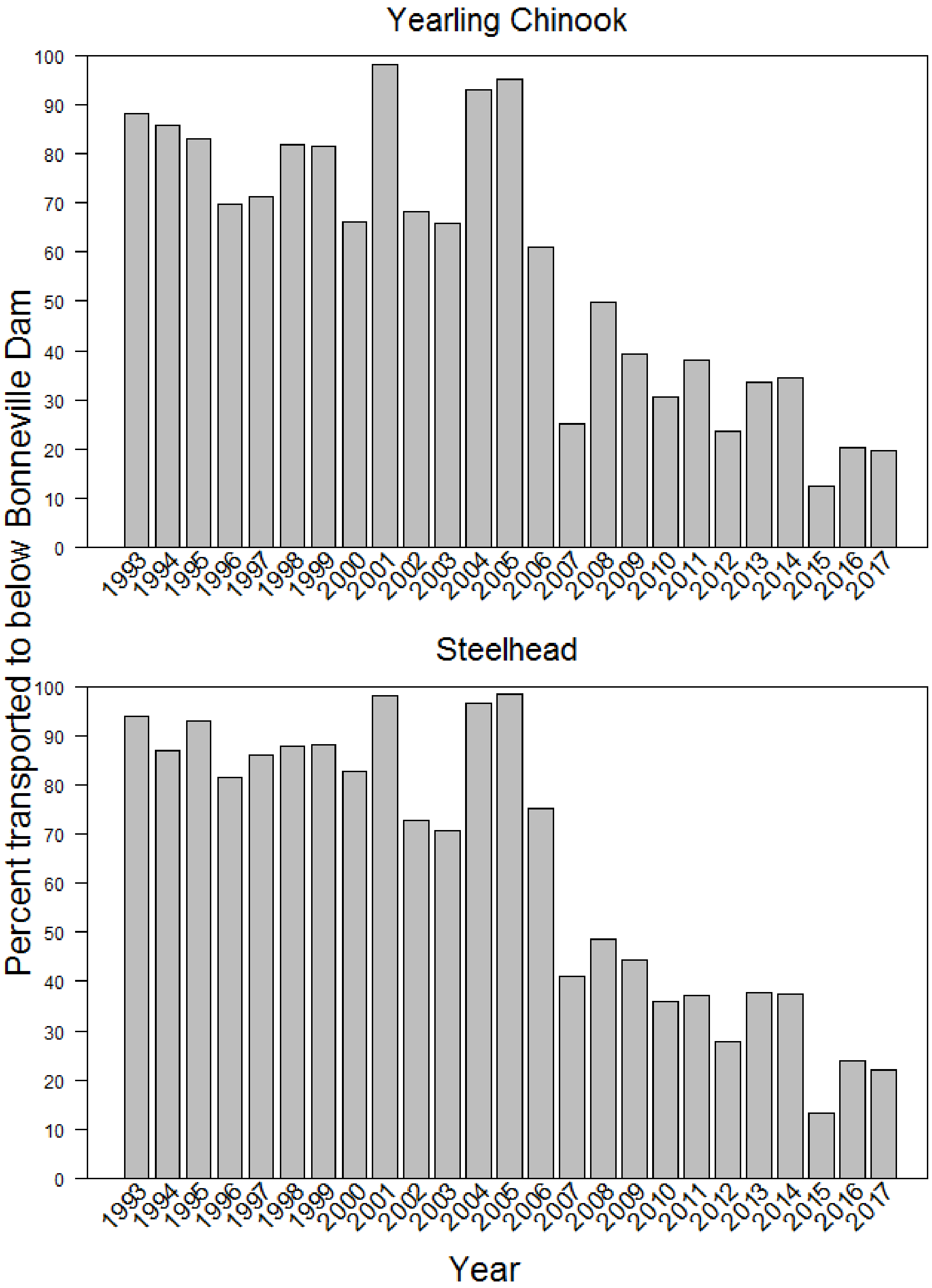


Figure 6. Estimated percent of yearling Chinook salmon and steelhead (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2017).

Table 23. Annual estimated percentages of migrating Snake River yearling Chinook salmon and steelhead that were transported (1993-2017). Estimates are shown for hatchery and wild fish separately. Separate arithmetic means are shown for each estimate over all years and across years with a common transportation operating schedule.

	Estimated percentage of fish transported (%)					
	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
2015	13.6	11.4	12.5	13.9	12.4	13.2
2016	21.0	19.3	20.2	22.9	24.4	23.7
2017	17.8	21.6	19.7	23.3	20.9	22.1
Mean						
1993-2017	**56.2**	**58.7**	**57.5**	**62.7**	**63.7**	**63.2**
1993-2006	**77.6**	**80.9**	**79.3**	**85.9**	**87.1**	**86.5**
2007-2017	**29.0**	**30.4**	**29.7**	**33.1**	**33.8**	**33.5**

For yearling Chinook salmon, a slightly smaller percentage of the total run passed before transportation began in 2017 than in 2016, while the reverse was true for steelhead. For yearling Chinook that passed the dam after transportation had begun, a smaller percentage of fish were transported in 2017 than in 2016. For steelhead that passed after transport had begun, about the same percentage of fish were transported in 2017 as in 2016. However, differences between the two years were small, in both the percentages passing prior to transportation and in percentages transported. As a result, the overall percentages of transported fish in 2017 were very close to those in 2016, with both years among the lowest recorded in our time series.

Survival estimates presented in this report are based largely on PIT-tagged fish that migrated in the river. These fish were either detected in juvenile bypass systems and returned to the river or they passed through turbines or spillways (including surface-passage structures). Tagged fish that were ultimately transported provided survival information only to the point where they were removed from the river.

Comparisons of Annual Survival Estimates

Comparison Among Years

We made two types of comparisons among annual survival estimates from 2017 and those obtained during the previous 24 years of the NMFS survival study. First, for Snake River hatchery yearling Chinook salmon, we compared estimated survival to Lower Granite Dam with distance of the respective hatcheries from the dam.

Second, for Snake and Columbia River yearling Chinook, steelhead, and sockeye salmon, we compared estimates of overall seasonal survival through specific reaches during 2017 with overall seasonal (tailrace-to-tailrace) survival estimates for those same reaches in all previous study years for which these data were available.

Snake River Stocks

Yearling Chinook Salmon—For yearling Chinook salmon from most Snake River Basin hatcheries, estimated survival to Lower Granite Dam in 2017 was slightly lower than estimates from recent years. Mean survival was below the long-term mean for fish from most hatcheries (Table 24). Over the years of the study, we have consistently observed an inverse relationship between estimated survival and distance of the release site to Lower Granite Dam. This relationship is illustrated for hatchery yearling Chinook salmon in Figure 7 ($R^2 = 0.788$, $P = 0.008$).

For combined wild and hatchery yearling Chinook salmon in 2017, mean estimated survival was 0.743 (95% CI 0.706-0.780) from Lower Granite to McNary Dam and 0.643 (0.335-0.951) from McNary to Bonneville Dam (Tables 25-26; Figures 8-9). These estimates were similar to the long-term mean for both reaches, with the estimate from Lower Granite to McNary Dam slightly above the long-term mean of 0.738 and the estimate from McNary to Bonneville Dam slightly below the long-term mean of 0.700.

Table 24. Estimated survival for yearling Chinook salmon from selected Snake River Basin hatcheries to the tailrace of Lower Granite Dam, 1993-2017. Distance to Lower Granite Dam is shown for each hatchery (km). 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)
2015	0.768 (0.018)	0.532 (0.027)	0.655 (0.035)	0.811 (0.024)	0.729 (0.030)	0.771 (0.036)	0.696 (0.036)	0.709 (0.035)
2016	0.714 (0.007)	0.684 (0.012)	0.704 (0.007)	0.815 (0.005)	0.654 (0.006)	0.772 (0.008)	0.676 (0.006)	0.717 (0.022)
2017	0.693 (0.013)	0.565 (0.025)	0.585 (0.020)	0.652 (0.010)	0.700 (0.012)	0.746 (0.012)	0.606 (0.010)	0.650 (0.025)
Mean	**0.772 (0.015)**	**0.664 (0.017)**	**0.657 (0.010)**	**0.708 (0.019)**	**0.598 (0.015)**	**0.538 (0.034)**	**0.470 (0.033)**	**0.630 (0.012)**

* Released at Imnaha River Weir.

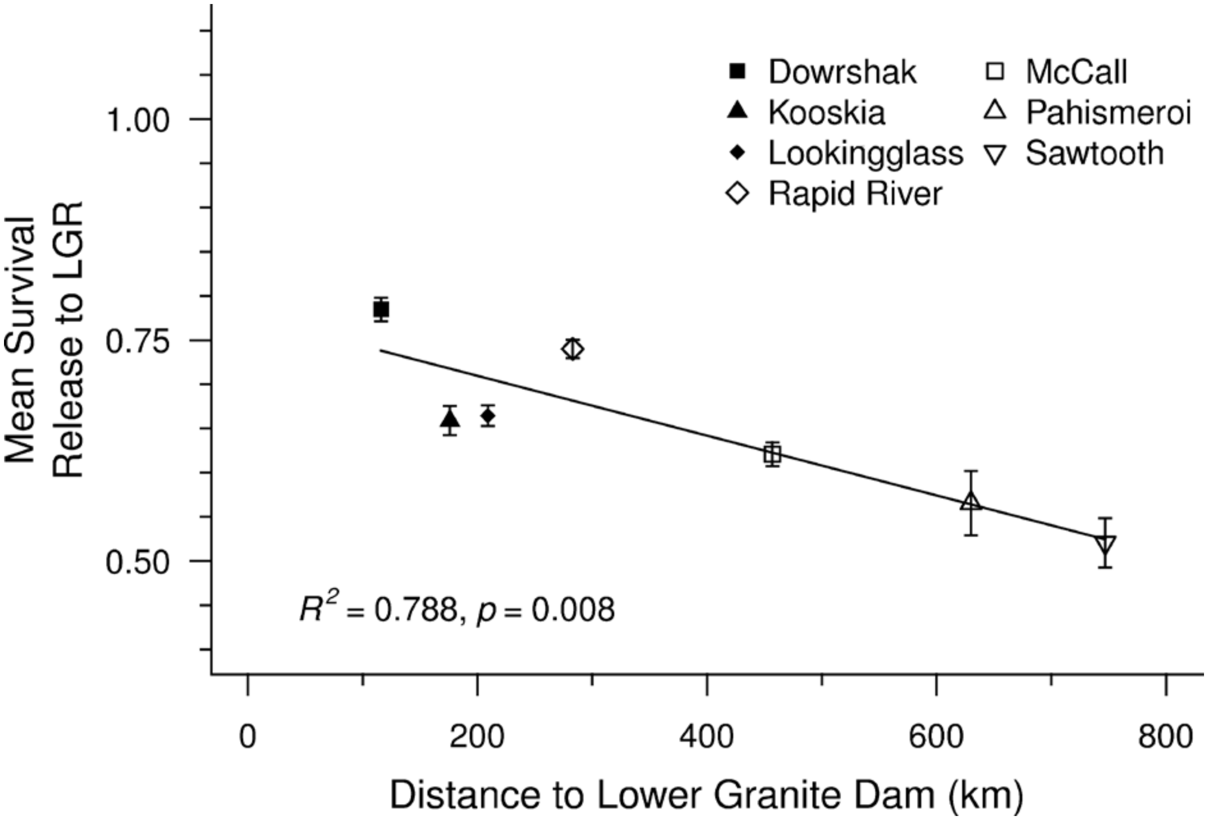


Figure 7. Mean estimated survival from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2017 vs. distance (km) to Lower Granite Dam. The coefficient of determination between survival and migration distance is also shown, along with a *P*-value for a test of the null hypothesis of zero correlation. Whiskers show standard errors.

Table 25. Annual weighted means of survival probability estimates for yearling Chinook salmon (hatchery and wild combined), 1995–2017. 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 are given across all available years (1993-2017).

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	NA	NA	NA
1996	0.977 (0.025)	0.926 (0.006)	0.929 (0.011)	0.756 (0.033)	0.870	NA	NA	NA
1997	NA	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.893	NA	NA	NA
1998	0.925 (0.009)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)	NA	NA
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
2015	0.909 (0.103)	0.928 (0.031)	0.960 (0.057)	0.785 (0.032)	0.886	0.724 (0.069)	0.937 (0.160)	0.968
2016	0.936 (0.015)	0.956 (0.006)	0.912 (0.010)	0.872 (0.013)	0.934	0.796 (0.039)	0.871 (0.047)	0.933
2017	NA	0.916 (0.009)	0.908 (0.013)	0.912 (0.024)	0.956	0.720 (0.041)	0.871 (0.200)	0.933
Mean	**0.932 (0.008)**	**0.927 (0.007)**	**0.922 (0.009)**	**0.863 (0.012)**	**0.928 (0.007)**	**0.865 (0.019)**	**0.809 (0.025)**	**0.898 (0.014)**

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), 1997–2017. Standard errors in parentheses. Simple arithmetic means are given; for Trap-LGR the mean is for 1993-2016, for LGR-MCN the mean is for 1995-2017.

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 (0.009)	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)
2015	0.909 (0.103)	0.727 (0.033)	0.629 (0.043)	0.457 (0.037)	0.415 (0.058)
2016	0.936 (0.015)	0.752 (0.011)	0.672 (0.060)	0.505 (0.046)	0.473 (0.043)
2017	NA	0.743 (0.019)	0.643 (0.157)	0.478 (0.117)	NA
Mean	**0.932 (0.008)**	**0.738 (0.012)**	**0.700 (0.020)**	**0.526 (0.020)**	**0.495 (0.020)**

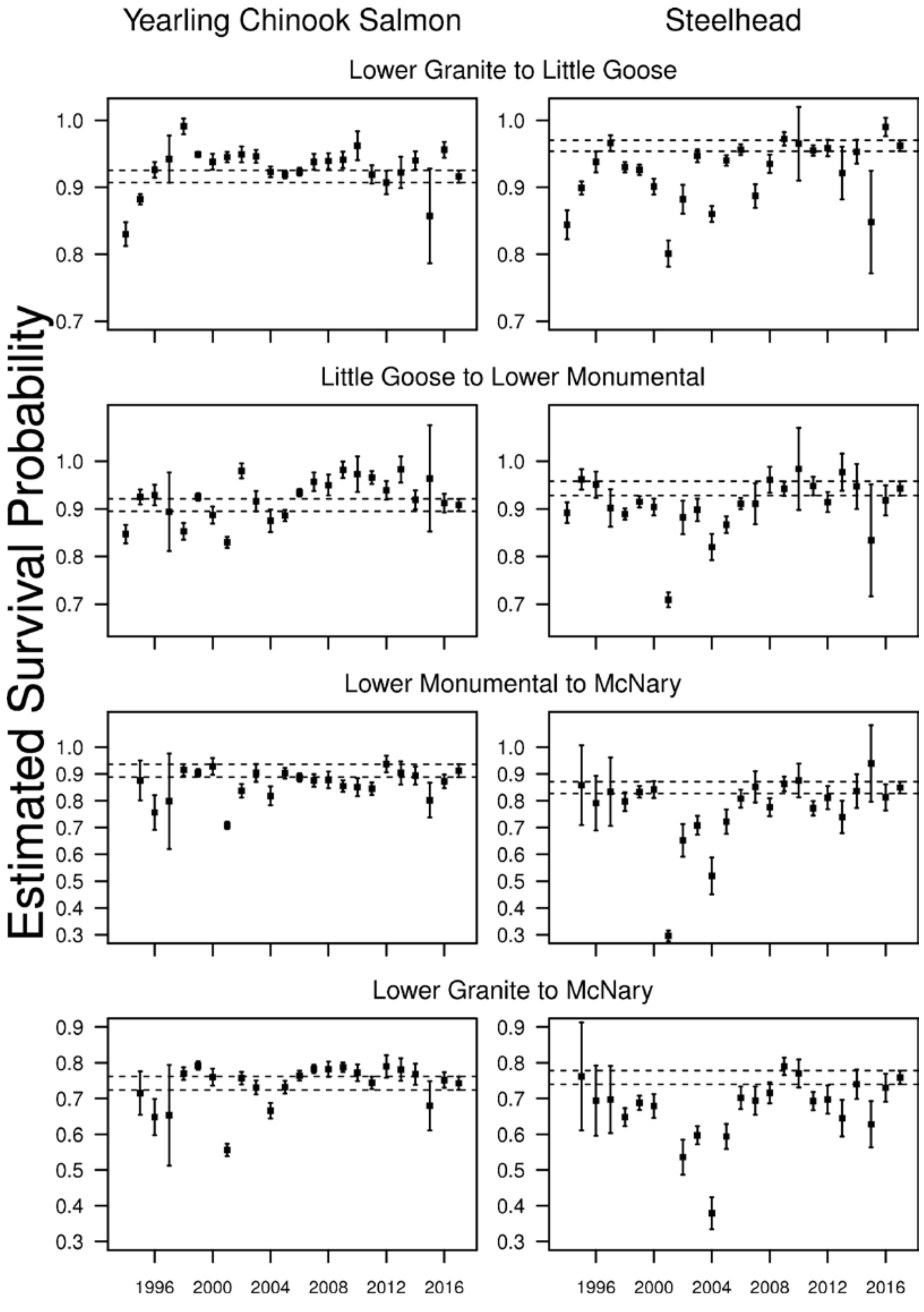


Figure 8. Annual weighted mean survival estimates for PIT-tagged yearling Chinook salmon and steelhead (hatchery and wild combined) through Snake River reaches, 1993-2017. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2017 estimates.

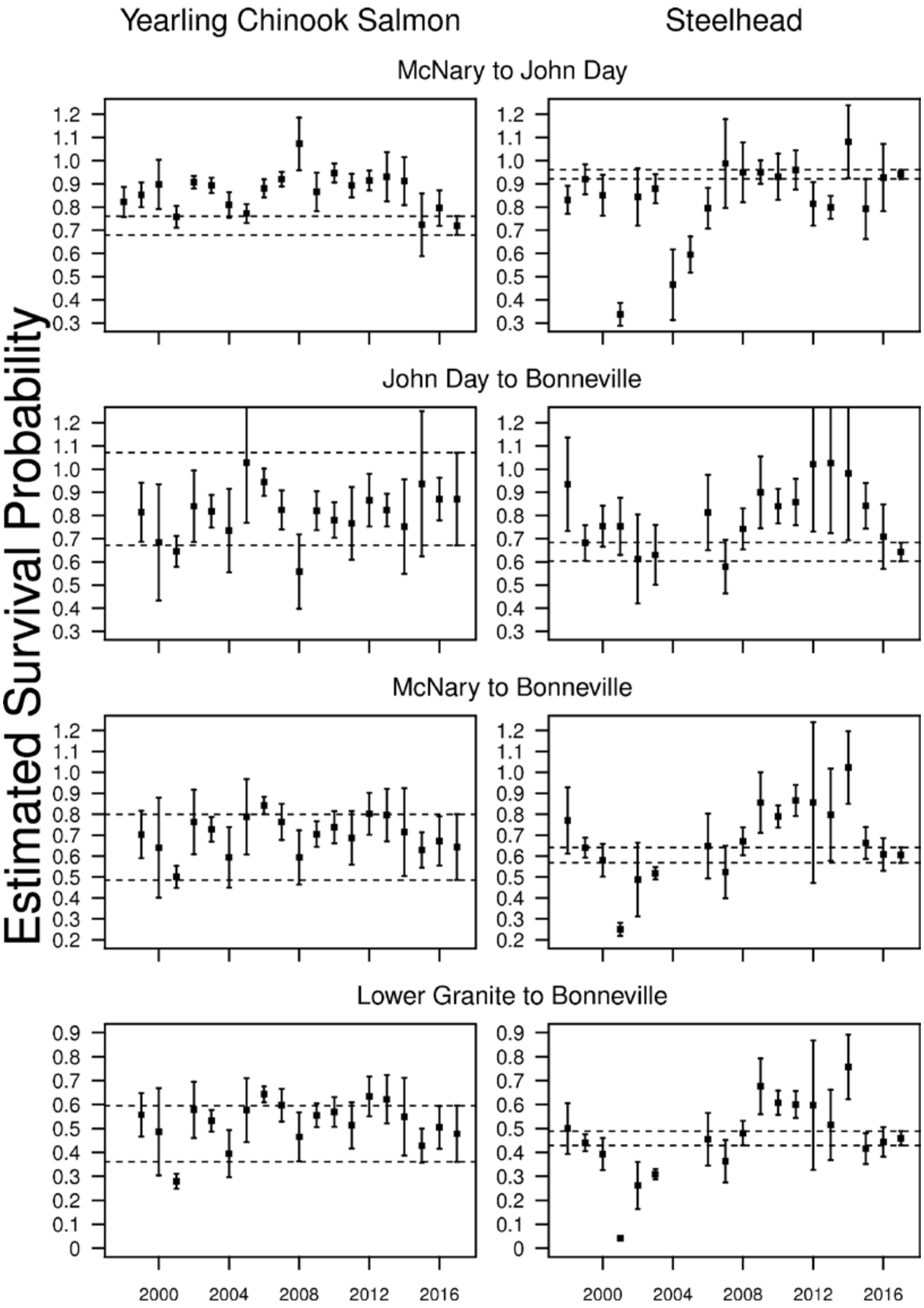


Figure 9. Annual weighted mean survival estimates for PIT-tagged Snake River yearling Chinook salmon and steelhead (hatchery and wild combined) through Columbia River reaches and from Lower Granite Dam to Bonneville Dam, 1993-2017. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2017 estimates.

Because the Snake River Trap was not operated in 2017, we were not able to estimate survival through the entire hydrosystem. Instead, we estimated survival from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam. For combined wild and hatchery yearling Chinook salmon in 2017, mean estimated survival from Lower Granite to Bonneville Dam was 0.478 (0.249-0.707; Table 26). This estimate was slightly below both the 21-year mean of 0.526 (1997-2017) and the 2016 mean of 0.505. However, the difference between estimates in 2016 and 2017 was not significant ($P = 0.83$).

For wild yearling Chinook salmon in 2017, mean estimated survival was 0.709 (95% CI 0.670-0.748) from Lower Granite to McNary Dam; this estimate was close to the long-term average of 0.728. However, survival of these fish from McNary to Bonneville Dam was 0.436 (0.313-0.559), which was below the long-term average of 0.650 (Table 27). For these wild fish, the estimated survival from Lower Granite to Bonneville Dam of 0.309 (0.221-0.397) was below the long-term average of 0.476 and was among the lowest of our time series.

Steelhead—For combined wild and hatchery steelhead, mean estimated survival was 0.759 (95% CI 0.722-0.796) from Lower Granite to McNary Dam. For combined steelhead in this reach, this estimate was higher than both the estimate in 2016 and the long-term average of 0.657. However, in the reach from McNary to Bonneville, estimated survival in 2017 was 0.605 (0.533-0.678), which was very close to the 2016 estimate of 0.608 but slightly below the long-term average of 0.674 (Tables 28-29; Figures 8-9).

Estimated survival from Lower Granite to Bonneville Dam for these steelhead was 0.459 (0.400-0.518; Table 29), which was similar to the long-term average of 0.466 and to the corresponding estimate in 2016 (0.444). The difference between estimates in 2016 and 2017 was not statistically significant ($P = 0.73$).

For wild steelhead in 2017, mean estimated survival from Lower Granite to McNary Dam was 0.723 (0.647-0.799), and was above the long-term average of 0.647 (Table 30). Estimated survival from McNary to Bonneville Dam was 0.413 (0.299-0.527), which was below the long-term average of 0.610 for these fish. For these wild steelhead, estimated survival from Lower Granite to Bonneville Dam was 0.299 (0.211-0.387) in 2017, which was also below the long-term average of 0.417.

Table 27. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling Chinook salmon (wild only) 1999–2017. Standard errors in parentheses. Simple arithmetic means are given; for Trap-LGR and LGR-MCN the mean extends back to 1998.

	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)
2015	0.867 (0.192)	0.647 (0.058)	0.843 (0.106)	0.545 (0.084)	0.473 (0.127)
2016	0.957 (0.019)	0.703 (0.017)	0.490 (0.095)	0.344 (0.067)	0.330 (0.065)
2017	NA	0.709 (0.020)	0.436 (0.063)	0.309 (0.045)	NA
Mean	**0.918 (0.012)**	**0.728 (0.015)**	**0.650 (0.034)**	**0.476 (0.029)**	**0.445 (0.027)**

Table 28. Annual weighted means of survival probability estimates for steelhead (hatchery and wild combined), 1995–2017. 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 (1993–2017) 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	NA	NA	NA
1996	0.951 (0.015)	0.938 (0.008)	0.951 (0.014)	0.791 (0.052)	0.889	NA	NA	NA
1997	0.964 (0.015)	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.913	NA	NA	NA
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
2015	0.874 (0.046)	1.017 (0.028)	0.829 (0.059)	0.923 (0.071)	0.961	0.792 (0.066)	0.842 (0.050)	0.918
2016	0.998 (0.016)	0.990 (0.007)	0.918 (0.016)	0.813 (0.025)	0.902	0.927 (0.074)	0.709 (0.071)	0.842
2017	NA	0.962 (0.008)	0.943 (0.015)	0.849 (0.022)	0.921	0.941 (0.020)	0.643 (0.040)	0.802
Mean	**0.950 (0.011)**	**0.929 (0.010)**	**0.907 (0.012)**	**0.773 (0.028)**	**0.875 (0.018)**	**0.833 (0.040)**	**0.796 (0.033)**	**0.889 (0.019)**

Table 29. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River steelhead (hatchery and wild combined), 1997–2017. Standard errors in parentheses. Simple arithmetic means are given; for Trap-LGR the mean is for 1993-2016, for LGR-MCN the mean is for 1995-2017.

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	0.964 (0.015)	0.728 (0.053)	0.651 (0.082)	0.474 (0.069)	0.457 (0.067)
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)
2015	0.874 (0.046)	0.733 (0.027)	0.663 (0.039)	0.486 (0.034)	0.425 (0.037)
2016	0.998 (0.016)	0.730 (0.020)	0.608 (0.040)	0.444 (0.032)	0.443 (0.032)
2017	NA	0.759 (0.019)	0.605 (0.037)	0.459 (0.030)	NA
Mean	**0.950 (0.011)**	**0.657 (0.029)**	**0.674 (0.040)**	**0.466 (0.036)**	**0.453 (0.040)**

Table 30. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River steelhead (wild only), 1999–2017. Standard errors in parentheses; simple arithmetic means are given; for Trap-LGR and LGR-MCN the mean extends back to 1998.

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)
2015	0.867 (0.139)	0.741 (0.080)	0.608 (0.051)	0.451 (0.062)	0.390 (0.082)
2016	0.958 (0.037)	0.644 (0.053)	0.436 (0.043)	0.281 (0.036)	0.269 (0.036)
2017	NA	0.723 (0.039)	0.413 (0.058)	0.299 (0.045)	NA
Mean	**0.961 (0.012)**	**0.647 (0.033)**	**0.610 (0.048)**	**0.417 (0.038)**	**0.408 (0.040)**

Sockeye Salmon—For pooled groups of wild and hatchery Snake River sockeye salmon, estimated survival from Lower Granite to McNary Dam was 0.544 in 2017 (95% CI 0.407-0.727; Table 31). This estimate was similar to the 2016 estimate of 0.523, but lower than the average of 0.625 for 1996-2017. For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.176 (0.097-0.320) in 2017. This estimate was the fourth lowest of our time series through this reach, and was well below the 1996-2017 average of 0.392.

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, 1996–2017. 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)
2015	0.702 (0.054)	0.531 (0.151)	0.373 (0.037)
2016	0.523 (0.047)	0.227 (0.059)	0.119 (0.030)
2017	0.544 (0.081)	0.324 (0.107)	0.176 (0.055)
Mean	**0.625 (0.036)**	**0.544 (0.071)**	**0.392 (0.053)**

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)
2015	0.763 (0.182)	0.446 (0.200)	0.340 (0.130)
2016	0.807 (0.082)	0.545 (0.126)	0.448 (0.144)
2017	0.719 (0.113)	0.611 (0.181)	0.500 (0.332)
Mean	**0.673 (0.032)**	**0.723 (0.078)**	**0.503 (0.055)**

Upper Columbia River Stocks

Sockeye Salmon—For Upper Columbia River sockeye salmon captured and tagged at Rock Island Dam, and released to the tailrace of the dam in 2017, estimated survival to McNary tailrace was 0.719 (95% CI 0.529-0.977; Table 31). This estimate was higher than the long-term average of 0.673, but lower than the 2016 estimate of 0.807. Estimated survival of sockeye from Rock Island to Bonneville Dam was 0.500 (0.153-1.635). This estimate was close to the mean of 0.503, but imprecise due to low detection probabilities at McNary and Bonneville Dam and in the pair trawl.

Yearling Chinook Salmon—For pooled groups of yearling Chinook from Upper Columbia River hatcheries, estimated survival from McNary tailrace to Bonneville tailrace was 0.944 (0.737-1.210). This estimate was above the 1999-2017 average of 0.818 for that reach (Table 32). However, as has often been the case for this reach, the estimate was imprecise due to low detection rates at McNary and Bonneville Dam and in the pair trawl.

Steelhead—For pooled groups of hatchery steelhead from Upper Columbia hatcheries, estimated survival from McNary to Bonneville tailrace in 2017 was 0.964 (0.660-1.408). This estimate was well above the long-term average of 0.747; however, as with the other two species, low detection rates at McNary and Bonneville Dam and in the pair trawl resulted in significant uncertainty (Table 32).

Table 32. Mean estimated survival and standard error (SE) through the lower Columbia River for hatchery yearling Chinook salmon (1999–2017) and steelhead (2003–2017) originating in the upper Columbia. Data for steelhead estimates were not available prior to 2003. Multiple release sites were used in each year and were not always consistent among years.

	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)
2015	0.512 (0.015)	0.843 (0.043)	1.032 (0.081)	0.870 (0.062)
2016	0.610 (0.009)	0.857 (0.027)	0.942 (0.068)	0.807 (0.055)
2017	0.582 (0.013)	0.853 (0.030)	1.107 (0.142)	0.944 (0.120)
Mean	**0.557 (0.012)**	**0.899 (0.023)**	**0.904 (0.044)**	**0.818 (0.033)**
	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)
2015	0.351 (0.019)	0.807 (0.084)	0.707 (0.073)	0.570 (0.043)
2016	0.416 (0.011)	0.771 (0.037)	0.633 (0.046)	0.487 (0.032)
2017	0.437 (0.025)	0.880 (0.062)	1.095 (0.210)	0.964 (0.188)
Mean	**0.419 (0.015)**	**0.894 (0.031)**	**0.846 (0.055)**	**0.747 (0.045)**

Comparison Among Snake and Columbia River Stocks

In 2017, estimated survival from McNary to Bonneville tailrace was lower for hatchery and wild spring/summer Chinook originating in the Snake River (0.643; 95% CI 0.335-0.951; Table 33) than for those originating in the Upper Columbia River Basin (0.978; 0.779-1.228), and the difference was marginally significant ($P = 0.08$).

Similarly, for hatchery and wild steelhead migrating in this same reach during 2017, estimated survival was lower for Snake (0.605; 0.533-0.678; Table 33) than for Upper Columbia River fish (0.951; 0.699-1.253), and the difference was statistically significant ($P = 0.02$).

For hatchery and wild sockeye salmon, estimated survival from McNary to Bonneville tailrace was lower for stocks originating in the Snake (0.324; 0.172-0.609) than in the Upper Columbia River Basin (0.620; 0.352-1.092), but the difference was not statistically significant ($P = 0.13$) due to the imprecision of the estimates.

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 2017. 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	17,523	0.720 (0.041)	0.871 (0.200)	0.643 (0.157)
Upper Columbia Chinook	Upper Columbia sites[a]	197,917	0.878 (0.027)	1.114 (0.131)	0.978 (0.114)
Upper Columbia Chinook	Yakima River sites[b]	46,246	0.860 (0.050)	0.841 (0.189)	0.724 (0.160)
Upper Columbia Coho	Upper Columbia sites	49,094	0.949 (0.070)	0.759 (0.162)	0.720 (0.152)
Upper Columbia Coho	Yakima River sites	14,412	1.237 (0.178)	0.425 (0.164)	0.525 (0.196)
Snake River Sockeye	Snake River sites[c]	50,682	0.723 (0.142)	0.448 (0.151)	0.324 (0.107)
Upper Columbia Sockeye	Upper Columbia sites	15,153	0.870 (0.117)	0.713 (0.215)	0.620 (0.183)
Snake River Steelhead	Snake River sites[c]	234,034	0.941 (0.020)	0.643 (0.040)	0.605 (0.037)
Upper Columbia Steelhead	Upper Columbia sites	72,434	0.904 (0.050)	1.052 (0.164)	0.951 (0.150)

[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

Because of high flows, the Snake River Trap was not operated in 2017, and comparisons to previous years we make here will use estimates from Lower Granite tailrace to Bonneville Dam tailrace rather than from the trap to Bonneville. For Snake River yearling Chinook salmon in 2017, estimated survival from Lower Granite to Bonneville Dam was 47.8% and was below the long-term average of 52.4% (1999-2017). For wild Snake River Chinook salmon, overall mean estimated survival from Lower Granite to Bonneville Dam was 30.9%. This estimate was considerably lower than the long-term average of 47.6% and was among the lowest of our time series.

For combined hatchery and wild steelhead in 2017, estimated survival from Lower Granite to Bonneville Dam was 45.9% and was only slightly below the long-term mean of 46.3%. However, 2017 was the third consecutive year with below-average estimated survival for Snake River steelhead. These low estimates followed seven consecutive years of survival estimates of 48% or higher. For wild steelhead, mean estimated survival through the entire hydrosystem was 29.9% in 2017, an estimate considerably lower than the long-term average of 41.7%.

For various stocks, including Snake river Chinook salmon and steelhead, survival in 2017 was below average from McNary to Bonneville Dam but not through the rest of the hydropower system. For Snake River Chinook and steelhead, survival between McNary and Bonneville Dam was below average for both wild fish and for wild and hatchery fish combined. Survival was also below average in this reach for both Columbia River and Snake River sockeye. However, both Columbia River Chinook and Columbia River steelhead had higher than average survival between McNary and Bonneville Dam. It is not clear exactly what was to blame for these low estimates of survival in the lower Columbia River, or why upper Columbia River stocks of Chinook and steelhead showed a different pattern than Snake River stocks.

Estimated survival of Snake River sockeye between Lower Granite and Bonneville Dam was 17.6%; this was the fourth lowest estimate in our time series (1998-2017). Survival estimates for the component reaches from Lower Granite to McNary and from McNary to Bonneville Dam were both low. Thus, 2017 was the third consecutive year with below-average survival for Snake River sockeye.

Low survival estimates for Snake River sockeye in the past three years have been primarily evident for fish from Springfield Hatchery, which first reared sockeye in 2015. Since Springfield Hatchery started operations, sockeye reared there have displayed poor survival. In 2017, estimated survival to McNary Dam was only 8% for Springfield hatchery fish release at the Redfish Lake Creek trap

Additionally, high rates of fungal infection have been reported among juvenile sockeye entering the bypass systems at both Lower Granite and Little Goose Dam (Fish Passage Advisory Committee notes, 26 May 2016). Researchers at the Idaho Department of Fish and Game (IDFG) have been investigating potential causes of the high infection rates and aforementioned poor survival. Their research indicates that differences in water chemistry between Springfield Hatchery and the release location at Redfish Lake Creek may be a major factor. The IDFG plans to adjust operations in future years to reduce the stress of acclimating fish to conditions at Redfish Lake Creek (Allen et al. 2017).

Environmental conditions in 2017 resulted in a year with average water temperatures but very high flow and spill throughout the migration season. Mean flow in the Snake River was far above average for the entire migration season; over our entire period of record (1993-2017) higher flow was observed only in 1997.

Spill percentages and spill discharge levels were well above average for the entire migration season; 2017 was the year with the highest mean spill percent and mean spill discharge on record. These high spill levels resulted in very low detection probability at McNary and Bonneville Dam, which reduced the precision of our survival estimates in the lower Columbia River.

Water temperatures in the Snake and Columbia Rivers were close to average throughout the season, with daily temperatures oscillating between slightly above and slightly below the long-term daily mean.

For both yearling Chinook salmon and steelhead, median estimated travel time between Lower Granite and Bonneville Dam was shorter in April 2017 than in any other year in our time series (1998-2017). These short travel times coincided with high levels of flow and spill, and because flows remained high for the entire migration period, travel time remained shorter than the long-term mean through June.

Since the institution of court-ordered spill in 2006 and the installation of surface collectors at four additional dams, average travel time between Lower Granite and Bonneville Dam has decreased for steelhead, but not as much for Chinook. Travel times are not influenced as strongly by flow as they once were; since 2006, travel time in low-flow years has been more similar to travel times in medium and high-flow years for both yearling Chinook and steelhead. Day of year is now a stronger predictor of travel time for yearling Chinook than either flow or spill.

Before the new spill regime, some of the lowest flow years were also low spill years. Therefore, the effect of average flow on travel time is difficult to separate from that of spill without the assistance of a statistical model. Flow and spill also vary within seasons, so comparisons of annual flow or spill do not provide much insight into differences in travel time, although they do allow for simple visual comparison of overall differences among years.

Decreased forebay delay and overall shortened travel times experienced since 2006 can potentially decrease exposure to the elevated water temperatures that may occur late in spring or early summer. In steelhead, warmer water can trigger smolt reversion to the parr stage, which is 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.

Suspended migration may influence survival estimates because a PIT-tagged smolt that ceases migration will not be detected at further downstream dams. The statistical models for PIT-tag data cannot distinguish between mortality and reversion to parr. If significant numbers of fish revert to parr, survival estimates will be biased downward.

Parr reversion 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). Yet in May 2015, temperatures were well in excess of 13°C, but estimated survival did not decline as it did in 2001. Reduced travel times associated with surface passage may have alleviated a tendency toward parr reversion that would otherwise have been more pronounced for steelhead confronted with the high temperatures of 2015.

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 recently harbored the second largest Caspian tern *Hydroprogne caspia* colony in North America, with an annual average of about 500 breeding pairs from 2000 through 2014. The island also has 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.*

Starting in 2015 and continuing through 2017, passive and active dissuasion measures were employed on the Crescent Island Caspian tern colony. These efforts resulted in elimination of nesting at that location. However, terns attempted to relocate these colonies or join others within the mid-Columbia basin such as the Blalock Islands colony in John Day Pool (Roby et al. 2016). In 2017, the relocated colony on the Blalock Islands was about the same size as the original colony on Crescent Island (RTR 2017).

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. On the same colonies, they found only 2% of the PIT-tags from yearling Chinook salmon detected at Bonneville Dam. Evans et al. (2015) found that avian predation probabilities in the lower Columbia River were two to four times higher for juvenile steelhead than for juvenile yearling Chinook.

We complied an index of percentages of PIT-tags detected at Lower Monumental Dam that were subsequently detected on bird colonies (Table 34). Based on this index, the proportions of PIT-tagged steelhead lost to piscivorous birds in 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).

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 and expanded use of surface passage at Snake River dams (all 4 dams since 2009).

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.

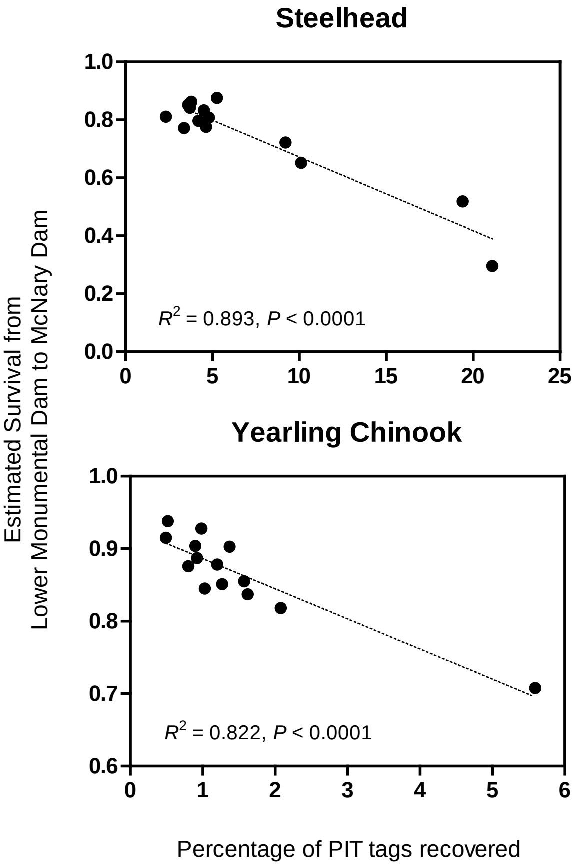


Figure 10. Estimated survival between Lower Monumental and McNary Dam vs. percentage of PIT-tags recovered on bird colonies from fish detected at Lower Monumental Dam, 1998-2012 (excluding 2003, which had incomplete recovery effort).

Piscivorous fish also contribute significantly to mortality of migrating Chinook salmon and steelhead smolts (Rieman et al. 1991). Reservoir-dwelling fish species 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. More recently, Porter (2012) reported that salmonid smolts accounted for 15% of identifiable prey items recovered from pikeminnow stomachs.

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. In recent years, abundance estimates for large fish have been only one-tenth those in 1990 (Porter 2012).

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2017 were the second lowest recorded in our time series of estimates (1993-2017). This was mostly because both species arrived in large proportions before the start of transportation: collection probabilities at collector dams were not unusually low during 2017 transportation operations.

Detection probabilities at dams have been lower in general since 2007, when programs were instituted at most dams to encourage spillway passage using increased spill and surface-passage structures. There is evidence that surface spill is disproportionately attractive to fish at lower flow levels. This combination of low flow and greater use of spill results in a higher proportion of fish passing through spillways, with a lower proportion entering juvenile bypass systems where PIT tags can be detected.

For survival estimates based on PIT-tag data, effective sample size is a result of both numbers of PIT-tagged fish migrating and detection rates during migration. Reduced sample sizes have become common in recent years as reliance on use of spill and surface passage has increased. 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, juvenile bypass systems provide the only dam-passage route for which PIT-tag monitoring technology is 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 degraded as a result of reduced probabilities of PIT-tag detection. Three consequences of reduced detection probabilities are:

1) Reduced certainty in survival estimates; 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 sampling variability will result in estimates that are 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 reaches from McNary to John Day and from John Day to Bonneville Dam, the two furthest downstream reaches for which we can estimate smolt survival within the migration corridor.

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 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.

If detection rates remain low, precision in survival estimates can be increased only by releasing larger numbers of tagged fish to the system. Unfortunately, this option would increase both the cost of monitoring and the burden on an already stressed biological resource. Therefore, assuming the emphasis on spillway passage will continue, the best option for retaining or increasing precision in survival estimates is to increase rates of detection by installing PIT-tag monitoring systems in additional fish-passage routes.

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 and can introduce bias to estimates of travel time. Detection capability in multiple passage routes will reduce this type of variation. Expanded monitoring ability will also advance our understanding of passage-route distributions 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. Higher rates of detection will provide larger sample sizes for estimates with increased statistical power without additional marking. Furthermore, detection of fish passing multiple routes will reduce the possibility of bias introduced if survival is not equal between detected and non-detected 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 estimation, the highest priority for new PIT-tag monitoring systems are the spillway(s) at Bonneville Dam and the surface-passage structures at 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 from the pair-trawl detection system operated in the estuary downstream from Bonneville Dam. However, rates of detection in the trawl are relatively low at present.

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

Lower Granite Dam and McNary Dam are important “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 an important research tool that yields a great deal of valuable information that cannot be obtained using any other tagging method. For example, the PIT tag allows monitoring of large numbers of individual fish through both the juvenile and adult migration. It is the only tagging method that allows direct 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 survival for juvenile salmonids passing Snake and Columbia River dams.

   High rates of spill and the use of surface-passage structures (RSWs, TSWs) in recent years have resulted in low detection rates and consequently reduced the value of information gained from existing PIT-tagging programs throughout the region.

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 dams with 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 during the migration year (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., guidance efficiency) 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 2017 there were more significant ($\alpha = 0.05$) tests than expected by chance alone (5%) for steelhead and also for yearling Chinook salmon (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 13 steelhead groups, the overall test was significant 3 times (23%). Counting all individual component tests (i.e., 2.C2, 3.SR3, etc.), 6 tests out of 50 (12%) were significant for yearling Chinook salmon and 11 out of 65 (17%) were significant for steelhead (Appendix Tables A1-A3). There is a 3.8% chance of 6 or more tests out of 50 being significant if the true $\alpha = 0.05$, and a 0.04% chance of 11 or more significant tests out of 65. This provides evidence that the results for both Chinook and steelhead indicate a significant number of assumption violations that cannot be explained by chance alone.

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, 9 of the 17 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.

For Chinook, the significant Test 2 results (all C2) were split, with one test showing fish detected at Little Goose Dam were less likely to be detected again downstream, and another test showing fish detected at Little Goose Dam were more likely to be detected below McNary Dam. For steelhead, all of the 3 significant Test 2.C2 tests showed that fish detected at Little Goose Dam were less likely to be detected downstream, while all of the 4 significant Test 2.C3 tests showed fish detected at Lower Monumental Dam were more likely to be detected at McNary Dam.

For weekly groups from McNary Dam, there was one significant contingency table test result for yearling Chinook out of 9 component tests (11%). The significant test for Chinook was for test C2, with results showing that fish detected at John Day Dam were less likely to be detected at Bonneville Dam than fish not detected at John Day Dam.

For steelhead, one of the three (33%) component tests was significant (Appendix Tables A4-A6). The significant test for steelhead was for Test 2.C2, with results showing that fish detected at John Day Dam were more likely to be detected at Bonneville Dam than fish not detected at John Day Dam. Low detection probabilities led to reduced power of these tests to detect significant differences when present, especially for steelhead. Therefore, a lack of significant results did not necessarily indicate that assumptions were met.

Discussion

We believe that inherent differences in detectability (guidance efficiency) of fish within a release group are the most likely cause of the patterns we observed in contingency table tests in 2017, as in previous years. Zabel et al. (2002, 2005) provided evidence of inherent differences related to length of fish at tagging, and similar observations were made in 2017 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). However, the fact that fish detected at an upstream site are not consistently more likely to be detected at downstream sites offers evidence against the idea that size selection is the only mechanism driving the assumption violations.

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 Dam 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 consecutive 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, 2017.

		Species		
Test		Chinook	Steelhead	Total
Test 2.C2	Tests (n)	10	13	23
	Significant tests (n)	2	3	5
Test 2.C3	Tests (n)	10	13	23
	Significant tests (n)	0	4	4
Test 3.SR3	Tests (n)	10	13	23
	Significant tests (n)	1	2	3
Test 3.Sm3	Tests (n)	10	13	23
	Significant tests (n)	2	2	4
Test 3.SR4	Tests (n)	10	13	23
	Significant tests (n)	1	0	1
Test 2 sum	Tests (n)	10	13	23
	Significant tests (n)	2	5	7
Test 3 sum	Tests (n)	10	13	23
	Significant tests (n)	1	2	3
Test 2 + 3	Tests (n)	10	13	23
	Significant tests (n)	3	3	6

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 2017.

	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	8.56	0.200	1.14	0.767	1.07	0.587	0.08	0.784
30 Mar–5 Apr	5.82	0.444	4.79	0.188	4.67	0.097	0.12	0.729
6 Apr–12 Apr	4.49	0.611	3.63	0.304	1.42	0.492	2.21	0.137
13 Apr–19 Apr	12.76	**0.047**	8.54	**0.036**	8.54	**0.014**	0.01	0.936
20 Apr–26 Apr	4.82	0.567	4.25	0.236	1.15	0.563	3.10	0.078
27 Apr–3 May	22.08	**0.001**	5.80	0.122	5.20	0.074	0.61	0.436
4 May–10 May	4.46	0.615	1.82	0.610	1.77	0.414	0.06	0.812
11 May–17 May	18.37	**0.005**	14.37	**0.002**	12.62	**0.002**	1.75	0.186
18 May–24 May	2.87	0.825	1.90	0.594	0.66	0.717	1.23	0.267
25 May–31 May	0.88	0.990	0.03	0.999	0.01	0.997	0.02	0.876
Total (df)	85.09 (60)	**0.018**	46.28 (30)	**0.029**	37.10 (20)	**0.011**	9.18 (10)	0.515

	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	7.42	0.060	0.07	0.799	4.41	**0.036**	2.94	0.087
30 Mar–5 Apr	1.02	0.796	0.48	0.487	0.54	0.465	0.00	0.949
6 Apr–12 Apr	0.86	0.835	0.79	0.373	0.07	0.794	0.00	0.996
13 Apr–19 Apr	4.22	0.239	1.12	0.289	0.21	0.645	2.89	0.089
20 Apr–26 Apr	0.57	0.903	0.36	0.548	0.16	0.689	0.05	0.822
27 Apr–3 May	16.27	**0.001**	5.30	**0.021**	6.53	**0.011**	4.43	**0.035**
4 May–10 May	2.63	0.452	0.64	0.423	0.05	0.818	1.94	0.164
11 May–17 May	4.00	0.262	1.17	0.279	1.17	0.279	1.65	0.199
18 May–24 May	0.97	0.808	0.07	0.789	0.20	0.655	0.70	0.402
25 May–31 May	0.85	0.838	0.82	0.367	0.00	0.961	0.03	0.865
Total (df)	38.81 (30)	0.130	10.83 (10)	0.371	13.35 (10)	0.205	14.63 (10)	0.146

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 2017.

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
23 Mar–29 Mar	2.82	0.831	1.25	0.741	0.57	0.752	0.68	0.410
30 Mar–5 Apr	4.11	0.662	0.96	0.812	0.89	0.642	0.07	0.789
6 Apr–12 Apr	11.00	0.088	10.03	**0.018**	4.02	0.134	6.00	**0.014**
13 Apr–19 Apr	22.89	**0.001**	8.53	**0.036**	0.30	0.862	8.23	**0.004**
20 Apr–26 Apr	8.51	0.203	1.18	0.759	0.58	0.747	0.59	0.441
27 Apr–3 May	7.80	0.253	6.86	0.076	6.82	**0.033**	0.04	0.843
4 May–10 May	29.47	**<0.001**	10.56	**0.014**	2.92	0.232	7.64	**0.006**
11 May–17 May	9.15	0.165	4.81	0.186	3.57	0.168	1.24	0.265
18 May–24 May	18.89	**0.004**	12.74	**0.005**	12.59	**0.002**	0.15	0.700
25 May–31 May	8.63	0.196	7.91	**0.048**	6.30	**0.043**	1.61	0.204
1 Jun–7 Jun	12.36	0.054	7.45	0.059	0.49	0.782	6.96	**0.008**
8 Jun–14 Jun	6.93	0.327	5.77	0.124	4.23	0.121	1.54	0.215
15 Jun–21 Jun	3.32	0.768	1.62	0.654	0.79	0.674	0.83	0.361
Total (df)	145.89 (78)	**<0.001**	79.66 (39)	**<0.001**	44.07 (26)	**0.015**	35.58 (13)	**<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
23 Mar–29 Mar	1.57	0.666	1.04	0.307	0.11	0.744	0.42	0.515
30 Mar–5 Apr	3.15	0.368	0.37	0.542	0.31	0.578	2.47	0.116
6 Apr–12 Apr	0.98	0.806	0.40	0.530	0.00	0.963	0.58	0.445
13 Apr–19 Apr	14.36	**0.002**	9.97	**0.002**	2.77	0.096	1.63	0.202
20 Apr–26 Apr	7.33	0.062	5.00	**0.025**	1.99	0.158	0.34	0.561
27 Apr–3 May	0.94	0.816	0.00	0.961	0.36	0.549	0.58	0.447
4 May–10 May	18.91	**<0.001**	0.03	0.871	18.88	**<0.001**	0.00	0.976
11 May–17 May	4.34	0.227	0.55	0.459	0.80	0.371	2.99	0.084
18 May–24 May	6.15	0.104	0.22	0.639	4.16	**0.042**	1.78	0.182
25 May–31 May	0.72	0.868	0.19	0.666	0.50	0.478	0.03	0.860
1 Jun–7 Jun	4.91	0.179	1.86	0.173	1.58	0.208	1.47	0.226
8 Jun–14 Jun	1.17	0.761	0.38	0.537	0.18	0.675	0.61	0.435
15 Jun–21 Jun	1.70	0.638	0.49	0.484	0.05	0.825	1.16	0.282
Total (df)	66.23 (39)	**0.004**	20.49 (13)	0.084	31.68 (13)	**0.003**	14.06 (13)	0.370

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, 2017.

	Test 2.C2		Test 3.SR3		Test 2 + 3	
Species	No.	sig.	No.	sig.	No.	sig.
Chinook	6	1	3	0	6	1
Steelhead	3	1	0	0	3	1
Total	9	2	3	0	9	2

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 2017.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
13 Apr–19 Apr	2.74	0.254	0.64	0.425	2.10	0.147
20 Apr–26 Apr	1.51	0.470	1.13	0.288	0.38	0.538
27 Apr–3 May	6.90	**0.032**	6.79	**0.009**	0.12	0.730
4 May–10 May	1.91	0.167	1.91	0.167	-	-
11 May–17 May	0.40	0.528	0.40	0.528	-	-
18 May–24 May	0.41	0.522	0.41	0.522	-	-
25 May–31 May	-	-	-	-	-	-
Total (df)	13.87 (12)	0.309	11.27 (6)	0.080	2.60 (3)	0.458

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 2017.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
21 Apr–4 May	0.187	0.666	0.187	0.666	-	-
5 May–18 May	4.125	**0.042**	4.125	**0.042**	-	-
19 May–1 Jun	0.006	0.937	0.006	0.937	-	-
Total (df)	4.32 (3)	0.229	4.32 (3)	0.229	-	-

Appendix B: Survival and Detection Data from Individual Hatcheries and Traps

Appendix Table B1. Estimated survival probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2017. 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						
Dworshak NFH	17,066	0.802 (0.015)	0.867 (0.024)	0.860 (0.036)	0.924 (0.059)	0.552 (0.029)
Kooskia	9,585	0.791 (0.017)	0.925 (0.030)	0.917 (0.050)	0.910 (0.082)	0.610 (0.046)
Powell Pond	25,466	0.621 (0.010)	0.890 (0.021)	0.892 (0.033)	0.970 (0.058)	0.478 (0.024)
Red River Pond	17,082	0.509 (0.015)	0.875 (0.043)	1.025 (0.075)	0.927 (0.100)	0.423 (0.036)
Selway River	17,088	0.750 (0.016)	0.853 (0.029)	0.984 (0.052)	0.965 (0.078)	0.608 (0.040)
Dworshak Hatchery						
N Fork Clearwater R	40,314	0.693 (0.013)	0.802 (0.020)	0.840 (0.028)	0.862 (0.041)	0.402 (0.015)
Kooskia Hatchery						
Clear Creek	7,206	0.565 (0.025)	0.835 (0.057)	0.995 (0.112)	0.746 (0.116)	0.351 (0.040)
Lookingglass Hatchery						
Catherine Creek Pond	20,923	0.420 (0.014)	1.072 (0.076)	0.761 (0.071)	0.884 (0.095)	0.303 (0.024)
Grande Ronde Pond	1,979	0.398 (0.032)	1.301 (0.218)	0.783 (0.170)	0.869 (0.273)	0.352 (0.096)
Imnaha River	8,959	0.620 (0.021)	0.892 (0.064)	1.064 (0.113)	0.768 (0.104)	0.452 (0.045)
Imnaha Weir	11,897	0.585 (0.020)	0.876 (0.063)	1.056 (0.104)	0.810 (0.100)	0.438 (0.041)
Lookingglass Hatchery	4,976	0.657 (0.026)	0.887 (0.062)	0.934 (0.078)	0.990 (0.136)	0.539 (0.067)
Lostine Pond	2,392	0.553 (0.029)	0.984 (0.087)	1.008 (0.128)	0.746 (0.144)	0.409 (0.067)
McCall Hatchery						
Knox Bridge	51,857	0.700 (0.012)	0.909 (0.033)	0.944 (0.044)	0.879 (0.048)	0.528 (0.021)
Pahsimeroi Hatchery						
Pahsimeroi Pond	22,370	0.746 (0.012)	0.936 (0.032)	0.895 (0.052)	0.897 (0.081)	0.560 (0.041)
Rapid River Hatchery						
Rapid River Hatchery	51,898	0.652 (0.010)	0.912 (0.025)	1.070 (0.042)	0.830 (0.042)	0.528 (0.020)
Sawtooth Hatchery						
Sawtooth Hatchery	20,787	0.606 (0.010)	0.908 (0.026)	0.970 (0.045)	0.874 (0.060)	0.466 (0.025)
Yankee Fork	2,490	0.592 (0.069)	1.346 (0.463)	0.755 (0.299)	0.658 (0.198)	0.396 (0.074)

Appendix Table B2. Estimated survival probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2017. 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			
Meadow Creek	10,421	0.894 (0.013)	0.952 (0.024)	0.911 (0.034)	0.917 (0.069)	0.711 (0.049)
S Fork Clearwater R	10,781	0.863 (0.015)	0.944 (0.026)	0.910 (0.038)	0.792 (0.065)	0.587 (0.042)
			Dworshak Hatchery			
S Fork Clearwater R	5,491	0.720 (0.015)	0.986 (0.029)	0.896 (0.046)	0.980 (0.117)	0.623 (0.068)
Dworshak NFH	27,335	0.765 (0.007)	0.983 (0.013)	0.941 (0.020)	0.864 (0.038)	0.612 (0.024)
			Hagerman Hatchery			
East Fork Salmon R	8,330	0.664 (0.034)	1.197 (0.166)	0.881 (0.139)	0.640 (0.115)	0.449 (0.067)
Sawtooth Hatchery	25,744	0.775 (0.009)	0.993 (0.022)	0.882 (0.027)	0.793 (0.050)	0.538 (0.031)
			Irrigon Hatchery			
Big Canyon Facility	6,802	0.783 (0.026)	0.962 (0.057)	0.859 (0.064)	0.996 (0.152)	0.644 (0.090)
Cottonwood Pond	3,996	0.944 (0.027)	1.019 (0.058)	0.867 (0.098)	1.090 (0.250)	0.909 (0.180)
Little Sheep Facility	15,005	0.783 (0.013)	1.042 (0.034)	0.790 (0.034)	0.974 (0.086)	0.627 (0.051)
Wallowa Hatchery	12,196	0.813 (0.013)	0.972 (0.026)	0.913 (0.040)	0.796 (0.071)	0.573 (0.046)
			Lyons Ferry Hatchery			
Cottonwood Pond	5,996	0.918 (0.023)	0.984 (0.040)	0.986 (0.070)	0.918 (0.155)	0.817 (0.127)
Wallowa Hatchery	3,968	0.794 (0.024)	0.903 (0.042)	0.913 (0.080)	0.765 (0.135)	0.500 (0.077)

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	4,374	0.882 (0.016)	1.003 (0.035)	0.916 (0.048)	1.033 (0.121)	0.838 (0.091)
Pahsimeroi R Trap	16,942	0.777 (0.011)	1.020 (0.026)	0.934 (0.036)	0.909 (0.088)	0.673 (0.061)
Yankee Fork	13,217	0.759 (0.018)	0.936 (0.042)	0.940 (0.056)	0.831 (0.092)	0.554 (0.055)
			Niagara Springs Hatchery			
Hells Canyon Dam	8,463	0.911 (0.019)	1.093 (0.057)	0.865 (0.065)	0.754 (0.104)	0.650 (0.079)
Little Salmon R	5,076	0.899 (0.018)	1.053 (0.042)	0.858 (0.053)	0.922 (0.128)	0.749 (0.096)
Pahsimeroi R Trap	8,961	0.746 (0.016)	1.000 (0.039)	0.949 (0.055)	0.751 (0.089)	0.532 (0.057)

Appendix Table B3. Estimated survival probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2017. 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
Springfield Hatchery								
Redfish Lake Cr Trap	18-28 April 17	49,937	0.162 (0.012)	0.863 (0.115)	0.675 (0.102)	0.809 (0.144)	0.471 (0.076)	0.076 (0.01)

Appendix Table B4. Estimated detection probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2017. 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		
Dworshak NFH	17,066	0.190 (0.005)	0.298 (0.007)	0.209 (0.008)	0.106 (0.006)
Kooskia	9,585	0.221 (0.006)	0.304 (0.010)	0.213 (0.011)	0.094 (0.008)
Powell Pond	25,466	0.216 (0.005)	0.292 (0.006)	0.210 (0.008)	0.093 (0.006)
Red River Pond	17,082	0.193 (0.007)	0.184 (0.008)	0.169 (0.011)	0.074 (0.007)
Selway River	17,088	0.208 (0.006)	0.218 (0.007)	0.184 (0.009)	0.079 (0.006)
			Dworshak Hatchery		
N Fork Clearwater R	40,314	0.125 (0.003)	0.270 (0.005)	0.208 (0.006)	0.126 (0.006)
			Kooskia Hatchery		
Clear Creek	7,206	0.180 (0.010)	0.236 (0.014)	0.170 (0.018)	0.110 (0.014)
			Lookingglass Hatchery		
Catherine Cr Pond	20,923	0.210 (0.008)	0.131 (0.009)	0.183 (0.013)	0.105 (0.009)
Grande Ronde Pond	1,979	0.212 (0.022)	0.105 (0.018)	0.156 (0.027)	0.074 (0.022)
Imnaha River	8,959	0.261 (0.010)	0.136 (0.010)	0.174 (0.016)	0.090 (0.010)
Imnaha Weir	11,897	0.242 (0.009)	0.125 (0.009)	0.176 (0.014)	0.086 (0.009)
Lookingglass Hatch	4,976	0.221 (0.011)	0.126 (0.010)	0.214 (0.015)	0.074 (0.010)
Lostine Pond	2,392	0.243 (0.017)	0.186 (0.017)	0.185 (0.022)	0.116 (0.021)
			McCall Hatchery		
Knox Bridge	51,857	0.195 (0.004)	0.108 (0.004)	0.176 (0.006)	0.089 (0.004)
			Pahsimeroi Hatchery		
Pahsimeroi Pond	22,370	0.257 (0.005)	0.191 (0.006)	0.178 (0.009)	0.060 (0.005)
			Rapid River Hatchery		
Rapid River Hatch	51,898	0.202 (0.004)	0.141 (0.004)	0.164 (0.006)	0.085 (0.004)
			Sawtooth Hatchery		
Sawtooth Hatchery	20,787	0.253 (0.006)	0.256 (0.007)	0.200 (0.009)	0.116 (0.007)
Yankee Fork	2,490	0.174 (0.022)	0.045 (0.015)	0.118 (0.028)	0.102 (0.022)

Appendix Table B5. Estimated detection probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2017. 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	10,421	0.268 (0.006)	0.272 (0.007)	0.297 (0.010)	0.062 (0.005)
S.F. Clearwater R	10,781	0.233 (0.006)	0.304 (0.008)	0.279 (0.011)	0.065 (0.006)
			Dworshak Hatchery		
S.F. Clearwater R	5,491	0.269 (0.009)	0.403 (0.012)	0.288 (0.015)	0.069 (0.009)
Dworshak NFH	27,335	0.280 (0.004)	0.377 (0.005)	0.278 (0.006)	0.084 (0.004)
			Hagerman Hatchery		
East Fork Salmon R	8,330	0.210 (0.012)	0.055 (0.008)	0.192 (0.018)	0.039 (0.007)
Sawtooth Hatchery	25,744	0.254 (0.004)	0.232 (0.005)	0.272 (0.007)	0.046 (0.003)
			Irrigon Hatchery		
Big Canyon Facility	6,802	0.221 (0.009)	0.163 (0.009)	0.228 (0.014)	0.036 (0.006)
Cottonwood Pond	3,996	0.246 (0.010)	0.293 (0.016)	0.240 (0.025)	0.036 (0.008)
Little Sheep Facility	15,005	0.278 (0.006)	0.201 (0.007)	0.284 (0.010)	0.050 (0.005)
Wallowa Hatchery	12,196	0.252 (0.006)	0.312 (0.008)	0.238 (0.010)	0.051 (0.005)
			Lyons Ferry Hatchery		
Cottonwood Pond	5,996	0.208 (0.008)	0.286 (0.011)	0.212 (0.014)	0.032 (0.006)
Wallowa Hatchery	3,968	0.225 (0.010)	0.396 (0.016)	0.258 (0.022)	0.054 (0.010)
			Magic Valley Hatchery		
Little Salmon R	4,374	0.328 (0.010)	0.277 (0.011)	0.304 (0.015)	0.051 (0.007)
Pahsimeroi R Trap	16,942	0.274 (0.005)	0.235 (0.006)	0.274 (0.009)	0.030 (0.003)
Yankee Fork	13,217	0.262 (0.008)	0.183 (0.008)	0.265 (0.013)	0.045 (0.005)
			Niagara Springs Hatchery		
Hells Canyon Dam	8,463	0.325 (0.008)	0.149 (0.008)	0.250 (0.015)	0.039 (0.006)
Little Salmon R	5,076	0.305 (0.009)	0.256 (0.011)	0.281 (0.016)	0.042 (0.007)
Pahsimeroi Trap	8,961	0.244 (0.007)	0.227 (0.009)	0.238 (0.012)	0.042 (0.006)

Appendix Table B6. Estimated detection probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2017. Estimates based on the single-release model. Standard errors in parentheses.

Juvenile sockeye salmon released at Redfish Lake Creek Trap					
Release date	Number released	Lower Granite	Little Goose	Lower Monumental	McNary
Springfield Hatchery					
18-28 April 17	49,937	0.142 (0.012)	0.108 (0.012)	0.184 (0.020)	0.084 (0.012)

Appendix Table B7. Estimated survival probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2017. Estimates based on the single-release model. Standard errors in parentheses.

Trap	Release dates	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
			Wild Chinook Salmon				
Catherine Creek	09 Mar-31 May	615	0.376 (0.043)	1.388 (0.383)	0.813 (0.343)	NA	NA
Crooked River	16 Mar-29 May	716	0.544 (0.077)	0.981 (0.262)	0.675 (0.217)	0.670 (0.263)	0.241 (0.076)
Elgin (G. Ronde)	06 Apr-31 May	414	0.736 (0.084)	1.042 (0.299)	1.523 (0.879)	0.958 (1.034)	1.118 (1.054)
Grande Ronde	28 Mar-27 May	3,896	0.856 (0.018)	0.932 (0.034)	0.916 (0.054)	0.931 (0.097)	0.681 (0.061)
Imnaha	01 Feb-28 May	2,458	0.782 (0.021)	0.884 (0.034)	0.992 (0.058)	1.052 (0.124)	0.722 (0.076)
Johnson Creek	01 Mar-20 May	292	0.453 (0.065)	0.784 (0.148)	1.178 (0.343)	1.831 (1.761)	0.767 (0.711)
Lemhi Weir	08 Mar-30 May	1,126	0.749 (0.041)	0.825 (0.068)	0.896 (0.095)	1.156 (0.238)	0.640 (0.119)
Lookingglass Cr	07 Feb-19 Apr	116	0.591 (0.128)	0.575 (0.157)	1.111 (0.367)	1.477 (1.340)	0.558 (0.478)
Lostine	14 Feb-18 May	603	0.600 (0.047)	1.016 (0.128)	0.854 (0.164)	1.636 (0.701)	0.851 (0.338)
Minam	14 Mar-23 May	530	0.586 (0.051)	0.940 (0.134)	0.873 (0.176)	0.791 (0.232)	0.380 (0.091)
Pahsimeroi	28 Feb-16 Apr	704	0.697 (0.035)	0.954 (0.066)	0.916 (0.108)	0.880 (0.207)	0.536 (0.112)
Salmon	06 Mar-05 May	6,593	0.848 (0.012)	0.929 (0.020)	0.903 (0.032)	0.836 (0.056)	0.594 (0.035)
Sawtooth	24 Mar-17 May	474	0.435 (0.047)	1.048 (0.227)	0.884 (0.300)	1.077 (0.450)	0.433 (0.137)
U. Grande Ronde	09 Mar-31 May	710	0.316 (0.038)	1.026 (0.252)	0.660 (0.252)	1.118 (0.648)	0.239 (0.116)
			Wild Sockeye Salmon				
Redfish Lake Cr	16 Apr-30 May	745	0.423 (0.048)	0.897 (0.161)	0.959 (0.269)	0.892 (0.441)	0.325 (0.141)

Appendix Table B7. Continued.

Trap	Release dates	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
			Wild Steelhead				
Asotin Creek	14 Feb-31 May	2,680	0.869 (0.033)	0.904 (0.063)	1.073 (0.139)	0.707 (0.156)	0.596 (0.107)
Catherine Creek	14 Mar-31 May	246	0.506 (0.132)	0.787 (0.336)	0.748 (0.350)	NA	NA
Elgin (G. Ronde)	04 Apr-31 May	558	0.706 (0.076)	0.732 (0.127)	1.228 (0.320)	1.768 (1.695)	1.123 (1.039)
Grande Ronde	28 Mar-20 May	1,200	0.839 (0.035)	1.060 (0.089)	0.906 (0.124)	1.070 (0.400)	0.863 (0.306)
Imnaha River	14 Feb-29 May	2,650	0.818 (0.029)	0.962 (0.066)	1.008 (0.110)	1.005 (0.239)	0.797 (0.174)
Lostine River	07 Mar-23 May	146	0.598 (0.105)	0.840 (0.256)	0.984 (0.394)	NA	NA
Minam River	14 Mar-26 May	159	0.551 (0.084)	1.349 (0.427)	1.729 (1.141)	0.626 (0.682)	0.804 (0.714)
Salmon River	13 Mar-05 May	358	0.860 (0.073)	0.953 (0.134)	0.867 (0.192)	1.143 (0.709)	0.812 (0.479)
Sawtooth River	24 Mar-23 May	218	0.269 (0.052)	NA	NA	NA	NA
Upper Grande Ronde	09 Mar-31 May	701	0.454 (0.041)	1.168 (0.220)	0.891 (0.247)	0.512 (0.248)	0.242 (0.104)
			Hatchery Chinook Salmon				
Grande Ronde	28 Mar-12 May	1,400	0.824 (0.056)	0.811 (0.086)	1.210 (0.186)	0.602 (0.137)	0.487 (0.090)
Salmon	14 Mar-05 May	3,979	0.739 (0.029)	1.056 (0.078)	0.886 (0.081)	1.018 (0.147)	0.705 (0.091)
			Hatchery Steelhead				
Grande Ronde	28 Mar-28 Apr	3,600	1.030 (0.027)	0.900 (0.035)	0.824 (0.042)	0.751 (0.075)	0.574 (0.052)
Salmon	31 Mar-05 May	3,035	0.966 (0.030)	0.957 (0.051)	0.860 (0.058)	0.727 (0.104)	0.578 (0.077)

Appendix Table B8. Estimated detection probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2017. 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			
Catherine Creek	09 Mar-31 May	615	0.333 (0.046)	0.168 (0.048)	0.128 (0.048)	NA
Crooked River	16 Mar-29 May	716	0.249 (0.041)	0.215 (0.051)	0.318 (0.074)	0.170 (0.062)
Elgin (G. Ronde)	06 Apr-31 May	414	0.325 (0.045)	0.169 (0.049)	0.110 (0.058)	0.044 (0.043)
Grande Ronde	28 Mar-27 May	3,896	0.340 (0.011)	0.349 (0.014)	0.319 (0.018)	0.133 (0.014)
Imnaha River	01 Feb-28 May	2,458	0.306 (0.013)	0.400 (0.016)	0.330 (0.021)	0.141 (0.017)
Johnson Creek	01 Mar-20 May	292	0.287 (0.054)	0.340 (0.064)	0.258 (0.079)	0.046 (0.044)
Lemhi Weir	08 Mar-30 May	1,126	0.315 (0.023)	0.349 (0.027)	0.310 (0.034)	0.114 (0.025)
Lookingglass Cr	07 Feb-19 Apr	116	0.292 (0.080)	0.412 (0.099)	0.384 (0.136)	0.125 (0.117)
Lostine River	14 Feb-18 May	603	0.282 (0.031)	0.314 (0.040)	0.266 (0.050)	0.089 (0.038)
Minam River	14 Mar-23 May	530	0.303 (0.035)	0.274 (0.041)	0.296 (0.056)	0.214 (0.059)
Pahsimeroi	28 Feb-16 Apr	704	0.314 (0.025)	0.437 (0.033)	0.345 (0.043)	0.120 (0.031)
Salmon River	06 Mar-05 May	6,593	0.316 (0.008)	0.447 (0.010)	0.380 (0.014)	0.159 (0.011)
Sawtooth River	24 Mar-17 May	474	0.330 (0.045)	0.273 (0.060)	0.194 (0.061)	0.143 (0.054)
U. Grande Ronde	09 Mar-31 May	710	0.352 (0.050)	0.266 (0.064)	0.230 (0.079)	0.115 (0.063)
			Wild Sockeye Salmon			
Redfish Lake Cr	16 Apr-30 May	745	0.257 (0.036)	0.240 (0.043)	0.186 (0.050)	0.109 (0.051)

Appendix Table B8. Continued.

Trap	Release dates	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Wild Steelhead			
Asotin Creek	14 Feb-31 May	2,680	0.316 (0.015)	0.287 (0.019)	0.221 (0.027)	0.078 (0.016)
Catherine Creek	14 Mar-31 May	246	0.257 (0.076)	0.201 (0.075)	0.299 (0.116)	NA
Elgin (G. Ronde)	04 Apr-31 May	558	0.284 (0.037)	0.213 (0.037)	0.234 (0.058)	0.019 (0.018)
Grande Ronde	28 Mar-20 May	1,200	0.346 (0.020)	0.276 (0.025)	0.264 (0.034)	0.035 (0.014)
Imnaha River	14 Feb-29 May	2,650	0.319 (0.015)	0.232 (0.016)	0.226 (0.023)	0.047 (0.012)
Lostine River	07 Mar-23 May	146	0.378 (0.080)	0.296 (0.088)	0.356 (0.132)	0.125 (0.117)
Minam River	14 Mar-26 May	159	0.286 (0.062)	0.142 (0.053)	0.132 (0.083)	0.056 (0.054)
Salmon River	13 Mar-05 May	358	0.279 (0.034)	0.312 (0.044)	0.230 (0.051)	0.029 (0.020)
Sawtooth River	24 Mar-23 May	218	0.375 (0.086)	NA	NA	NA
Upper Grande Ronde	09 Mar-31 May	701	0.314 (0.036)	0.202 (0.040)	0.265 (0.061)	0.054 (0.031)
			Hatchery Chinook Salmon			
Grande Ronde	28 Mar-12 May	1,400	0.207 (0.018)	0.190 (0.020)	0.161 (0.024)	0.099 (0.022)
Salmon	14 Mar-05 May	3,979	0.212 (0.011)	0.126 (0.010)	0.184 (0.014)	0.078 (0.011)
			Hatchery Steelhead			
Grande Ronde	28 Mar-28 Apr	3,600	0.238 (0.009)	0.334 (0.012)	0.290 (0.015)	0.081 (0.010)
Salmon	31 Mar-05 May	3,035	0.256 (0.011)	0.204 (0.012)	0.271 (0.016)	0.049 (0.008)

Appendix Table B9. Estimated survival probabilities for PIT-tagged yearling Chinook, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2017. 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	9,506	0.735 (0.062)	0.646 (0.079)	0.847 (0.335)	0.548 (0.216)	0.402 (0.155)
Chiwawa Pond	10,148	0.473 (0.033)	0.890 (0.106)	1.815 (1.031)	1.617 (0.912)	0.764 (0.428)
Dryden Pond	20,604	0.720 (0.043)	0.817 (0.086)	0.725 (0.208)	0.593 (0.166)	0.427 (0.117)
Chief Joseph						
Chief Joseph Hatchery	4,815	0.600 (0.067)	0.871 (0.146)	0.870 (0.481)	0.757 (0.416)	0.454 (0.245)
Omak Pond	4,830	0.636 (0.103)	0.922 (0.241)	1.618 (1.617)	1.492 (1.480)	0.948 (0.928)
River Pond	5,032	0.345 (0.046)	1.213 (0.298)	NA	NA	NA
Cle Elum						
Clark Flat Pond	16,001	0.280 (0.014)	0.909 (0.081)	1.045 (0.410)	0.950 (0.369)	0.266 (0.103)
Easton Pond	12,001	0.302 (0.023)	0.800 (0.102)	0.852 (0.406)	0.682 (0.322)	0.206 (0.096)
Jack Creek Pond	12,000	0.248 (0.016)	0.846 (0.092)	0.629 (0.207)	0.532 (0.172)	0.132 (0.042)
Entiat						
Entiat Hatchery	20,058	0.639 (0.040)	0.775 (0.073)	1.265 (0.323)	0.981 (0.248)	0.627 (0.154)
Leavenworth						
Leavenworth NFH	19,528	0.540 (0.022)	0.811 (0.060)	1.271 (0.553)	1.031 (0.446)	0.556 (0.240)
Methow						
Chewuch Pond	4,989	0.505 (0.057)	1.023 (0.186)	1.175 (0.804)	1.202 (0.815)	0.607 (0.406)
Goatwall Pond	4,934	0.475 (0.061)	0.873 (0.171)	0.766 (0.514)	0.669 (0.446)	0.318 (0.208)
Methow Hatchery	4,996	0.427 (0.045)	1.164 (0.204)	NA	NA	NA
Twisp Pond	4,995	0.542 (0.073)	0.728 (0.134)	1.200 (0.810)	0.873 (0.591)	0.473 (0.314)
Winthrop						
Winthrop NFH	19,919	0.578 (0.031)	0.919 (0.073)	1.074 (0.327)	0.987 (0.299)	0.570 (0.170)

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			
East Bank						
Wenatchee River	2,512	0.209 (0.056)	0.674 (0.243)	NA	NA	NA
Wells						
Methow River	4,999	0.448 (0.045)	1.092 (0.177)	0.897 (0.504)	0.980 (0.545)	0.439 (0.240)
Omak Pond	9,994	0.405 (0.067)	0.711 (0.139)	0.522 (0.185)	0.371 (0.140)	0.150 (0.051)
Salmon Creek	5,014	0.544 (0.084)	0.874 (0.167)	1.765 (1.004)	1.542 (0.892)	0.838 (0.468)
Similkameen Pond	4,977	0.575 (0.108)	0.904 (0.196)	1.994 (1.389)	1.802 (1.285)	1.036 (0.713)
Twisp Pond	4,999	0.316 (0.048)	0.991 (0.208)	NA	NA	NA
Wells Hatchery	4,999	0.504 (0.062)	0.972 (0.168)	1.040 (0.585)	1.010 (0.568)	0.509 (0.280)
Winthrop						
Winthrop NFH	20,790	0.548 (0.072)	0.730 (0.110)	0.993 (0.307)	0.725 (0.238)	0.397 (0.119)
			Coho Salmon			
Cascade						
Beaver Creek Pond	2,984	0.362 (0.059)	1.141 (0.320)	NA	NA	NA
Leavenworth NFH	10,453	0.335 (0.026)	0.851 (0.111)	0.994 (0.427)	0.846 (0.358)	0.284 (0.118)
Twisp Pond	4,381	0.424 (0.049)	1.490 (0.365)	0.298 (0.143)	0.443 (0.197)	0.188 (0.081)
Eagle						
Natches River	5,007	0.385 (0.059)	1.882 (0.587)	0.282 (0.147)	0.530 (0.250)	0.204 (0.091)
Yakima R (rkm 256)	5,002	0.117 (0.022)	1.750 (0.796)	0.289 (0.283)	0.506 (0.457)	0.059 (0.052)
Prosser						
Yakima R (rkm 76)	2,876	0.375 (0.040)	0.761 (0.142)	NA	NA	NA
Willard						
Beaver Creek Pond	2,993	0.232 (0.055)	0.789 (0.262)	NA	NA	NA
Butcher Pond	5,930	0.305 (0.080)	0.479 (0.152)	0.501 (0.260)	0.240 (0.133)	0.073 (0.036)
Winthrop NFH	4,380	0.432 (0.066)	0.750 (0.171)	1.670 (1.624)	1.252 (1.214)	0.541 (0.518)
Winthrop						
Winthrop NFH	3,956	0.404 (0.045)	0.944 (0.179)	0.790 (0.430)	0.746 (0.398)	0.301 (0.157)

Appendix Table B10. Estimated detection probabilities for PIT-tagged yearling Chinook salmon, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2017. 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	9,506	0.081 (0.008)	0.220 (0.020)	0.093 (0.036)
Chiwawa Pond	10,148	0.133 (0.010)	0.170 (0.018)	0.052 (0.029)
Dryden Pond	20,604	0.094 (0.006)	0.129 (0.012)	0.082 (0.023)
Chief Joseph				
Chief Joseph Hatchery	4,815	0.089 (0.011)	0.168 (0.022)	0.118 (0.064)
Omak Pond	4,830	0.067 (0.012)	0.104 (0.022)	0.036 (0.036)
River Pond	5,032	0.101 (0.015)	0.120 (0.026)	NA
Cle Elum				
Clark Flat Pond	16,001	0.185 (0.010)	0.259 (0.021)	0.093 (0.036)
Easton Pond	12,001	0.141 (0.012)	0.209 (0.023)	0.119 (0.056)
Jack Creek Pond	12,000	0.170 (0.013)	0.270 (0.026)	0.169 (0.054)
Entiat				
Entiat Hatchery	20,058	0.087 (0.006)	0.130 (0.010)	0.081 (0.020)
Leavenworth				
Leavenworth NFH	19,528	0.155 (0.007)	0.234 (0.015)	0.066 (0.028)
Methow				
Chewuch Pond	4,989	0.096 (0.012)	0.122 (0.019)	0.097 (0.065)
Goatwall Pond	4,934	0.088 (0.013)	0.154 (0.024)	0.134 (0.088)
Methow Hatchery	4,996	0.101 (0.012)	0.126 (0.019)	0.046 (0.045)
Twisp Pond	4,995	0.074 (0.011)	0.164 (0.022)	0.112 (0.075)
Winthrop				
Winthrop NFH	19,919	0.090 (0.006)	0.168 (0.011)	0.101 (0.030)
		Steelhead		
East Bank				
Wenatchee River	2,512	0.080 (0.024)	0.268 (0.069)	NA
Wells				
Methow River	4,999	0.098 (0.012)	0.202 (0.027)	0.085 (0.047)
Omak Pond	9,994	0.034 (0.006)	0.218 (0.024)	0.175 (0.060)
Salmon Creek	5,014	0.044 (0.008)	0.196 (0.024)	0.055 (0.031)
Similkameen Pond	4,977	0.026 (0.006)	0.221 (0.025)	0.044 (0.031)
Twisp Pond	4,999	0.063 (0.011)	0.220 (0.034)	0.031 (0.031)
Wells Hatchery	4,999	0.066 (0.009)	0.204 (0.026)	0.081 (0.045)
Winthrop				
Winthrop NFH	20,790	0.022 (0.003)	0.171 (0.013)	0.085 (0.026)

Appendix Table B10. Continued

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Coho Salmon		
Cascade				
Beaver Creek Pond	2,984	0.101 (0.019)	0.123 (0.030)	NA
Leavenworth NFH	10,453	0.140 (0.012)	0.168 (0.019)	0.118 (0.049)
Twisp Pond	4,381	0.120 (0.016)	0.083 (0.019)	0.252 (0.109)
Eagle				
Natches River	5,007	0.077 (0.013)	0.058 (0.016)	0.184 (0.083)
Yakima R (rkm 256)	5,002	0.137 (0.029)	0.078 (0.034)	0.203 (0.181)
Prosser				
Yakima R (rkm 76)	2,876	0.181 (0.022)	0.303 (0.050)	NA
Willard				
Beaver Creek Pond	2,993	0.083 (0.022)	0.157 (0.040)	NA
Butcher Pond	5,930	0.048 (0.013)	0.173 (0.034)	0.274 (0.135)
Winthrop NFH	4,380	0.091 (0.015)	0.133 (0.024)	0.077 (0.074)
Winthrop				
Winthrop NFH	3,956	0.132 (0.017)	0.146 (0.024)	0.167 (0.088)

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 for yearling Chinook salmon and steelhead in 2017 (hatchery and wild combined) from the Columbia River DART website[1] on 6 September, 2017. We created plots to compare daily measures of flow, temperature, and spill at Little Goose Dam from 2017 to those from 2010-2016. We calculated long-term daily averages for flow, temperature, and spill as the mean daily value for 1993-2017. We created plots and calculated passage proportions to compare daily estimates of proportion of smolts passing Lower Granite Dam in 2017 to those of 2014-2016.

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

Environmental conditions in 2017 resulted in a year with average water temperatures but very high flow and spill throughout the migration season. Mean flow at Little Goose Dam during the main migration period (1 April-15 June 2017) was 138.7 kcfs, which was much above the long-term (1993-2017) mean of 91.8 kcfs; only 1997 had higher mean flow. Daily flow values were well above long-term daily means for almost the entire migration period; daily flow only approached the mean for a brief period in late May (Appendix Figure C1).

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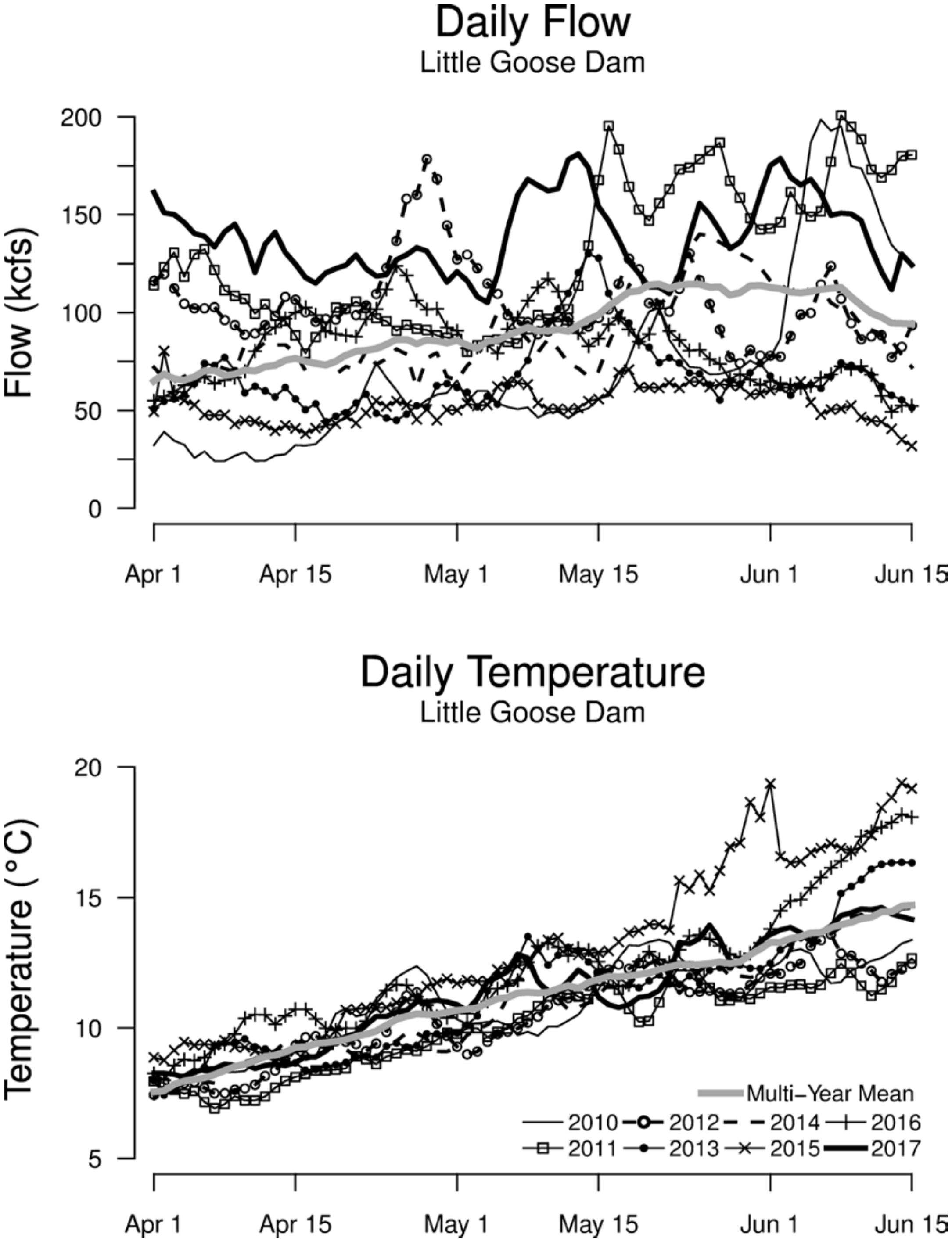
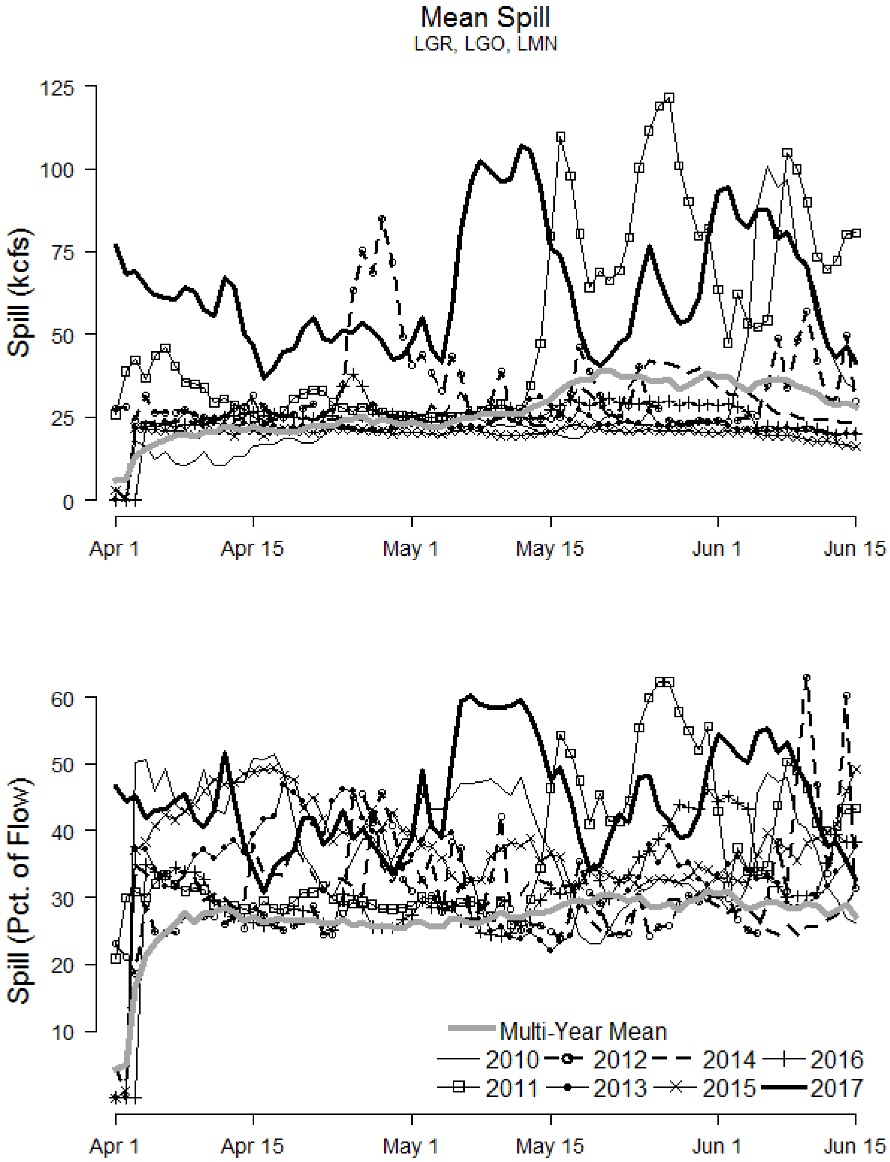
[1] www.cbr.washington.edu/dart



Appendix Figure C1. Daily Snake River flow (kcfs) and temperature (°C) measured at Little Goose Dam from April through mid-June, 2010-2017, including daily long-term means (1993-2017).

Mean water temperature at Little Goose Dam in 2017 during the migration period was 11.3°C, which was very near the long-term mean of 11.2°C. Daily water temperatures generally tracked the long-term daily mean, oscillating between slightly above and slightly below the mean through May and June (Appendix Figure C1).

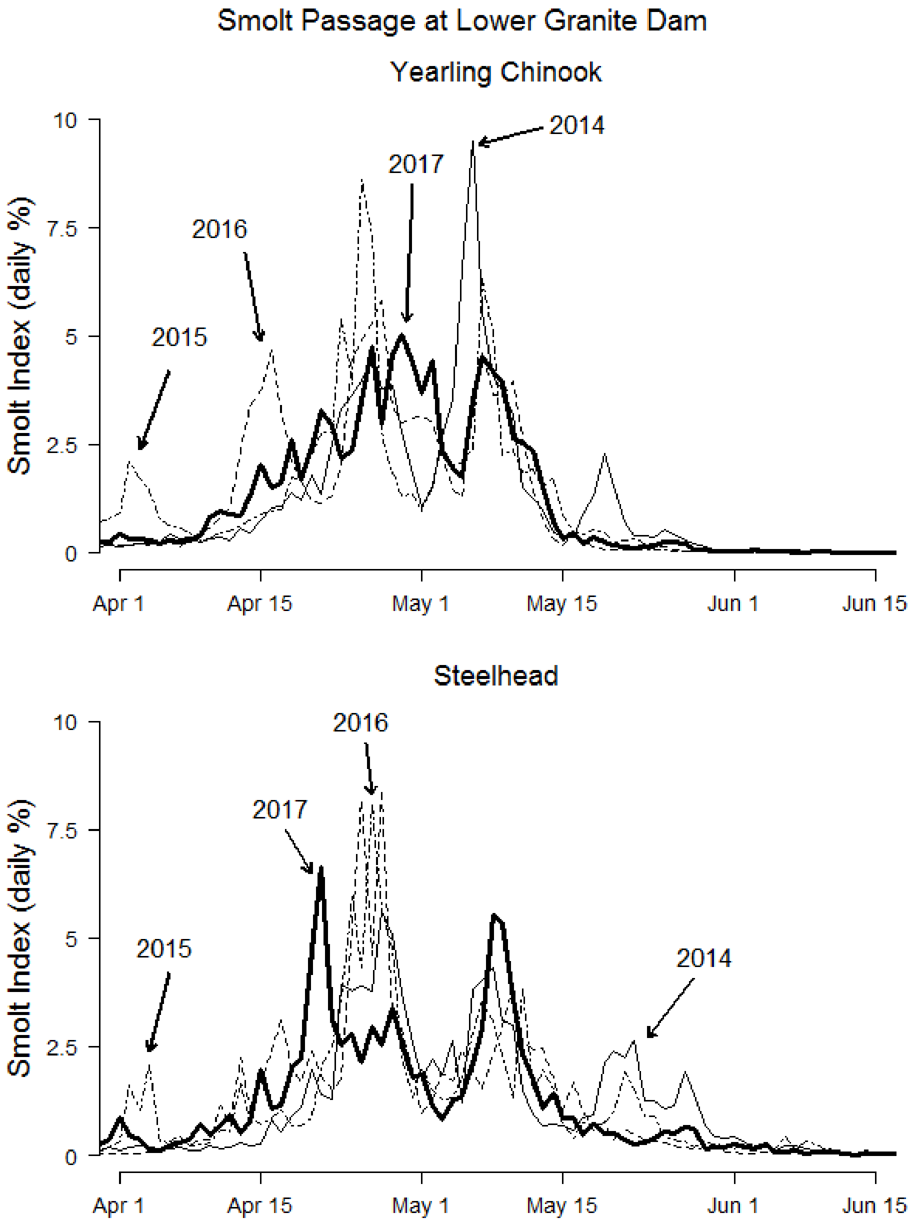


Appendix Figure C2. Daily mean spill (top = kcfs; bottom = percentage of total flow) averaged across Lower Granite, Little Goose and Lower Monumental dams from April through mid-June, 2010-2017, including daily long-term means (1993-2017).

Mean spill discharge at Snake River dams during the 2017 migration was 63.7 kcfs, which was far above the long-term mean of 27.2 kcfs (1993-2017). Thus, 2017 was the year with the highest average spill discharge of our time series. Daily spill discharges remained above the long-term daily mean throughout the season, with especially high spill discharge in early May and early June (Appendix Figure C2).

Spill as a percentage of flow at Snake River dams averaged 44.5% in 2017, which was above the long-term mean of 26.8% (1993-2017) and was the highest mean spill percentage in our time series. Daily mean spill percentages in 2017 were above the long-term daily means for the entire migration period (Appendix Figure C2).

A rapid increase in both flow and spill around 7 May (Appendix Figure C1) corresponded with one peak in smolt arrival at Lower Granite Dam for both Chinook and steelhead in 2017 (Appendix Figure C3). However, the majority of smolts had already passed the dam by the time that peak occurred, and earlier peaks in smolt passage do not appear to correspond with any change in flow or spill; though it must be noted that flow and spill were high throughout the migration period.



Appendix Figure C3. Daily smolt passage index of yearling Chinook salmon and steelhead passing Lower Granite Dam, 2014-2017.

Appendix D: List of Tables and Figures

Tables

Figures