Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2019

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Report of research by

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for

Division of Fish and Wildlife
Bonneville Power Administration
U.S. Department of Energy
Contract 40735, Project 199302900

June 2020

Executive Summary

In 2019, we completed the 27th 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 20,926 hatchery steelhead *O. mykiss*, 14,791 wild steelhead, and 6,366 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 River.

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 detection 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 2019 were:

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

In 2019, 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 and weekly groups leaving Lower Granite and biweekly groups leaving McNary Dam.

Hatchery and wild fish were combined in some analyses. For combined groups of PIT-tagged fish detected or released at Lower Granite Dam, overall percentages by origin were 69% hatchery and 31% wild for yearling Chinook and 76% hatchery and 24% 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 90.1% of the overall yearling Chinook run in 2019 was of hatchery origin. We estimated that 89.7% of the overall steelhead run was of hatchery origin in 2019; this estimate is based on counts

of steelhead produced by the Fish Passage Center which use fin erosion as a marker to distinguish hatchery origin fish from wild fish

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 E1 for groups of combined wild and hatchery yearling Chinook salmon and steelhead.

Table E1. Average survival estimates by reach for combined hatchery and wild yearling Chinook salmon and steelhead during 2019 (standard errors in parentheses).

	Yearling Chinook salmon (SE)	Steelhead (SE)
Snake River trap to Lower Granite Dam	0.785 (0.027)	0.965 (0.027)
Lower Granite to Little Goose Dam	0.874 (0.015)	0.968 (0.006)
Little Goose to Lower Monumental Dam	0.953 (0.027)	0.981 (0.011)
Lower Monumental to McNary Dam[a]	0.792 (0.032)	0.774 (0.019)
Lower Monumental to Ice Harbor Dam	0.901 (0.033)	0.981 (0.022)
Ice Harbor to McNary Dam	0.877 (0.052)	0.809 (0.013)
McNary to John Day Dam	1.015 (0.088)	1.029 (0.084)
John Day to Bonneville Dam[b]	0.798 (0.111)	0.734 (0.110)
Snake River trap to Bonneville Dam[c]	0.407 (0.037)	0.412 (0.077)

[a] Two-project reach, including Ice Harbor Dam and reservoir.
[b] Two-project reach, including The Dalles Dam and reservoir.
[c] Entire hydropower system, including eight dams and reservoirs.

We also estimated average survival through the entire hydropower system from the Snake River smolt trap at the head of Lower Granite reservoir to the tailrace of Bonneville Dam (eight hydroelectric projects) (Table E1). These estimates were the product of average survival estimates through the following three reaches: Snake River smolt trap to Lower Granite Dam, Lower Granite to McNary Dam, and McNary to Bonneville Dam. For combined wild and hatchery Snake River fish, average estimated survival in 2019 through the entire hydropower system was 0.407 (95% CI 0.334-0.479) for yearling Chinook and 0.412 (0.261-0.562) 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 0.904 (SE 0.110) for East Bank Hatchery fish released to the Chelan River to 0.176 (0.016) for Cle Elum Hatchery fish released to Jack Creek Pond. For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.516 (0.045) for Wells Hatchery fish released from Wells Hatchery to 0.236 (0.067) for Wells Hatchery fish released from Winthrop Hatchery.

For smolts that arrived at Lower Granite Dam, we estimated that 37.6% of yearling Chinook (mean of wild and hatchery estimates) and 39.8% of steelhead were transported from a Snake River collector dam. These estimates were substantially higher than those from 2015-2017, but not as high as those from 2018.

The higher proportion of transported smolts resulted in part from timing of the transportation program, which started on 24 April in 2019, earlier than in most other years since 2006. We estimated that 38% of the wild yearling Chinook and 32% of the hatchery yearling Chinook population had passed Lower Granite Dam before transportation began. For steelhead, we estimated that 32% of the wild and 47% of the hatchery population had passed Lower Granite Dam by the time transportation began.

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 and Bonneville Dam (461 km). For yearling Chinook during May and for steelhead throughout the 2019 migration season, median travel time between Lower Granite and Bonneville Dam was similar to that in other high-flow years under the present spill regime. However, in April 2019, median travel times were longer for yearling Chinook than in other recent high-flow years.

In 2019, as in other recent years, estimated proportions of PIT-tagged fish detected during dam passage were low. Notably, detection at Little Goose Dam was low during May, and detection at McNary and John Day Dam were very low for nearly the entire season. Low detection probabilities in 2019 were likely the result of high spill levels.

In recent years, spill levels have been increased in an attempt to boost juvenile salmonid survival through the hydropower system. In 2019, spill levels were again increased, to levels that produce the maximum allowable percentage of total dissolved gas in the tailrace (120%). This additional spill appears to have further reduced detection probabilities, especially in the lower Columbia River.

Lower detection probabilities greatly reduce the precision of survival estimates from PIT-tag data. In light of present operations, which have reduced detection probabilities to very low levels at some sites, we believe the need is increasingly urgent to develop PIT-tag detection capability in passage routes other than the bypass system.

Specifically, the region should continue to place high priority on development and installation of PIT-monitoring systems for conventional spillways as well as for surface-passage structures. In 2020, a new PIT-tag detection system is scheduled to become operational in the RSW spillbay of Lower Granite Dam. We have high hopes for the success of this new system, and recommend that similar systems be installed at other dams on the Snake and Columbia Rivers.

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 PIT-tag data. Because of its low cost and long life, the PIT tag allows nearly 2 million individual fish to be tagged annually and monitored through both the juvenile and adult migration. At present, there is no other tagging method that allows direct comparison of smolt-to-adult return ratios between 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 existing levels of tagging.

Contents

Introduction

Accurate and precise estimates of survival are critical for recovery of depressed stocks of Pacific salmon *Oncorhynchus* spp. that 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 smolt 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 2019, the National Marine Fisheries Service (NMFS) has estimated survival for Pacific salmon 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, Widener et al. 2018, 2019). These annual survival estimates are based on data from detections of juvenile salmonids implanted with passive integrated transponder (PIT) tags (Prentice et al. 1990a). Here we report results for smolts that migrated in spring 2019, the 27th year of the study. Research objectives in 2019 were:

1) Estimate reach survival and travel time throughout the yearling Chinook salmon and steelhead juvenile migration period
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 probability 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 2019 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 annual multi-agency *Comparative Survival Study* (e.g., McCann et al. 2019).

Tagged study fish are detected at dams with monitoring facilities only if they were diverted into the juvenile bypass systems at those dams (Figure 1). The following eight sites on the mainstem Snake and Columbia rivers were equipped with monitoring facilities in 2019 (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)

During 2019, the farthest downstream detection site was in the Columbia River estuary, where NMFS operated a pair-trawl detection system (Ledgerwood et al. 2004). Besides the juvenile bypass system in Powerhouse 2 at Bonneville Dam, a second passage route has been monitored since 2006; the corner collector in Powerhouse 2. Using the SR model, detection at the last downstream site (pair-trawl system) is required for an estimate of survival to the second-to-last downstream detection site (Bonneville Dam). In 2019, 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, though the resulting estimates were often imprecise.

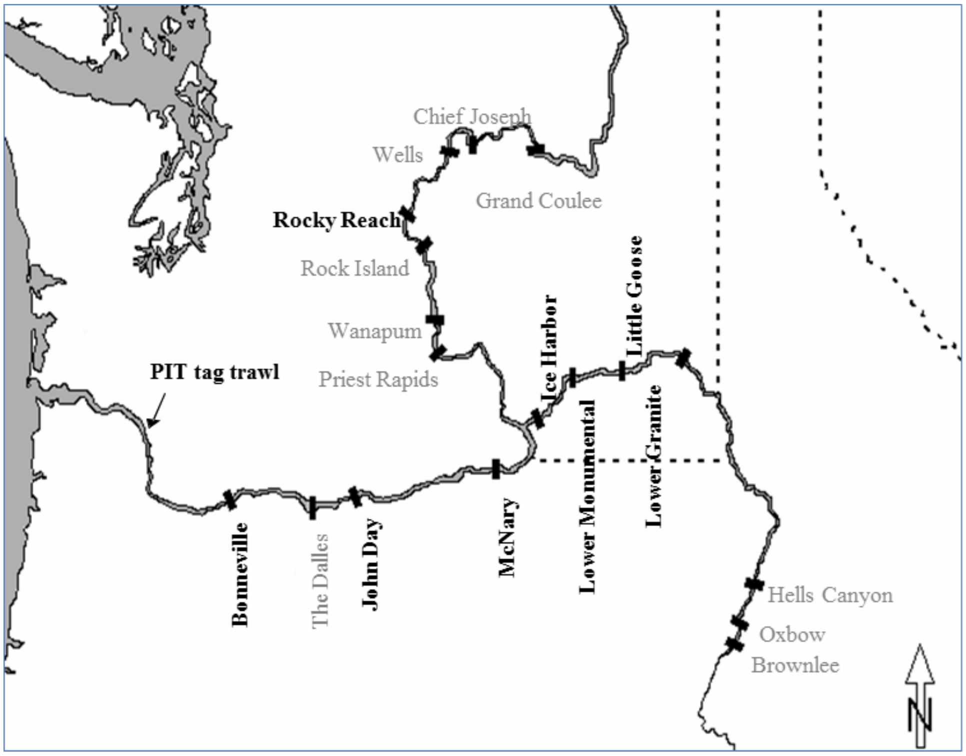


Figure 1. Study area showing the eight sites with PIT-tag detection capability in boldface, including seven dams and the PIT-tag trawl in the Columbia River estuary. Dams with names in gray do not have detection facilities.

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 estimated 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 2019. 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 Dam. From 2006 to 2019, 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, with all estimates between dams spanning tailrace to tailrace:

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

Study Fish

Releases from Lower Granite Dam—During 2019, we collected hatchery and wild steelhead *O. mykiss* and wild yearling Chinook salmon smolts at the Lower Granite Dam juvenile bypass facility. Fish were PIT tagged and released to the tailrace for the express purpose of estimating downstream survival. Numbers of 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. We tagged relatively more fish during the early and late periods to ensure adequate detection numbers for estimates during these periods.

No hatchery yearling Chinook 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 early and late in the season, some daily groups were too small, even when pooled, to form weekly groups of sufficient size for reliable estimates of either survival or travel time. These fish were excluded from analyses of survival for daily or weekly groups.

At Lower Granite Dam, we PIT tagged and released 20,926 hatchery steelhead, 14,791 wild steelhead, and 6,366 wild yearling Chinook salmon from 3 April through 15 June 2019 (Table 1). From these numbers, total tagging mortalities were 14, 11, and 15 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. Tag codes from mortalities and shed tags were removed from the dataset before analysis.

A total of 32,341 yearling Chinook salmon (22,369 hatchery, 9,962 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 71,623 steelhead (54,368 hatchery, 17,254 wild) were tagged and released or detected and returned to the tailrace of Lower Granite Dam.

We estimated that 90.1% of the overall yearling Chinook run was of hatchery origin in 2019. This estimate was based on counts of the run at large (both tagged and non-tagged fish) by the Fish Passage Center and on our own estimates of daily detection probability at Lower Granite Dam (based on tagged fish only).

We estimated that 89.7% of the overall steelhead run was of hatchery origin in 2019. The estimate for steelhead was based on unpublished data from the *Smolt Monitoring Program* (Fish Passage Center), using fin erosion as a marker to distinguish hatchery-origin fish from wild fish.

In the combined PIT-tagged groups used to estimate survival, estimated proportions of hatchery fish were 69% for yearling Chinook salmon and 76% for steelhead. Our tagging at Lower Granite Dam intentionally emphasizes wild fish; without this emphasis, their numbers would likely be insufficient for separate estimates of survival. As a result, the combined wild and hatchery groups used for analyses have a higher proportion of wild fish than do the overall runs.

Table 1. Number by date of hatchery and wild steelhead, and wild yearling Chinook salmon PIT tagged and released at Lower Granite Dam for survival estimates in 2019. 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
3 Apr	726	-	-	115	-	1	229	1	-
4 Apr	314	-	-	125	-	-	513	1	-
10 Apr	717	-	-	191	-	-	112	1	-
11 Apr	736	-	-	158	-	-	93	-	-
17 Apr	925	-	-	260	-	-	233	-	-
18 Apr	912	1	-	358	1	-	137	-	-
23 Apr	787	-	-	797	-	-	75	1	-
24 Apr	760	-	-	306	-	-	85	1	-
25 Apr	703	1	-	548	-	-	298	-	-
26 Apr	716	-	-	568	-	-	231	-	-
27 Apr	595	3	-	466	2	-	365	1	-
30 Apr	813	-	-	580	-	-	510	1	-
1 May	821	-	-	621	1	-	346	2	-
2 May	800	1	2	537	1	1	216	1	-
3 May	799	2	-	343	-	-	225	-	-
9 May	1,486	3	4	678	-	-	347	1	-
10 May	1,254	1	1	680	-	-	187	-	-
11 May	628	-	-	695	-	-	208	1	-
14 May	497	-	4	851	1	3	428	1	1
16 May	1,018	-	7	641	-	2	241	-	-
17 May	759	-	-	470	-	-	241	-	-
18 May	221	1	-	499	1	1	202	-	-
21 May	410	-	1	734	-	1	87	1	-
22 May	414	-	2	443	1	2	113	-	-
23 May	440	-	-	370	-	-	158	-	1
24 May	404	-	-	338	1	1	76	1	-
25 May	114	-	1	365	1	3	78	-	-
29 May	303	-	-	293	-	3	62	-	-
30 May	303	1	-	379	-	2	112	-	-
31 May	306	-	4	297	-	1	77	-	-
1 Jun	150	-	-	171	1	-	64	-	-
4 Jun	154	-	-	229	-	1	-	-	-
5 Jun	151	-	-	197	-	1	-	-	-
6 Jun	149	-	1	135	-	-	-	-	-
7 Jun	150	-	-	91	-	-	-	-	-
8 Jun	50	-	-	61	-	-	-	-	-
11 Jun	125	-	-	50	-	-	-	-	-
12 Jun	202	-	-	56	-	-	-	-	-
13 Jun	40	-	-	32	-	-	-	-	-
14 Jun	16	-	-	15	-	-	-	-	-
15 Jun	17	-	-	14	-	-	-	-	-
	20,885	14	27	14,757	11	23	6,349	15	2

Releases from McNary Dam—For tagged yearling Chinook and steelhead released from locations throughout the Snake River Basin, 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 and biweekly groups for analyses. For Snake River fish, we report estimated survival from McNary to John Day and from John Day to Bonneville Dam for biweekly groups only, as detection data in 2019 were too sparse to estimate survival for daily or weekly groups.

For tagged yearling Chinook and steelhead released from locations throughout the Columbia River Basin upstream from McNary Dam, we created virtual daily, weekly, and biweekly groups in the same way as for Snake River fish. However, these groups were not sufficient for estimates downstream from McNary Dam. Instead, we pooled all fish into a single group for the entire year, and used the pooled data for estimates.

Releases from Hatcheries and Smolt Traps—In 2019, 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 wild and hatchery yearling Chinook, steelhead, and wild sockeye that had been caught, PIT tagged, and released from smolt traps throughout the Snake River Basin. These estimates included the Salmon (White Bird), Snake, Grand Ronde, and Redfish Lake Creek traps.

Data Analysis

Tagging and detection data were first downloaded on 2 August 2019, and again on 8 November 2019 (see below) 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%).

We published a memo of preliminary survival estimates for 2019 on 19 September 2019. We subsequently learned that yearling Chinook reared at Pahsimeroi Hatchery in 2019 suffered an outbreak of bacterial kidney disease (BKD) just prior to release (Doug Engemann pers. comm. 2019). These diseased fish were likely not representative of yearling Chinook populations throughout the wider Snake River basin.

Therefore, we proceeded with separate estimates of survival and detection probability for the Pahsimeroi group, but for estimates of survival downstream from Lower Granite or McNary Dam, we removed fish known to be of Pahsimeroi Hatchery origin from the dataset used to create daily virtual release groups. Accordingly, tagging and detection data were re-downloaded from PTAGIS on 8 November 2019, and fish tagged at Pahsimeroi Hatchery were eliminated from all across-population datasets.

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, as well as disposition after detection for each detected fish. 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 8 November 2019. It is possible that data in the PTAGIS database may have been updated or corrected after this date. Thus, estimates we provide or data used for future analyses may differ slightly from those presented here.

Tests of Assumptions—We evaluated assumptions of the SR model as applied to the detection-history data generated from PIT-tagged juvenile salmonids in the Snake and Columbia Rivers (Burnham et al. 1987). Chi-square contingency tests were used to evaluate model assumptions, with assumption violations indicated by significant differences between observed and expected proportions of fish in different detection-history categories (Appendix A).

In many cases, sample sizes were large enough that these tests had sufficient power to detect very small violations of model assumptions. For most SR 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 of our survival estimates were calculated from a release point or from the tailrace of an upstream 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; Lady et al. 2013).

Estimates of survival probability under the SR model are random variables, subject to sampling variability, and the SR model does not constrain parameter estimates to below 1.0. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for these estimates to exceed 1.0, even when model assumptions are not violated. 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 from the same stock, we calculated a weighted average of these estimates over the migration season. When these series extended across all or most of the season, we considered this weighted average to be the seasonal average for the year. For each estimate in the series, the weight was inversely proportional to the estimated relative variance (coefficient of variation squared) of the survival estimate.

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. 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 virtual daily groups of fish released from Lower Granite Dam.
3) Weighted mean estimated survival from McNary to Bonneville Dam for virtual weekly 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 nine consecutive weeks during 23 March-31 May (Table 2). Mean estimated survival was 0.874 (SE 0.015) from Lower Granite to Little Goose, 0.953 (0.027) from Little Goose to Lower Monumental, and 0.792 (0.032) from Lower Monumental to McNary Dam. For the combined reaches from Lower Granite to McNary Dam, mean estimated survival was 0.628 (0.027).

Table 2. Estimated survival probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	320	0.832 (0.075)	1.035 (0.234)	0.597 (0.183)	0.514 (0.110)
30 Mar–5 Apr	3,548	0.836 (0.034)	0.951 (0.072)	0.692 (0.075)	0.550 (0.047)
6–12 Apr	4,914	0.853 (0.026)	0.962 (0.060)	0.709 (0.064)	0.582 (0.041)
13–19 Apr	3,673	0.783 (0.022)	0.997 (0.059)	0.919 (0.114)	0.717 (0.080)
20–26 Apr	4,891	0.953 (0.025)	0.929 (0.051)	0.885 (0.103)	0.784 (0.082)
27 Apr–3 May	4,851	0.885 (0.040)	1.008 (0.080)	0.754 (0.097)	0.673 (0.074)
4 –10 May	3,516	0.957 (0.080)	0.955 (0.133)	0.648 (0.119)	0.593 (0.087)
11–17 May	4,195	0.893 (0.032)	0.956 (0.056)	0.869 (0.107)	0.741 (0.085)
18–24 May	1,477	0.958 (0.068)	0.794 (0.084)	0.894 (0.180)	0.681 (0.126)
25–31 May	538	1.158 (0.238)	0.631 (0.180)	0.812 (0.273)	0.593 (0.162)
Weighted mean*		**0.874 (0.015)**	**0.953 (0.027)**	**0.792 (0.032)**	**0.628 (0.027)**

* Weighted mean estimates for daily groups (25 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 8 consecutive weeks during 6 April-31 May. Detection probabilities in 2019 were low at McNary and Bonneville Dam and in the pair trawl detection system; thus, these estimates were imprecise. We pooled weekly groups into four biweekly groups to increase precision (Table 3). Mean estimated survival was 1.015 (SE 0.088) from McNary to John Day, 0.798 (0.111) from John Day to Bonneville, and 0.825 (0.060) for the combined reaches from McNary to Bonneville Dam.

Table 3. Estimated survival probabilities for biweekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected at McNary Dam and released to the tailrace in 2019. Daily groups were pooled for biweekly estimates, and weighted means are of independent estimates for biweekly 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
6–19 Apr	617	0.710 (0.123)	1.891 (1.845)	1.342 (1.290)
20 Apr–3 May	3,395	1.092 (0.117)	0.785 (0.187)	0.858 (0.182)
4–17 May	5,015	0.984 (0.135)	0.742 (0.208)	0.730 (0.178)
18–31 May	2,148	1.199 (0.225)	0.746 (0.368)	0.894 (0.408)
Weighted mean		**1.015 (0.088)**	**0.798 (0.111)**	**0.825 (0.060)**

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 0.518 (SE 0.044) from the tailrace of Lower Granite Dam to Bonneville Dam. For combined wild and hatchery yearling Chinook salmon released from the Snake River trap, estimated survival was 0.785 (0.027) from release to the tailrace of Lower Granite Dam. Thus, estimated survival probability through all eight hydropower projects encountered by Snake River yearling Chinook salmon was 0.407 (SE 0.037).

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for weekly groups of hatchery vs. wild yearling Chinook (Table 4). Survival from Lower Granite to McNary Dam was higher for wild than for hatchery fish from early weekly groups (30 Mar-19 April) but higher for hatchery than wild fish from later weekly groups (20 Apr-24 May) (Table 4). Weighted mean estimated survival across the season was higher for wild than for hatchery Chinook salmon, but the difference was not significant.

Table 4. Estimated survival probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild separately) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	262	0.802 (0.074)	1.079 (0.276)	0.555 (0.199)	0.480 (0.119)
30 Mar–5 Apr	2,575	0.846 (0.046)	0.864 (0.085)	0.698 (0.092)	0.511 (0.051)
6–12 Apr	4,107	0.825 (0.030)	0.941 (0.068)	0.744 (0.077)	0.578 (0.046)
13–19 Apr	2,890	0.779 (0.029)	1.084 (0.092)	0.789 (0.124)	0.667 (0.089)
20–26 Apr	3,522	0.909 (0.030)	0.933 (0.066)	0.980 (0.141)	0.831 (0.107)
27 Apr–3 May	2,673	0.938 (0.074)	1.039 (0.140)	0.688 (0.137)	0.670 (0.111)
4–10 May	2,645	1.061 (0.130)	1.053 (0.223)	0.609 (0.159)	0.680 (0.133)
11–17 May	2,670	0.963 (0.057)	0.932 (0.087)	0.925 (0.181)	0.831 (0.151)
18–24 May	686	0.992 (0.121)	0.840 (0.160)	0.971 (0.407)	0.809 (0.318)
Weighted mean		**0.864 (0.024)**	**0.960 (0.026)**	**0.781 (0.041)**	**0.634 (0.040)**
		Wild yearling Chinook			
30 Mar–5 Apr	973	0.855 (0.052)	1.083 (0.131)	0.703 (0.137)	0.651 (0.106)
6–12 Apr	804	1.008 (0.056)	0.990 (0.117)	0.635 (0.116)	0.633 (0.094)
13–19 Apr	782	0.854 (0.035)	0.887 (0.069)	1.121 (0.234)	0.850 (0.168)
20–26 Apr	1,369	1.067 (0.044)	0.875 (0.076)	0.741 (0.144)	0.691 (0.124)
27 Apr–3 May	2,175	0.885 (0.047)	0.960 (0.093)	0.786 (0.132)	0.668 (0.098)
4–10 May	870	0.938 (0.104)	0.836 (0.148)	0.610 (0.154)	0.479 (0.102)
11–17 May	1,524	0.890 (0.038)	0.950 (0.069)	0.832 (0.130)	0.704 (0.102)
18–24 May	791	0.949 (0.082)	0.775 (0.098)	0.896 (0.203)	0.659 (0.137)
25–31 May	398	1.230 (0.293)	0.635 (0.216)	0.818 (0.324)	0.639 (0.202)
Weighted mean		**0.934 (0.030)**	**0.921 (0.028)**	**0.792 (0.049)**	**0.669 (0.028)**

We also 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 pooling groups over two or more consecutive days to create sufficient sample sizes for survival probability estimates.

Statistical sampling error in these daily estimates was high in 2019, which made it difficult to assess within-season trends in survival through Snake River reaches (Table 5; Figure 2). Survival appeared to be mostly below the mean from March through mid-April and mostly above the mean in late April and early May, but estimates through the remainder of May and June were too variable and imprecise to determine an overall trend.

Table 5. Estimated survival probabilities for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Consecutive daily groups were pooled as needed for sufficient sample size. 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
25 Mar	13	1.154 (0.503)	0.600 (0.498)	0.444 (0.406)	0.308 (0.200)
26–27 Mar	150	0.783 (0.077)	1.077 (0.293)	0.766 (0.336)	0.646 (0.221)
28 Mar	89	1.022 (0.273)	1.044 (0.659)	0.400 (0.294)	0.427 (0.183)
29 Mar	68	0.853 (0.224)	1.009 (0.587)	0.489 (0.334)	0.421 (0.170)
30 Mar	180	1.176 (0.300)	0.576 (0.230)	0.411 (0.167)	0.278 (0.076)
31 Mar	625	0.991 (0.119)	0.700 (0.134)	0.688 (0.170)	0.478 (0.093)
1 Apr	823	0.767 (0.070)	1.148 (0.211)	0.570 (0.142)	0.502 (0.091)
2 Apr	725	0.807 (0.075)	0.881 (0.149)	0.799 (0.194)	0.569 (0.110)
3 Apr	433	0.753 (0.088)	0.924 (0.191)	0.769 (0.237)	0.535 (0.138)
4 Apr	663	0.866 (0.063)	1.120 (0.170)	0.844 (0.220)	0.820 (0.182)
5 Apr	99	0.698 (0.129)	1.324 (0.582)	0.616 (0.347)	0.570 (0.203)
6 Apr	135	0.646 (0.103)	0.935 (0.291)	0.824 (0.366)	0.498 (0.180)
7–8 Apr	467	0.795 (0.064)	1.317 (0.266)	0.712 (0.232)	0.746 (0.192)
9 Apr	837	0.880 (0.066)	0.795 (0.110)	0.673 (0.120)	0.471 (0.063)
10 Apr	1,641	0.999 (0.060)	0.786 (0.088)	0.891 (0.156)	0.699 (0.102)
11 Apr	1,300	0.773 (0.046)	1.091 (0.135)	0.594 (0.102)	0.501 (0.063)
12 Apr	534	0.731 (0.057)	1.374 (0.263)	0.655 (0.193)	0.658 (0.148)

Table 5. Continued.

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
13 Apr	479	0.697 (0.058)	1.161 (0.219)	0.633 (0.192)	0.513 (0.120)
14–15 Apr	948	0.794 (0.052)	0.920 (0.111)	1.319 (0.390)	0.963 (0.265)
16 Apr	636	0.812 (0.059)	1.340 (0.268)	0.424 (0.122)	0.462 (0.093)
17 Apr	729	0.760 (0.041)	0.899 (0.088)	1.111 (0.270)	0.759 (0.173)
18–19 Apr	881	0.826 (0.044)	0.994 (0.123)	1.221 (0.405)	1.002 (0.310)
20–21 Apr	1,126	0.870 (0.044)	1.288 (0.207)	1.032 (0.338)	1.157 (0.326)
22 Apr	920	0.997 (0.064)	0.812 (0.112)	1.047 (0.258)	0.848 (0.180)
23 Apr	638	0.906 (0.063)	0.953 (0.124)	1.250 (0.441)	1.079 (0.361)
24 Apr	616	0.888 (0.055)	0.821 (0.093)	0.780 (0.179)	0.568 (0.120)
25 Apr	925	1.018 (0.062)	0.883 (0.112)	0.608 (0.151)	0.546 (0.121)
26 Apr	666	1.007 (0.081)	0.812 (0.120)	1.092 (0.422)	0.892 (0.327)
27 Apr	657	0.948 (0.078)	0.879 (0.137)	0.582 (0.146)	0.485 (0.103)
28 Apr	563	0.891 (0.102)	1.061 (0.256)	0.881 (0.368)	0.833 (0.299)
29 Apr	653	0.796 (0.089)	1.226 (0.273)	0.588 (0.199)	0.573 (0.159)
30 Apr	1,044	1.030 (0.123)	0.803 (0.151)	0.901 (0.296)	0.745 (0.220)
1 May	849	0.944 (0.136)	0.952 (0.207)	1.172 (0.474)	1.053 (0.390)
2 May	471	0.688 (0.093)	1.410 (0.348)	0.565 (0.203)	0.549 (0.159)
3 May	614	0.897 (0.140)	0.976 (0.263)	0.870 (0.326)	0.761 (0.231)
4–6 May	1,142	0.944 (0.138)	1.017 (0.266)	1.051 (0.453)	1.008 (0.376)
7 May	531	0.919 (0.241)	1.174 (0.524)	0.582 (0.328)	0.628 (0.270)
8 May	530	1.943 (1.047)	0.533 (0.360)	0.311 (0.167)	0.323 (0.114)
9 May	746	0.864 (0.160)	0.717 (0.189)	0.844 (0.295)	0.522 (0.155)
10 May	567	1.126 (0.154)	1.106 (0.294)	0.464 (0.155)	0.578 (0.140)
11 May	462	0.900 (0.127)	0.792 (0.178)	0.614 (0.214)	0.437 (0.133)
12–13 May	683	0.837 (0.114)	1.276 (0.281)	0.821 (0.324)	0.877 (0.310)
14 May	952	0.798 (0.059)	1.022 (0.116)	1.161 (0.350)	0.947 (0.274)
15 May	695	0.956 (0.073)	0.962 (0.126)	1.063 (0.368)	0.978 (0.322)
16 May	845	0.941 (0.060)	0.885 (0.094)	0.888 (0.203)	0.740 (0.157)
17 May	558	0.989 (0.093)	0.892 (0.153)	0.565 (0.163)	0.498 (0.125)
18 May	595	0.957 (0.088)	0.697 (0.095)	1.245 (0.498)	0.830 (0.322)
19–21 May	415	0.823 (0.096)	1.720 (0.481)	0.596 (0.303)	0.845 (0.369)
22 May	166	1.043 (0.231)	0.552 (0.164)	0.621 (0.212)	0.358 (0.105)
23 May	188	1.613 (0.796)	0.458 (0.249)	0.919 (0.372)	0.680 (0.236)
24–31 May	651	1.328 (0.280)	0.520 (0.142)	0.917 (0.286)	0.633 (0.167)
Weighted mean		**0.874 (0.015)**	**0.953 (0.027)**	**0.792 (0.032)**	**0.628 (0.027)**

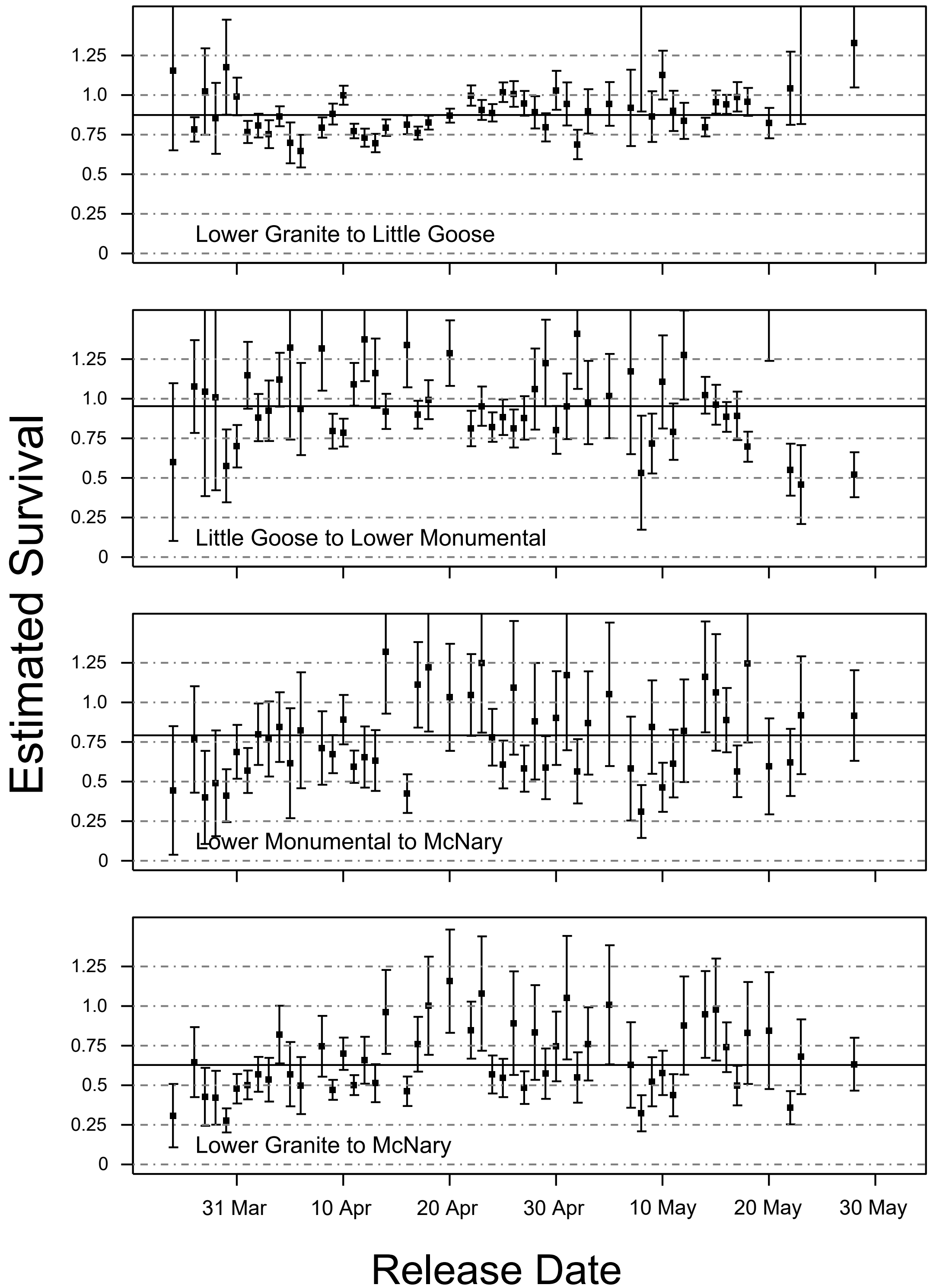


Figure 2. Estimated survival probabilities through various reaches vs. release date at Lower Granite Dam for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined), 2019. Whiskers extend one standard error above and below point estimates. Solid horizontal lines indicate annual mean estimates (weighted mean of daily 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 Lower Monumental and lowest at John Day and McNary Dams. After the beginning of May, detection probability dropped substantially at all Columbia River dams. Detection probability estimates at Snake River dams 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 or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	320	0.383 (0.044)	0.218 (0.052)	0.255 (0.064)
30 Mar–5 Apr	3,548	0.252 (0.013)	0.229 (0.017)	0.156 (0.016)
6–12 Apr	4,914	0.298 (0.011)	0.255 (0.015)	0.168 (0.014)
13–19 Apr	3,673	0.361 (0.013)	0.338 (0.019)	0.109 (0.014)
20–26 Apr	4,891	0.344 (0.011)	0.302 (0.016)	0.105 (0.012)
27 Apr–3 May	4,851	0.182 (0.010)	0.177 (0.013)	0.096 (0.012)
4 –10 May	3,516	0.111 (0.011)	0.103 (0.013)	0.074 (0.012)
11–17 May	4,195	0.218 (0.010)	0.272 (0.015)	0.074 (0.010)
18–24 May	1,477	0.190 (0.017)	0.276 (0.025)	0.082 (0.017)
25–31 May	538	0.106 (0.025)	0.155 (0.036)	0.120 (0.037)

Table 7. Estimated detection probabilities for biweekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected at McNary Dam and released to the tailrace in 2019. Daily groups were pooled for biweekly 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
6–19 Apr	617	0.318 (0.059)	0.056 (0.054)
20 Apr–3 May	3,395	0.095 (0.011)	0.211 (0.045)
4–17 May	5,015	0.071 (0.010)	0.144 (0.036)
18–31 May	2,148	0.072 (0.014)	0.155 (0.071)

Table 8. Estimated detection probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild separately) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	262	0.424 (0.050)	0.225 (0.061)	0.237 (0.069)
30 Mar–5 Apr	2,575	0.234 (0.016)	0.230 (0.021)	0.155 (0.019)
6–12 Apr	4,107	0.288 (0.013)	0.251 (0.017)	0.164 (0.015)
13–19 Apr	2,890	0.331 (0.016)	0.282 (0.023)	0.103 (0.016)
20–26 Apr	3,522	0.338 (0.014)	0.282 (0.019)	0.096 (0.014)
27 Apr–3 May	2,673	0.135 (0.013)	0.136 (0.016)	0.078 (0.014)
4–10 May	2,645	0.083 (0.011)	0.066 (0.012)	0.060 (0.013)
11–17 May	2,670	0.162 (0.012)	0.222 (0.018)	0.053 (0.011)
18–24 May	686	0.165 (0.025)	0.232 (0.038)	0.048 (0.021)
		Wild Yearling Chinook		
30 Mar–5 Apr	973	0.286 (0.023)	0.234 (0.028)	0.156 (0.029)
6–12 Apr	804	0.336 (0.025)	0.281 (0.033)	0.178 (0.032)
13–19 Apr	782	0.440 (0.026)	0.459 (0.036)	0.125 (0.028)
20–26 Apr	1,369	0.356 (0.019)	0.363 (0.030)	0.130 (0.026)
27 Apr–3 May	2,175	0.231 (0.016)	0.221 (0.020)	0.118 (0.019)
4–10 May	870	0.174 (0.023)	0.202 (0.032)	0.108 (0.027)
11–17 May	1,524	0.295 (0.017)	0.341 (0.024)	0.105 (0.018)
18–24 May	791	0.208 (0.023)	0.306 (0.034)	0.106 (0.026)
25–31 May	398	0.106 (0.029)	0.145 (0.040)	0.135 (0.047)

Snake River Steelhead

Survival Probabilities—For weekly groups of steelhead, we estimated probabilities of survival from Lower Granite to multiple downstream dams for 11 consecutive weeks during 23 March-7 June (Table 9). Mean estimated survival was 0.968 (SE 0.006) from Lower Granite to Little Goose, 0.981 (0.011) from Little Goose to Lower Monumental, and 0.774 (0.019) from Lower Monumental to McNary Dam. For the combined reaches from Lower Granite to McNary Dam, estimated survival averaged 0.717 (0.017).

Table 9. Estimated survival probabilities for weekly groups of Snake River juvenile steelhead (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	587	0.894 (0.015)	1.102 (0.077)	0.646 (0.098)	0.637 (0.083)
30 Mar–5 Apr	3,343	0.891 (0.030)	1.030 (0.057)	0.765 (0.056)	0.702 (0.041)
6–12 Apr	12,593	0.964 (0.010)	0.993 (0.021)	0.763 (0.032)	0.730 (0.027)
13–19 Apr	10,088	0.949 (0.013)	0.974 (0.022)	0.858 (0.057)	0.793 (0.050)
20–26 Apr	13,467	0.994 (0.008)	0.988 (0.020)	0.751 (0.047)	0.738 (0.044)
27 Apr–3 May	9,593	0.981 (0.021)	0.918 (0.036)	0.732 (0.080)	0.659 (0.068)
4–10 May	5,097	0.981 (0.062)	0.865 (0.075)	0.920 (0.172)	0.780 (0.139)
11–17 May	6,825	1.019 (0.052)	0.889 (0.062)	0.772 (0.109)	0.700 (0.093)
18–24 May	4,931	1.004 (0.064)	0.865 (0.076)	0.668 (0.101)	0.580 (0.080)
25–31 May	2,554	0.808 (0.085)	1.043 (0.151)	0.821 (0.195)	0.692 (0.148)
1–7 Jun	1,804	1.075 (0.124)	0.894 (0.166)	0.620 (0.216)	0.596 (0.189)
Weighted mean*		**0.968 (0.006)**	**0.981 (0.011)**	**0.774 (0.019)**	**0.717 (0.017)**

* Weighted mean of estimates for daily groups (25 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 over 10 consecutive weeks during 6 April-14 June. Detection probabilities were low at McNary and Bonneville Dam and in the pair trawl detection system; thus, these estimates were very imprecise. To increase precision, we pooled the 10 weekly groups into 5 biweekly groups (Table 10).

From these biweekly groups, pooled overall estimated mean survival was 1.029 (SE 0.084) from McNary to John Day, 0.734 (SE 0.110) from John Day to Bonneville, and 0.595 (SE 0.109) 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 Snake River juvenile steelhead (hatchery and wild combined) detected at McNary Dam and released to the tailrace in 2019. Daily groups were pooled for biweekly estimates, and weighted means are of independent estimates for biweekly 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
6–19 Apr	3,529	1.117 (0.089)	0.719 (0.254)	0.803 (0.277)
20 Apr–3 May	2,654	1.045 (0.088)	0.864 (0.232)	0.904 (0.230)
4–17 May	969	1.014 (0.265)	0.441 (0.150)	0.448 (0.097)
18–31 May	633	0.587 (0.121)	0.662 (0.220)	0.389 (0.103)
1–14 Jun	202	0.323 (0.116)	1.410 (0.954)	0.455 (0.269)
Overall mean		**1.029 (0.084)**	**0.734 (0.110)**	**0.595 (0.109)**

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 0.427 (SE 0.079) from the tailrace of Lower Granite Dam to Bonneville Dam. For wild and hatchery steelhead released from the Snake River trap, estimated survival probability to Lower Granite Dam tailrace was 0.965 (0.027). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.412 (0.077).

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 wild than for hatchery steelhead released in the same week, but precision was poor for almost all wild cohorts, making the true relationship between hatchery and wild survival uncertain.

Table 11. Estimated survival probabilities for weekly groups of Snake River juvenile steelhead (hatchery and wild separately) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	571	0.891 (0.016)	1.116 (0.078)	0.647 (0.098)	0.644 (0.084)
30 Mar–5 Apr	3,038	0.892 (0.032)	1.045 (0.063)	0.741 (0.057)	0.691 (0.041)
6–12 Apr	11,928	0.965 (0.010)	0.992 (0.022)	0.748 (0.032)	0.716 (0.027)
13–19 Apr	9,284	0.942 (0.013)	0.986 (0.024)	0.850 (0.060)	0.790 (0.053)
20–26 Apr	10,734	0.998 (0.010)	0.993 (0.024)	0.728 (0.054)	0.722 (0.051)
27 Apr–3 May	6,627	0.967 (0.025)	0.911 (0.040)	0.765 (0.099)	0.674 (0.084)
4–10 May	3,448	0.968 (0.071)	0.927 (0.096)	0.827 (0.173)	0.743 (0.146)
11–17 May	3,799	1.018 (0.072)	0.914 (0.083)	0.701 (0.120)	0.652 (0.105)
18–24 May	2,385	0.931 (0.081)	0.937 (0.117)	0.718 (0.169)	0.627 (0.136)
25–31 May	1,155	0.773 (0.095)	1.099 (0.196)	0.689 (0.208)	0.585 (0.158)
1–7 Jun	909	1.071 (0.179)	1.073 (0.300)	0.417 (0.188)	0.479 (0.187)
Weighted mean		**0.963 (0.011)**	**0.989 (0.012)**	**0.756 (0.016)**	**0.714 (0.013)**
	Wild steelhead				
30 Mar–5 Apr	305	0.884 (0.091)	0.924 (0.138)	1.081 (0.305)	0.882 (0.232)
6–12 Apr	664	0.963 (0.033)	0.982 (0.073)	0.991 (0.147)	0.937 (0.124)
13–19 Apr	804	1.022 (0.050)	0.869 (0.065)	0.926 (0.199)	0.823 (0.171)
20–26 Apr	2,733	0.981 (0.015)	0.966 (0.038)	0.784 (0.092)	0.743 (0.083)
27 Apr–3 May	2,966	0.993 (0.038)	1.000 (0.084)	0.596 (0.120)	0.591 (0.111)
4–10 May	1,649	1.014 (0.123)	0.734 (0.118)	1.272 (0.534)	0.946 (0.384)
11–17 May	3,026	0.989 (0.073)	0.888 (0.096)	0.908 (0.225)	0.798 (0.187)
18–24 May	2,546	1.079 (0.100)	0.799 (0.100)	0.634 (0.125)	0.546 (0.097)
25–31 May	1,399	0.930 (0.180)	0.901 (0.223)	1.008 (0.380)	0.845 (0.289)
1–7 Jun	895	1.076 (0.172)	0.755 (0.186)	0.977 (0.551)	0.794 (0.421)
Weighted mean		**0.983 (0.008)**	**0.936 (0.022)**	**0.847 (0.054)**	**0.771 (0.044)**

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). Survival in late March was generally below the seasonal mean, while survival through most of April was either at or above the seasonal mean. During May, precision was poor, and estimates varied from substantially above to substantially below the mean, making it impossible to discern a consistent pattern in survival (Table 12; Figure 3).

Table 12. Estimated survival probabilities for daily groups of Snake River juvenile steelhead (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Consecutive daily groups were pooled as needed for sufficient sample size. 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
25 Mar	31	0.916 (0.055)	0.840 (0.073)	0.544 (0.253)	0.418 (0.199)
26 Mar	54	0.972 (0.027)	1.029 (0.080)	1.038 (0.457)	1.038 (0.447)
27 Mar	170	0.947 (0.020)	1.093 (0.102)	0.665 (0.186)	0.688 (0.177)
28 Mar	139	0.878 (0.037)	1.205 (0.251)	0.579 (0.206)	0.612 (0.162)
29 Mar	193	0.881 (0.042)	1.389 (0.630)	0.433 (0.227)	0.530 (0.118)
30 Mar	357	0.918 (0.062)	1.185 (0.428)	0.509 (0.203)	0.554 (0.087)
31 Mar	467	0.805 (0.083)	1.184 (0.270)	0.622 (0.158)	0.592 (0.082)
1 Apr	597	0.793 (0.083)	1.310 (0.251)	0.648 (0.151)	0.674 (0.106)
2 Apr	388	0.838 (0.105)	1.179 (0.218)	0.815 (0.181)	0.805 (0.139)
3 Apr	957	0.866 (0.051)	1.053 (0.091)	0.716 (0.083)	0.653 (0.063)
4 Apr	505	0.895 (0.068)	0.992 (0.102)	1.266 (0.279)	1.124 (0.235)
5 Apr	72	0.956 (0.182)	1.438 (0.549)	0.480 (0.286)	0.661 (0.320)
6 Apr	181	1.062 (0.104)	0.895 (0.136)	0.934 (0.255)	0.887 (0.220)
7 Apr	382	1.008 (0.097)	1.006 (0.164)	0.618 (0.127)	0.627 (0.101)
8 Apr	1,432	0.956 (0.045)	0.971 (0.072)	0.790 (0.099)	0.733 (0.082)
9 Apr	2,620	1.013 (0.023)	0.968 (0.044)	0.668 (0.057)	0.655 (0.049)
10 Apr	4,126	0.967 (0.014)	1.020 (0.040)	0.757 (0.058)	0.748 (0.051)
11 Apr	3,000	0.930 (0.019)	0.965 (0.041)	0.852 (0.070)	0.765 (0.056)
12 Apr	852	0.876 (0.029)	1.109 (0.081)	0.836 (0.161)	0.812 (0.145)
13 Apr	1,156	0.919 (0.047)	1.004 (0.088)	0.712 (0.125)	0.656 (0.104)
14 Apr	1,612	0.896 (0.029)	1.022 (0.063)	0.765 (0.102)	0.700 (0.085)
15 Apr	1,168	0.980 (0.043)	0.863 (0.069)	0.830 (0.153)	0.702 (0.121)
16 Apr	1,147	0.922 (0.039)	0.927 (0.062)	0.860 (0.184)	0.735 (0.151)

Table 12. Continued.

Date at Lower Granite Dam	Number released	Estimated survival of daily steelhead groups from Lower Granite Dam (SE)			
		Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
17 Apr	2,302	0.998 (0.027)	0.955 (0.042)	0.989 (0.162)	0.943 (0.151)
18 Apr	1,854	0.943 (0.027)	0.992 (0.045)	0.934 (0.146)	0.874 (0.133)
19–20 Apr	1,404	0.980 (0.035)	0.961 (0.062)	1.342 (0.394)	1.264 (0.364)
21 Apr	1,491	0.975 (0.023)	1.023 (0.064)	1.144 (0.334)	1.141 (0.324)
22 Apr	2,622	0.989 (0.016)	0.977 (0.063)	0.586 (0.094)	0.566 (0.083)
23 Apr	2,987	0.959 (0.013)	0.987 (0.036)	0.819 (0.090)	0.775 (0.080)
24 Apr	1,730	1.024 (0.034)	0.981 (0.055)	0.937 (0.174)	0.941 (0.170)
25 Apr	1,972	1.044 (0.025)	0.933 (0.048)	0.791 (0.119)	0.771 (0.111)
26 Apr	2,110	0.997 (0.022)	1.092 (0.065)	0.466 (0.070)	0.508 (0.071)
27 Apr	1,892	1.019 (0.034)	1.015 (0.071)	0.696 (0.157)	0.720 (0.156)
28 Apr	532	1.076 (0.083)	1.064 (0.176)	0.672 (0.418)	0.770 (0.465)
29 Apr	583	0.882 (0.076)	1.052 (0.157)	0.736 (0.327)	0.683 (0.290)
30 Apr	1,922	1.038 (0.052)	0.825 (0.075)	0.658 (0.138)	0.564 (0.110)
1 May	1,814	1.049 (0.062)	0.967 (0.109)	0.625 (0.172)	0.634 (0.163)
2 May	1,542	0.954 (0.059)	0.783 (0.077)	0.796 (0.195)	0.595 (0.139)
3–5 May	1,587	0.912 (0.063)	0.840 (0.096)	1.062 (0.395)	0.815 (0.294)
6–8 May	379	0.911 (0.226)	1.214 (0.496)	0.474 (0.415)	0.524 (0.425)
9 May	2,327	1.014 (0.089)	0.845 (0.099)	0.879 (0.237)	0.753 (0.195)
10 May	2,112	0.954 (0.103)	0.848 (0.128)	1.102 (0.332)	0.891 (0.252)
11 May	1,481	0.921 (0.078)	0.851 (0.124)	0.855 (0.303)	0.670 (0.223)
12 May	115	0.803 (0.188)	1.253 (0.564)	0.407 (0.364)	0.410 (0.327)
13 May	130	1.023 (0.287)	0.924 (0.450)	0.378 (0.338)	0.358 (0.285)
14 May	1,527	0.740 (0.124)	1.128 (0.225)	0.845 (0.257)	0.706 (0.200)
15 May	232	1.026 (0.143)	0.910 (0.214)	0.750 (0.461)	0.700 (0.410)
16 May	1,896	1.071 (0.119)	0.925 (0.130)	0.706 (0.190)	0.699 (0.178)
17 May	1,444	1.250 (0.150)	0.780 (0.116)	0.810 (0.228)	0.789 (0.212)
18 May	883	0.809 (0.106)	0.897 (0.176)	0.726 (0.293)	0.527 (0.199)
19 May	219	1.152 (0.253)	0.675 (0.248)	0.292 (0.223)	0.227 (0.160)
20–21 May	1,302	1.262 (0.201)	0.733 (0.140)	0.764 (0.225)	0.707 (0.195)
22 May	892	1.070 (0.167)	0.725 (0.141)	0.503 (0.124)	0.390 (0.086)
23 May	865	0.983 (0.108)	1.173 (0.253)	0.729 (0.321)	0.841 (0.335)
24 May	770	0.733 (0.193)	1.150 (0.386)	0.817 (0.397)	0.688 (0.302)
25–27 May	575	0.921 (0.275)	0.804 (0.271)	0.929 (0.421)	0.688 (0.292)
28–30 May	1,346	0.769 (0.097)	1.448 (0.316)	0.674 (0.247)	0.750 (0.238)
31 May	633	0.792 (0.196)	0.832 (0.250)	0.831 (0.354)	0.547 (0.211)
Weighted mean		**0.968 (0.006)**	**0.981 (0.011)**	**0.774 (0.019)**	**0.717 (0.017)**

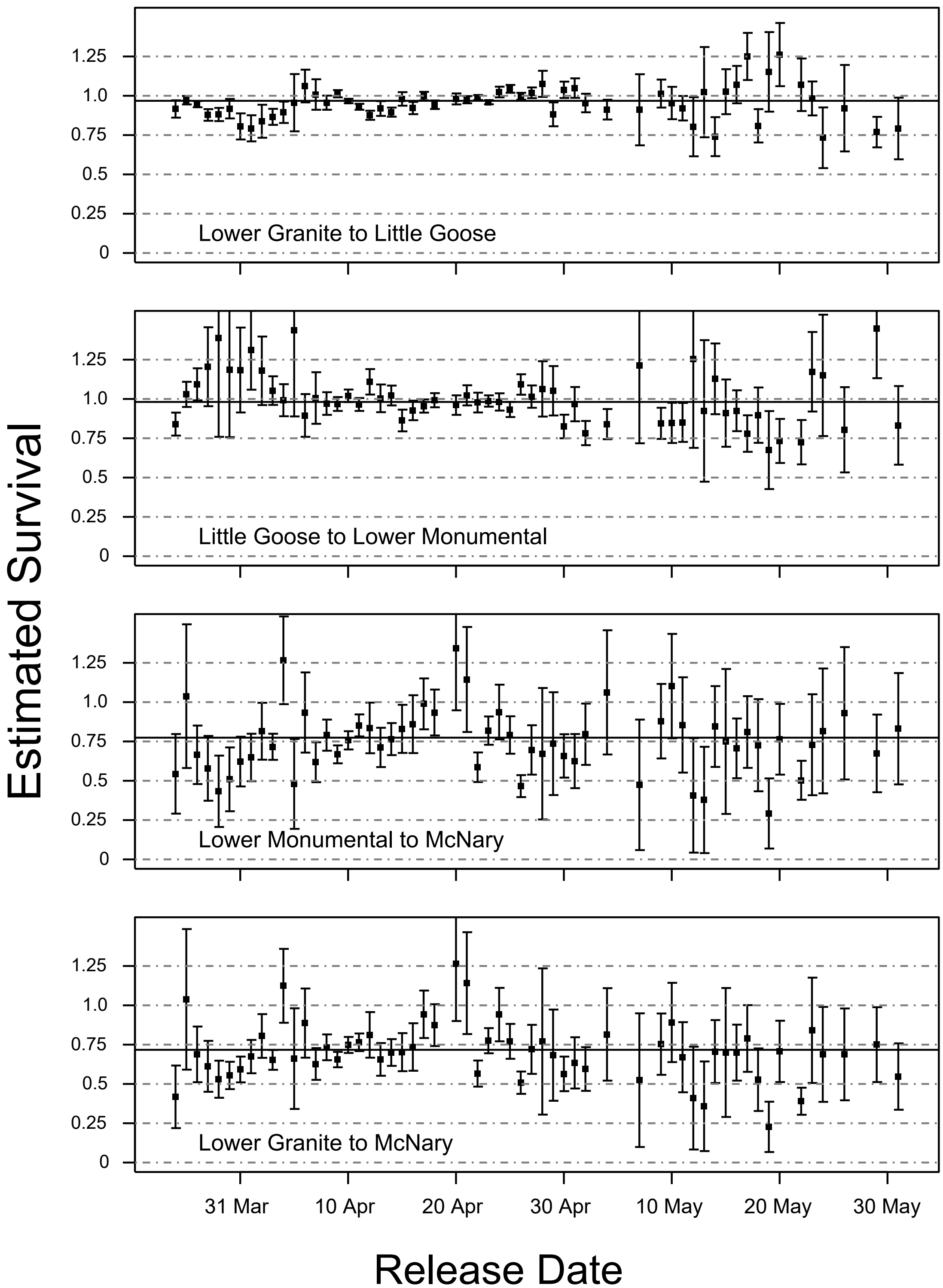


Figure 3. Estimated survival probabilities through various reaches vs. release date at Lower Granite Dam for daily groups of Snake River steelhead (hatchery and wild combined), 2019. Whiskers extend one standard error above and below point estimates. Solid horizontal lines indicate annual mean estimates (weighted mean of daily estimates).

Detection Probabilities—For weekly groups of steelhead, estimated detection probabilities were extremely low at McNary Dam during April and May (Tables 13-15). Detection probability estimates were average at other dams, with the exception of Little Goose and John Day, where detection rates were poor in May. There did not appear to be any consistent difference in detection probability estimates between wild and hatchery steelhead released in the same week (Table 15).

Table 13. Estimated detection probabilities for weekly groups of Snake River juvenile steelhead (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	587	0.888 (0.016)	0.475 (0.041)	0.341 (0.051)
30 Mar–5 Apr	3,343	0.224 (0.011)	0.255 (0.014)	0.194 (0.014)
6–12 Apr	12,593	0.420 (0.006)	0.375 (0.008)	0.145 (0.007)
13–19 Apr	10,088	0.311 (0.006)	0.462 (0.010)	0.064 (0.005)
20–26 Apr	13,467	0.492 (0.006)	0.411 (0.009)	0.063 (0.005)
27 Apr–3 May	9,593	0.259 (0.007)	0.298 (0.011)	0.042 (0.005)
4–10 May	5,097	0.098 (0.008)	0.188 (0.013)	0.029 (0.006)
11–17 May	6,825	0.097 (0.006)	0.223 (0.012)	0.036 (0.006)
18–24 May	4,931	0.099 (0.008)	0.225 (0.015)	0.058 (0.009)
25–31 May	2,554	0.075 (0.010)	0.189 (0.021)	0.054 (0.013)
1–7 Jun	1,804	0.107 (0.014)	0.175 (0.027)	0.046 (0.016)

Table 14. Estimated detection probabilities for biweekly groups of Snake River juvenile steelhead (hatchery and wild combined) detected at McNary Dam and released to the tailrace in 2019. 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
6–19 Apr	3,529	0.222 (0.019)	0.156 (0.054)
20 Apr–3 May	2,654	0.177 (0.017)	0.201 (0.052)
4–17 May	969	0.059 (0.017)	0.414 (0.092)
18–31 May	633	0.108 (0.027)	0.500 (0.134)
1–14 Jun	202	0.138 (0.064)	0.250 (0.153)

Table 15. Estimated detection probabilities for weekly groups of Snake River juvenile steelhead (hatchery and wild separately) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. 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	571	0.891 (0.016)	0.471 (0.041)	0.345 (0.052)
30 Mar–5 Apr	3,038	0.222 (0.011)	0.245 (0.014)	0.201 (0.015)
6–12 Apr	11,928	0.417 (0.006)	0.378 (0.009)	0.145 (0.007)
13–19 Apr	9,284	0.315 (0.007)	0.461 (0.010)	0.065 (0.005)
20–26 Apr	10,734	0.472 (0.007)	0.405 (0.010)	0.056 (0.005)
27 Apr–3 May	6,627	0.246 (0.008)	0.315 (0.013)	0.038 (0.006)
4–10 May	3,448	0.100 (0.009)	0.179 (0.015)	0.032 (0.007)
11–17 May	3,799	0.083 (0.007)	0.247 (0.016)	0.041 (0.008)
18–24 May	2,385	0.107 (0.011)	0.230 (0.022)	0.054 (0.013)
25–31 May	1,155	0.100 (0.016)	0.222 (0.032)	0.070 (0.021)
1–7 Jun	909	0.099 (0.019)	0.151 (0.036)	0.058 (0.025)
			Wild steelhead	
30 Mar–5 Apr	305	0.237 (0.035)	0.359 (0.049)	0.125 (0.039)
6–12 Apr	664	0.463 (0.025)	0.335 (0.029)	0.148 (0.025)
13–19 Apr	804	0.279 (0.021)	0.461 (0.031)	0.061 (0.016)
20–26 Apr	2,733	0.568 (0.013)	0.433 (0.019)	0.087 (0.012)
27 Apr–3 May	2,966	0.292 (0.014)	0.250 (0.020)	0.055 (0.012)
4–10 May	1,649	0.094 (0.013)	0.212 (0.025)	0.021 (0.009)
11–17 May	3,026	0.118 (0.010)	0.190 (0.017)	0.030 (0.008)
18–24 May	2,546	0.092 (0.010)	0.221 (0.020)	0.063 (0.013)
25–31 May	1,399	0.050 (0.011)	0.162 (0.027)	0.041 (0.015)
1–7 Jun	895	0.115 (0.021)	0.200 (0.040)	0.035 (0.020)

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 0.688 (SE 0.013) for Dworshak Hatchery fish released to the North Fork of the Clearwater River to 0.262 (0.013) for Clearwater Hatchery fish released to Red River Pond on the South Fork Clearwater River (Appendix Table B1).

For steelhead, estimated survival to Lower Granite ranged from 0.923 (0.015) for Clearwater Hatchery fish released to the South Fork of the Clearwater River to 0.359 (0.013) for Magic Valley fish released to the Yankee Fork of the Salmon River (Appendix Table B2).

Two groups of hatchery-reared sockeye salmon were released in 2019. Estimated survival to Lower Granite Dam was 0.786 (0.039) for Sawtooth Hatchery fish released in early May at Redfish Lake Creek trap, and 0.603 (0.040) for Springfield Hatchery fish released one or two days earlier at the same site (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 generally lower than in 2018 (not shown) and similar among release groups of the same species and rearing type from different traps (Appendix Table B8).

Estimated detection probabilities at Snake River dams were consistently higher for wild Chinook than for hatchery conspecifics released from the same location (e.g., Grande Ronde and Salmon River traps). Estimated detection probabilities were also higher for wild than hatchery steelhead at Lower Granite Dam, but the relationship between wild and hatchery detection rates was inconsistent at other Snake River dams. These differences in detection probability could be due to fish size (Zabel et al. 2005, Faulkner et al. 2019) but could also be partly due to differences in migration timing. Detection rates at McNary Dam were generally low for both rearing types of both species.

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).

For Upper Columbia River yearling Chinook, estimated survival to McNary Dam ranged from 0.904 (SE 0.110) for East Bank Hatchery fish released to the Chelan River to 0.176 (0.016) for Cle Elum Hatchery fish released to Jack Creek Pond.

For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.516 (0.045) for Wells Hatchery fish released from the hatchery to 0.236 (0.067) for Wells Hatchery fish released from Winthrop Hatchery.

For coho salmon, estimated survival to McNary Dam ranged from 0.543 (0.136) for Willard Hatchery fish released from Mid-Valley Pond on the Methow River to 0.126 (0.057) for Willard Hatchery fish released to Early Winters Pond on the Methow River.

Survival Between Lower Monumental and Ice Harbor Dam

A PIT-tag detection system installed at Ice Harbor Dam became operational in 2005. In most years since then, detection probabilities have been very low, but sufficient to estimate survival from Lower Monumental to Ice Harbor and from Ice Harbor to McNary. In 2019, detections at Ice Harbor Dam were poor; lower than at other Snake River dams (Table 16). For yearling Chinook salmon in 2019, mean estimated survival was 0.901 (SE 0.033) from Lower Monumental to Ice Harbor and 0.877 (0.052) from Ice Harbor to McNary Dam. For steelhead, mean estimated survival through these two reaches was 0.981 (0.022) and 0.809 (0.013), respectively.

Table 16. Estimated survival and detection probabilities between Lower Monumental and McNary Dam, including Ice Harbor Dam, for weekly groups of Snake River yearling Chinook and juvenile steelhead (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival probability		
Date at Lower Granite Dam	Number released	Lower Monumental to Ice Harbor Dam	Ice Harbor to McNary Dam	**Detection probability Ice Harbor Dam**
		Hatchery and wild yearling Chinook salmon		
23–29 Mar	320	0.908 (0.338)	0.571 (0.212)	0.096 (0.034)
30 Mar–5 Apr	3,548	0.971 (0.094)	0.722 (0.084)	0.133 (0.013)
6–12 Apr	4,914	0.925 (0.072)	0.804 (0.075)	0.142 (0.011)
13–19 Apr	3,673	0.945 (0.091)	0.983 (0.136)	0.125 (0.013)
20–26 Apr	4,891	0.779 (0.066)	1.101 (0.140)	0.128 (0.011)
27 Apr–3 May	4,851	0.842 (0.123)	0.885 (0.153)	0.047 (0.007)
4–10 May	3,516	1.526 (0.657)	0.434 (0.192)	0.009 (0.004)
11–17 May	4,195	0.847 (0.128)	1.042 (0.191)	0.035 (0.006)
18–24 May	1,477	1.041 (0.244)	0.857 (0.249)	0.045 (0.012)
Weighted mean		**0.901 (0.033)**	**0.877 (0.052)**	
		Hatchery and wild steelhead		
23–29 Mar	587	0.999 (0.218)	0.697 (0.171)	0.088 (0.023)
30 Mar–5 Apr	3,343	0.892 (0.083)	0.877 (0.089)	0.070 (0.008)
6–12 Apr	12,593	0.997 (0.048)	0.784 (0.045)	0.084 (0.005)
13–19 Apr	10,088	1.089 (0.063)	0.818 (0.069)	0.078 (0.005)
20–26 Apr	13,467	0.948 (0.044)	0.824 (0.060)	0.106 (0.006)
27 Apr–3 May	9,593	0.876 (0.061)	0.836 (0.102)	0.095 (0.007)
4–10 May	5,097	1.111 (0.171)	0.833 (0.190)	0.039 (0.006)
11–17 May	6,825	0.998 (0.118)	0.798 (0.138)	0.047 (0.006)
18–24 May	4,931	1.009 (0.153)	0.697 (0.138)	0.048 (0.008)
25–31 May	2,554	1.015 (0.276)	0.838 (0.279)	0.031 (0.009)
1–7 Jun	1,804	1.011 (0.403)	0.618 (0.304)	0.028 (0.011)
Weighted mean		**0.981 (0.022)**	**0.809 (0.013)**	

Travel Time and Migration Rates

Methods

We calculated travel time of yearling Chinook salmon and steelhead through the following eight reaches:

- Lower Granite to Little Goose Dam (60 km)
- Little Goose to Lower Monumental Dam (46 km)
- Lower Monumental to McNary Dam (119 km)
- Lower Granite to McNary Dam (225 km)
- Lower Granite to Bonneville Dam (461 km)
- McNary to John Day Dam (123 km)
- John Day to Bonneville Dam (113 km)
- McNary 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 within a given reach. We defined travel time for each reach 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; fish arrive in the tailrace within minutes of detection near this site.

Thus, our estimates of travel time included the time required to move through the tailrace of the upstream dam and through the reservoir and 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 travel time for both detected and non-detected fish. However, travel time cannot be determined for fish that traverse 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

Median travel time decreased over the 2019 migration season (Tables 17-22). For both species, estimated migration rates were generally highest in the lower river sections. For Chinook salmon in April, travel time between Lower Granite and Bonneville Dam was longer than in other high-flow years since 2006, when the present spill regime was instituted (Figure 4). Travel time for Chinook was much shorter in May than in April, becoming similar to May travel time from recent high-flow years. For steelhead, short travel times were observed for the whole season and were similar to seasonal means from recent high-flow years (Figure 4).

For yearling Chinook salmon, an observed decrease in travel time in mid-April appeared to coincide with an increase in flow, though the effect seemed to be slightly lagged. However, steelhead travel time was relatively short throughout the season and did not show a tendency to correspond with flow, despite large changes in flow through the season. For both species, general decreases in travel time throughout the season were presumably related to increased levels of smolt readiness (Figure 5).

Table 17. Travel time statistics for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Daily groups were pooled for weekly statistics.

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	102	3.7	4.8	11.7	24	1.7	2.3	3.1	6	4.0	4.8	5.2
30 Mar–5 Apr	749	5.6	8.6	15.7	132	1.6	2.3	4.2	49	4.5	6.3	8.3
6–12 Apr	1,247	3.4	7.1	12.8	203	1.5	2.3	4.0	66	4.1	5.1	7.1
13–19 Apr	1,039	4.0	6.1	9.9	223	1.3	1.7	2.4	52	3.0	4.2	5.6
20–26 Apr	1,602	2.9	3.8	5.8	322	1.2	1.7	2.4	92	3.6	4.5	5.8
27 Apr–3 May	783	3.4	4.2	5.9	143	1.5	1.9	2.4	53	3.5	4.4	5.1
4–10 May	374	2.3	2.9	3.4	40	1.2	1.4	1.6	18	2.3	3.3	4.7
11–17 May	818	2.0	2.7	3.1	222	1.0	1.2	1.7	77	2.5	3.2	4.1
18–24 May	268	2.6	3.0	3.5	58	1.3	1.4	1.9	22	3.0	3.6	4.1
25–31 May	66	1.9	2.0	3.0	6	1.0	1.6	2.0	8	2.4	2.7	3.2
1–7 Jun	29	1.9	2.0	2.4	1	1.5	1.5	1.5	1	5.2	5.2	5.2

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	38	11.6	18.1	22.8	17	18.6	25.4	35.6
30 Mar–5 Apr	269	14.3	19.9	26.5	220	26.0	30.1	35.7
6–12 Apr	387	11.2	16.9	22.6	404	21.7	25.8	30.8
13–19 Apr	217	8.7	12.0	17.7	317	15.6	19.3	23.5
20–26 Apr	336	8.2	10.5	13.7	473	12.7	15.4	18.6
27 Apr–3 May	309	8.7	10.4	12.6	314	12.8	14.3	16.6
4–10 May	153	6.6	7.6	8.6	215	9.4	10.4	12.3
11–17 May	227	5.8	6.7	8.1	418	8.8	9.9	11.6
18–24 May	81	7.4	8.2	9.5	158	10.2	11.4	12.9
25–31 May	38	5.8	6.3	7.2	44	8.2	8.8	10.1
1–7 Jun	17	5.0	5.5	6.3	16	8.2	9.3	9.8

Table 18. Migration rate statistics for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Daily groups were pooled for weekly statistics.

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	102	5.1	12.6	16.3	24	15.0	19.7	26.9	6	22.8	24.9	29.7
30 Mar–5 Apr	749	3.8	7.0	10.7	132	10.8	20.1	28.4	49	14.3	18.9	26.3
6–12 Apr	1,247	4.7	8.5	17.8	203	11.6	20.0	29.9	66	16.7	23.5	29.2
13–19 Apr	1,039	6.1	9.9	15.1	223	19.6	27.4	35.9	52	21.2	28.2	39.4
20–26 Apr	1,602	10.4	15.6	21.0	322	19.3	27.1	37.1	92	20.3	26.5	33.3
27 Apr–3 May	783	10.2	14.4	17.6	143	18.9	23.8	31.3	53	23.2	27.1	34.3
4–10 May	374	17.6	20.5	26.4	40	27.9	32.9	37.7	18	25.2	36.4	52.7
11–17 May	818	19.5	22.6	30.2	222	26.4	37.1	47.4	77	28.8	37.7	46.7
18–24 May	268	17.0	20.1	23.4	58	24.5	31.7	35.7	22	29.0	33.1	39.7
25–31 May	66	19.8	29.3	31.6	6	23.0	29.1	46.9	8	37.1	43.6	50.6
1–7 Jun	29	25.5	30.2	31.7	1	30.7	30.7	30.7	1	22.7	22.7	22.7

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	38	9.9	12.4	19.4	17	12.9	18.1	24.8
30 Mar–5 Apr	269	8.5	11.3	15.8	220	12.9	15.3	17.8
6–12 Apr	387	10.0	13.3	20.2	404	15.0	17.9	21.3
13–19 Apr	217	12.7	18.7	25.7	317	19.6	23.9	29.6
20–26 Apr	336	16.4	21.4	27.5	473	24.8	30.0	36.3
27 Apr–3 May	309	17.8	21.6	25.9	314	27.8	32.2	35.9
4–10 May	153	26.1	29.7	34.2	215	37.4	44.4	49.1
11–17 May	227	27.7	33.7	38.5	418	39.7	46.7	52.1
18–24 May	81	23.6	27.5	30.3	158	35.8	40.5	45.0
25–31 May	38	31.2	35.9	38.7	44	45.8	52.2	56.2
1–7 Jun	17	35.4	40.7	45.3	16	46.8	49.5	56.0

Table 19. Travel time and migration rate statistics for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected at McNary Dam and released to the tailrace in 2019. Daily groups were pooled for weekly statistics.

Date at McNary Dam	Hatchery and wild yearling Chinook salmon from McNary Dam											
	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
6–12 Apr	15	3.6	3.9	5.0	1	1.8	1.8	1.8	10	5.5	5.7	6.3
13–19 Apr	124	4.8	5.9	7.9	15	1.7	2.1	2.7	36	6.8	9.1	12.6
20–26 Apr	236	3.8	4.7	5.9	37	1.9	2.3	2.7	178	5.8	7.2	9.0
27 Apr–3 May	119	3.8	4.1	5.1	23	1.8	2.1	2.4	442	5.5	6.4	7.5
4–10 May	81	3.0	3.9	5.2	13	1.7	1.8	2.3	297	4.7	5.2	6.0
11–17 May	277	2.9	3.1	3.6	25	1.3	1.5	1.7	257	3.8	4.2	4.8
18–24 May	159	2.7	2.9	3.3	18	1.4	1.6	1.8	257	3.8	4.3	4.9
25–31 May	27	2.7	3.0	3.9	4	1.4	1.6	1.8	41	4.0	4.5	5.3
1–7 Jun	9	2.0	2.5	3.0	0	NA	NA	NA	15	3.3	3.7	4.1
	Migration rate (km/d)											
6–12 Apr	15	24.5	31.6	34.4	1	64.6	64.6	64.6	10	37.3	41.1	42.8
13–19 Apr	124	15.5	20.9	25.6	15	41.7	53.3	65.3	36	18.7	25.9	34.8
20–26 Apr	236	21.0	25.9	32.7	37	41.5	48.7	60.1	178	26.1	32.7	41.0
27 Apr–3 May	119	24.0	29.8	31.9	23	46.5	52.6	61.7	442	31.6	37.0	43.2
4–10 May	81	23.8	31.8	41.7	13	49.1	62.8	67.3	297	39.6	45.0	50.6
11–17 May	277	33.8	40.2	42.7	25	68.1	75.8	85.6	257	49.1	56.9	62.9
18–24 May	159	37.4	42.1	45.9	18	62.1	71.1	77.9	257	48.3	55.3	61.5
25–31 May	27	31.5	41.3	46.2	4	61.4	71.1	78.5	41	44.7	52.2	59.6
1–7 Jun	9	41.0	48.2	60.0	0	NA	NA	NA	15	57.4	63.4	71.5

Table 20. Travel time statistics for weekly groups of Snake River juvenile steelhead (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Daily groups were pooled for weekly statistics.

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	466	3.3	3.8	4.5	197	1.9	2.3	3.3	38	4.2	5.7	7.7
30 Mar–5 Apr	667	3.2	3.8	5.6	142	1.5	2.3	4.0	94	2.3	3.1	4.6
6–12 Apr	5,100	1.7	2.1	2.7	1,299	1.0	1.3	2.0	370	3.1	3.8	5.2
13–19 Apr	2,981	2.3	2.8	3.6	989	1.2	1.8	3.7	185	2.4	3.0	4.3
20–26 Apr	6,586	1.6	1.8	2.4	1,975	0.9	1.2	2.3	232	2.4	2.8	3.6
27 Apr–3 May	2,436	1.8	2.0	2.8	664	1.2	1.7	3.1	84	2.7	3.0	3.5
4–10 May	491	1.9	2.1	2.6	83	1.1	1.5	2.1	25	1.9	2.2	2.5
11–17 May	674	1.8	1.9	2.1	151	0.9	1.2	1.8	39	2.0	2.3	2.6
18–24 May	491	1.8	1.9	2.2	101	1.0	1.2	1.7	41	2.0	2.4	2.9
25–31 May	154	1.6	1.9	2.0	38	0.9	1.1	1.3	17	1.8	1.9	2.4
1–7 Jun	207	1.4	1.8	1.9	31	0.8	0.9	1.6	4	1.7	1.8	2.0
8–14 Jun	15	1.9	2.0	2.1	0	NA	NA	NA	1	2.7	2.7	2.7

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	92	10.7	11.8	13.9	21	16.7	20.1	31.8
30 Mar–5 Apr	416	8.1	9.7	12.1	299	12.6	14.8	18.2
6–12 Apr	1,070	6.0	7.3	9.8	1,043	10.8	12.6	18.9
13–19 Apr	411	6.2	7.8	10.8	809	10.3	12.5	16.5
20–26 Apr	504	5.0	6.1	8.4	2,204	9.4	10.5	12.3
27 Apr–3 May	258	5.9	6.8	8.7	1,348	9.8	10.7	11.9
4–10 May	114	5.2	5.5	6.3	534	8.3	8.8	9.9
11–17 May	173	4.3	5.1	5.5	851	7.5	8.1	8.8
18–24 May	165	4.9	5.3	6.2	500	7.8	8.4	9.1
25–31 May	93	4.2	4.4	5.2	166	7.4	7.7	8.5
1–7 Jun	49	4.2	5.1	5.6	133	7.6	8.5	9.8
8–14 Jun	7	5.2	5.2	6.2	68	9.5	10.3	11.3

Table 21. Migration rate statistics for weekly groups of Snake River juvenile steelhead (hatchery and wild combined) detected or tagged at Lower Granite Dam and released to the tailrace in 2019. Daily groups were pooled for weekly statistics.

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	466	13.2	16.0	18.3	197	14.0	20.3	24.7	38	15.4	21.0	28.5
30 Mar–5 Apr	667	10.8	15.6	18.5	142	11.4	19.9	29.9	94	26.0	38.4	51.5
6–12 Apr	5,100	22.0	29.1	36.1	1,299	22.9	34.8	47.4	370	22.7	31.2	38.5
13–19 Apr	2,981	16.6	21.3	26.5	989	12.6	26.3	38.3	185	27.8	39.0	49.8
20–26 Apr	6,586	25.1	32.4	38.0	1,975	19.7	37.1	49.5	232	33.0	42.2	49.6
27 Apr–3 May	2,436	21.1	29.9	32.6	664	14.8	26.9	38.0	84	33.7	39.5	44.6
4–10 May	491	23.2	28.6	31.4	83	21.6	31.5	41.4	25	47.0	55.1	62.6
11–17 May	674	28.3	31.4	33.0	151	26.0	39.3	49.5	39	45.1	51.1	58.9
18–24 May	491	27.6	31.7	32.6	101	26.7	38.3	45.1	41	40.8	49.0	58.9
25–31 May	154	30.0	31.9	36.4	38	34.3	43.8	52.9	17	50.0	61.3	68.0
1–7 Jun	207	31.1	32.4	44.4	31	29.7	48.9	59.0	4	60.1	64.3	69.6
8–14 Jun	15	28.0	30.2	31.2	0	NA	NA	NA	1	44.6	44.6	44.6

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23–29 Mar	92	16.1	19.0	21.1	21	14.5	22.9	27.6
30 Mar–5 Apr	416	18.7	23.1	27.8	299	25.3	31.3	36.6
6–12 Apr	1,070	22.9	30.7	37.5	1,043	24.4	36.6	42.6
13–19 Apr	411	20.7	28.7	36.5	809	27.9	36.9	44.6
20–26 Apr	504	26.8	36.9	45.1	2,204	37.5	43.9	49.2
27 Apr–3 May	258	25.9	32.8	38.0	1,348	38.8	43.1	47.0
4–10 May	114	35.4	40.9	43.5	534	46.7	52.4	55.2
11–17 May	173	40.8	44.1	52.0	851	52.3	57.3	61.1
18–24 May	165	36.3	42.3	45.8	500	50.5	54.7	58.7
25–31 May	93	42.9	50.7	54.0	166	54.4	59.9	62.3
1–7 Jun	49	40.2	44.4	53.2	133	47.2	54.4	60.8
8–14 Jun	7	36.2	42.9	43.2	68	40.9	44.8	48.4

Table 22. Travel time and migration rate statistics for weekly groups of Snake River juvenile steelhead (hatchery and wild combined) detected at McNary Dam and released to the tailrace in 2019. Daily groups were pooled for weekly statistics.

	Hatchery and wild juvenile steelhead from McNary Dam											
	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
Date at McNary Dam	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
30 Mar–5 Apr	7	4.9	5.0	6.5	0	NA	NA	NA	2	7.6	9.5	11.4
6–12 Apr	222	3.2	3.9	5.4	34	1.5	1.8	2.0	133	4.7	5.6	6.7
13–19 Apr	652	4.1	5.0	6.4	60	1.4	1.6	1.8	309	5.4	5.8	6.8
20–26 Apr	368	3.2	3.7	4.8	48	1.4	1.5	1.7	140	4.5	5.3	5.9
27 Apr–3 May	124	3.4	4.2	5.2	29	1.6	1.8	2.1	342	4.8	5.3	6.2
4–10 May	19	3.0	3.5	4.2	4	1.4	1.6	1.7	117	4.4	4.8	5.3
11–17 May	39	2.9	3.4	4.2	6	1.3	1.3	1.4	62	3.6	3.7	4.3
18–24 May	23	2.0	3.1	3.4	9	1.3	1.4	1.5	76	3.6	3.8	4.5
25–31 May	17	2.2	3.0	3.4	5	1.2	1.3	1.4	47	3.6	3.8	4.3
1–7 Jun	7	1.9	2.2	2.4	2	1.5	1.6	1.6	15	3.7	3.9	4.6
	Migration rate (km/d)											
30 Mar–5 Apr	7	19.0	24.4	24.9	0	NA	NA	NA	2	20.6	24.7	30.9
6–12 Apr	222	22.6	31.5	38.2	34	57.4	63.1	74.3	133	35.5	42.1	50.5
13–19 Apr	652	19.2	24.6	29.9	60	62.1	71.5	77.9	309	34.7	40.3	43.7
20–26 Apr	368	25.5	33.2	38.1	48	65.3	74.8	83.7	140	40.2	44.7	52.9
27 Apr–3 May	124	23.7	29.6	35.9	29	54.3	63.8	71.1	342	38.1	44.3	49.3
4–10 May	19	29.6	35.3	40.3	4	66.9	72.9	79.0	117	44.8	49.3	54.1
11–17 May	39	29.4	36.1	42.0	6	81.9	86.3	88.3	62	55.3	63.3	66.3
18–24 May	23	35.9	39.9	60.0	9	77.4	80.1	86.9	76	52.4	61.3	66.1
25–31 May	17	36.5	41.0	55.2	5	80.7	88.3	90.4	47	55.1	61.9	65.9
1–7 Jun	7	51.2	56.4	64.7	2	69.8	72.4	75.3	15	51.8	60.8	64.0

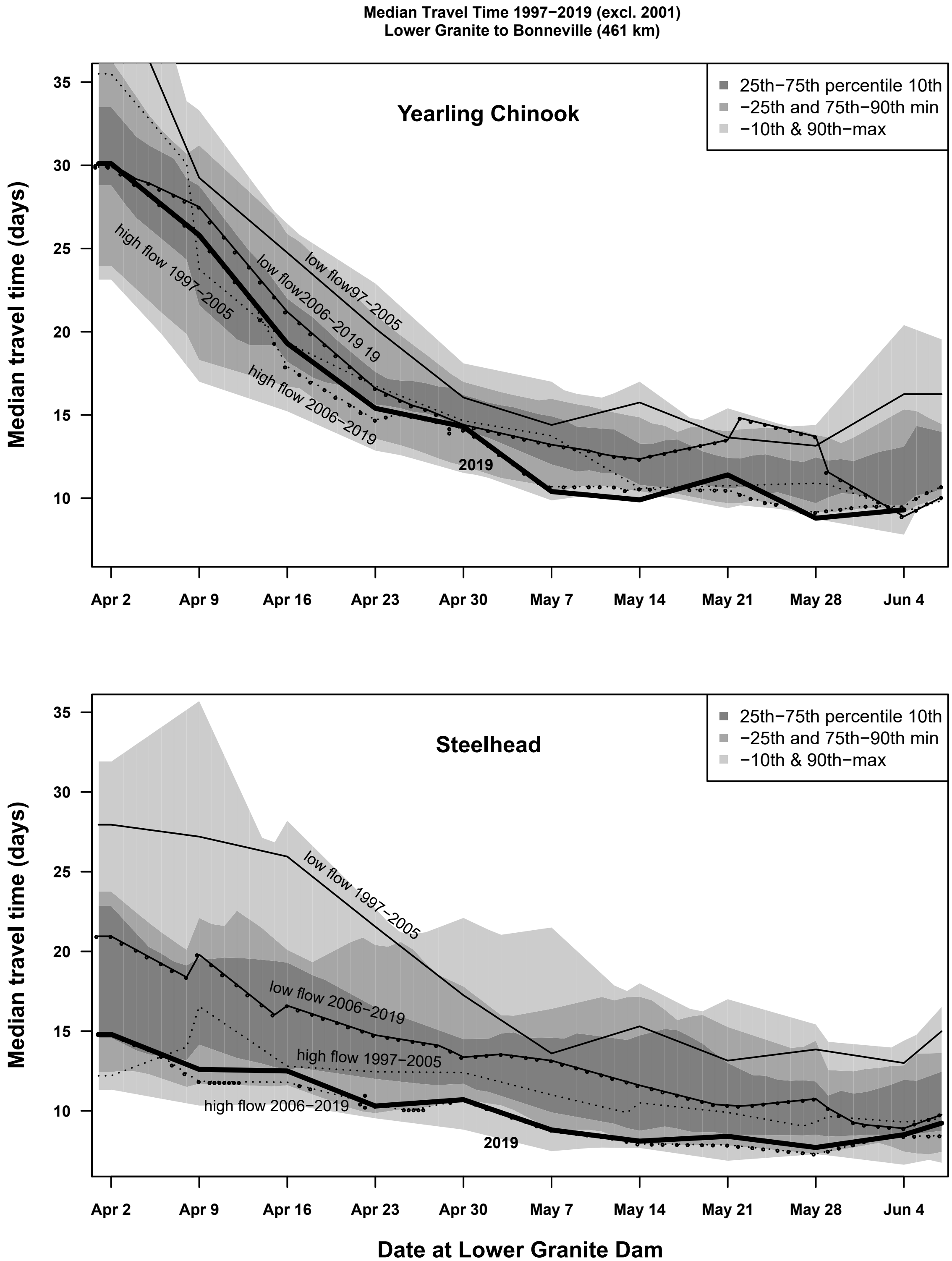


Figure 4. Median travel time (d) from Lower Granite to Bonneville Dam (461 km) for weekly groups of yearling Chinook salmon and juvenile steelhead. Shaded regions show daily quantiles during 1997-2019 (excluding 2001). Lines show daily medians from low- and high-flow years by spill regime, 1997-2005 or 2006-2019. Low-flow years were 2004 and 2005 during the former regime, and 2007, 2010, 2013, and 2015 during the present regime. High-flow years were 1997 and 2006 in the former regime, and 2011, 2012, 2017, 2018, and 2019 during the present regime.

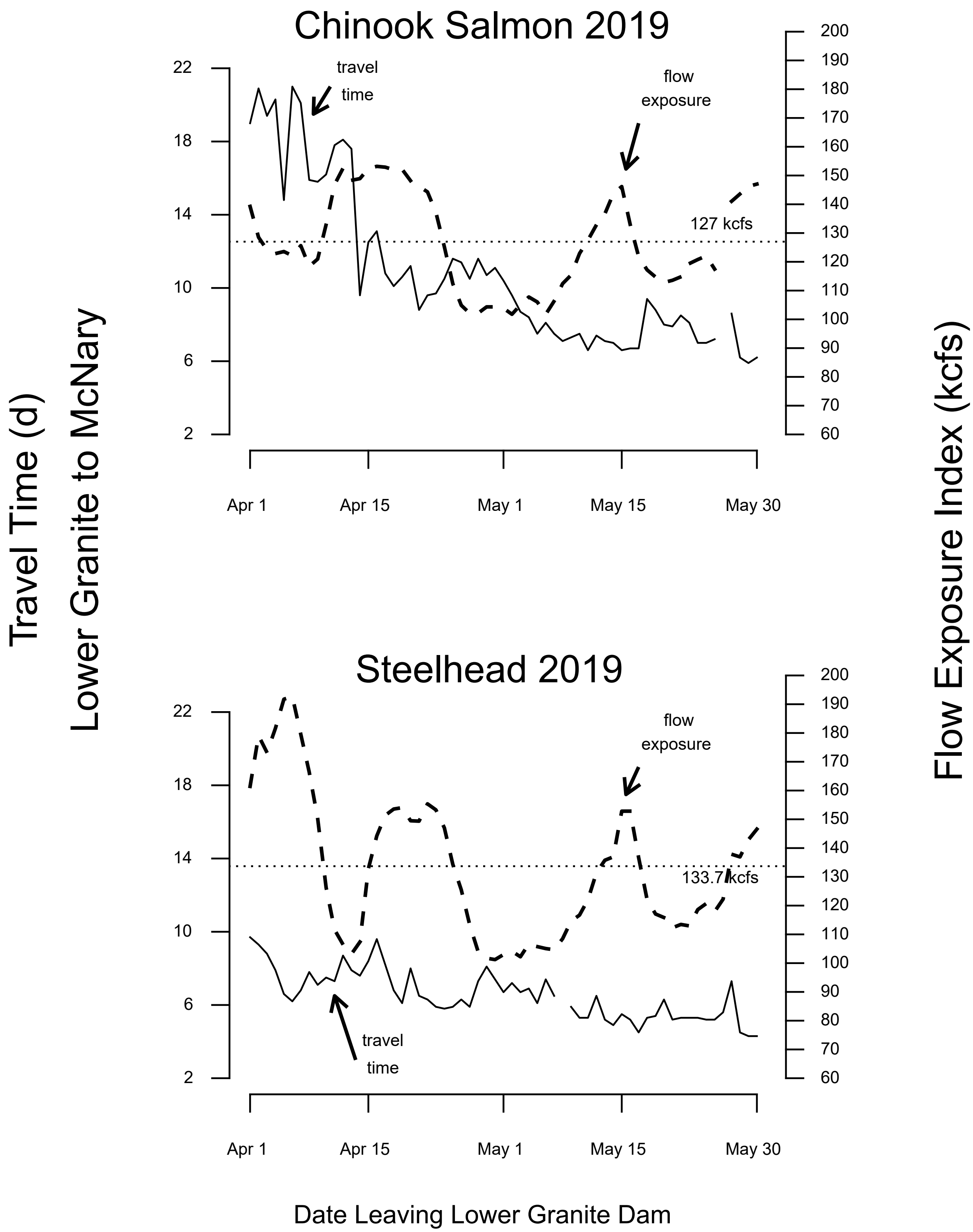


Figure 5. Median travel time (d) from Lower Granite to McNary Dam for daily groups of PIT-tagged yearling Chinook salmon and juvenile steelhead and index of flow exposure at Lower Monumental Dam (kcfs) during 2019 (see Appendix C). Dashed horizontal lines represent the mean flow exposure index for the year, weighted by the number of PIT-tagged fish in each group.

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 non-tagged) 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 non-tagged 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 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 that entered the collection system at each collector dam and were transported from that dam.

   For groups arriving at Lower Granite Dam after the starting date of the general transportation program at a collector dam, the proportion transported is almost always 100% for non-tagged fish. There can be short, intermittent disruptions, usually resulting from unforeseen circumstances.

   For daily groups arriving at Lower Granite Dam before the transportation starting date, the estimated proportion that is eventually transported depends on travel time distribution and arrival at 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 arrive at 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 of Lower Granite *equivalents* from each group that were transported from each dam.

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

Results

In 2019, collection for transportation began on 22 April at Lower Granite Dam and on 24 April at Little Goose and Lower Monumental Dams. The first barge departed on 24 April from each of these dams. Before these dates, smolts collected at Snake River dams were bypassed to the tailraces. Estimated percentages of non-tagged spring/summer Chinook salmon transported during the entire 2019 season were 41.6% for wild and 33.6% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 44.1% for wild and 35.5% 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. As in 2018, estimated percentages of transported fish were greater than any during 2015-2017; this was in part because transportation started about one week earlier in 2018 and 2019 than in most years since 2006 (Figure 6; Table 23).

Before 2006, collected fish were transported throughout the season, starting from the first day on which the collection system was supplied with water. Between 2007 and 2013, collected fish were bypassed until a designated date, 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). In 2014, transportation began simultaneously at all three collector dams; this pattern continued in 2019.

By the time collection for transport began at Lower Granite Dam in 2019, about 38% of wild and 32% of hatchery yearling Chinook smolts had already passed the dam. During general transportation operations, we estimated that approximately 59% of wild and 42% of hatchery yearling Chinook smolts that arrived at Lower Granite were transported, either from Lower Granite or from a downstream collector dam. The difference in proportion of transported fish between rear-types during this period resulted from a difference in the probability of entering the collection system.

By the time collection for transport began at Lower Granite Dam in 2019, about 32% of wild and 47% of hatchery steelhead smolts had already passed the dam. During general transportation operations, we estimated that approximately 59% of wild and 58% of hatchery steelhead smolts that arrived at Lower Granite were transported, either from Lower Granite or from a downstream collector dam.

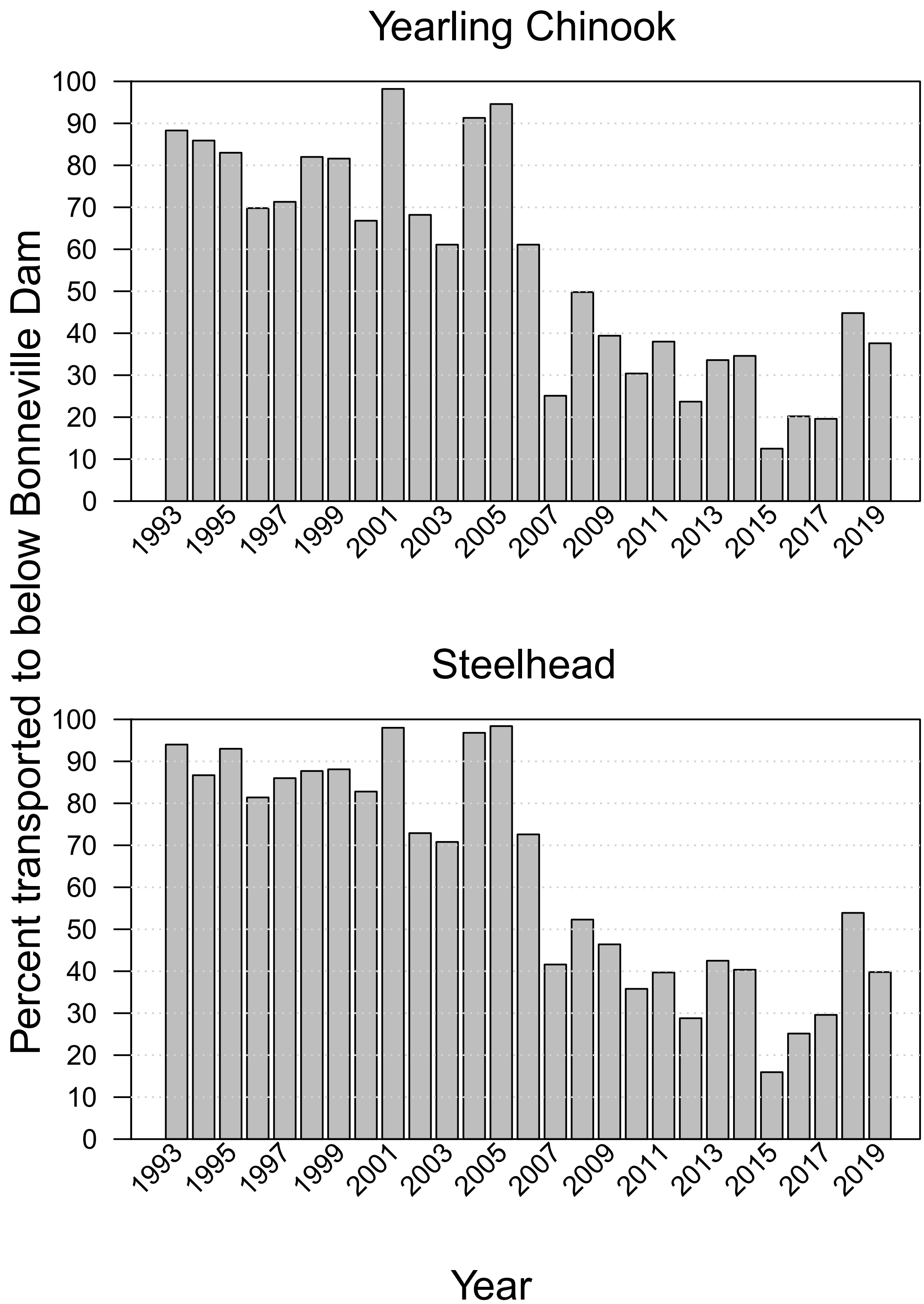


Figure 6. Annual estimated percentages of yearling Chinook salmon and juvenile steelhead (average of estimates for hatchery and wild) arriving at Lower Granite Dam that were transported to below Bonneville Dam (1993-2019).

Table 23. Annual estimated percentages of Snake River yearling Chinook salmon and juvenile steelhead (hatchery and wild separately) arriving at Lower Granite Dam that were transported to below Bonneville Dam (1993-2019). Estimates are shown for hatchery and wild fish separately. Arithmetic means are given for the full period, and for periods with similar transportation operating schedules (1993-2006 and 2007-2019).

	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	93.0
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	81.5	82.5	82.0	87.3	88.1	87.7
1999	77.3	85.9	81.6	88.5	87.6	88.1
2000	63.0	70.5	66.8	81.5	84.0	82.8
2001	97.3	99.0	98.2	96.7	99.3	98.0
2002	64.3	72.1	68.2	70.6	75.2	72.9
2003	51.7	70.4	61.1	68.6	72.9	70.8
2004	90.5	92.0	91.3	97.3	96.3	96.8
2005	93.9	95.3	94.6	98.2	98.6	98.4
2006	62.3	59.9	61.1	76.7	68.4	72.6
2007	25.4	24.8	25.1	41.3	41.9	41.6
2008	45.3	54.3	49.8	46.9	57.7	52.3
2009	38.3	40.4	39.4	43.7	49.0	46.4
2010	22.6	38.2	30.4	35.0	36.6	35.8
2011	40.7	35.2	38.0	36.1	43.3	39.7
2012	24.7	22.7	23.7	26.2	31.4	28.8
2013	31.0	36.1	33.6	33.6	51.4	42.5
2014	38.3	30.9	34.6	33.3	47.4	40.4
2015	13.6	11.4	12.5	13.2	18.7	16.0
2016	21.0	19.3	20.2	22.6	27.7	25.2
2017	21.4	17.8	19.6	19.0	40.2	29.6
2018	45.4	44.1	44.8	44.5	63.3	53.9
2019	33.6	41.6	37.6	35.5	44.1	39.8
Mean						
1993-2019	**54.6**	**57.4**	**56.0**	**60.6**	**65.4**	**63.0**
1993-2006	**76.7**	**80.9**	**78.8**	**86.0**	**86.7**	**86.4**
2007-2019	**30.9**	**32.1**	**31.5**	**33.1**	**42.5**	**37.8**

For both yearling Chinook and steelhead smolts that passed the dam after transportation had begun, transported percentages were generally lower in 2019 than in 2018. This may be because spill and spill percent were both slightly higher after the start of transportation in 2019 than they were in 2018.

The estimated total proportion of smolts transported was also lower in 2019 than in 2018. This was primarily because migration timing was earlier, especially for hatchery Chinook salmon and steelhead. We estimated that 32% of hatchery Chinook and about 47% of both hatchery and wild steelhead had passed dams before the start of transportation in 2019, whereas the corresponding numbers for 2018 were 24% and 37%.

A trend toward earlier smolt migration has been apparent for several years. Steelhead were particularly early in 2019: estimated dates of median passage were the earliest ever observed for both hatchery (24 April) and wild (28 April) steelhead. For both wild and hatchery steelhead, median passage occurred 9 days earlier than their respective mean dates of median passage from 2006 to 2018.

Our survival estimates 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). Detections of fish that were ultimately transported were included in the dataset used for survival estimates only to the point where they were transported. For survival estimates downstream from the point of transport, these fish were removed from the dataset.

Comparisons of Annual Survival Estimates

Comparison Among Years

We made two types of comparisons between annual survival estimates from 2019 and those obtained during the previous 26 years of the NMFS survival study. First, for Snake River hatchery yearling Chinook, 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 2019 with overall seasonal 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 hatcheries, estimated survival to Lower Granite Dam was below average in 2019. Only yearling Chinook from McCall and Sawtooth hatchery had above-average survival to Lower Granite Dam (Table 24). Survival was especially low in fish from Pahsimeroi and Rapid River Hatcheries; Pahsimeroi Hatchery suffered a disease outbreak in 2019, which we describe in more detail in the discussion.

Over the 26 years of our annual survival studies, we have consistently observed an inverse relationship between estimated survival and distance of the release site from Lower Granite Dam. This relationship is illustrated in Figure 7 for hatchery yearling Chinook, using mean estimated survival across years ($R^2 = 0.804$, $P = 0.006$).

For combined wild and hatchery yearling Chinook salmon in 2019, mean estimated survival was 0.628 (95% CI 0.575-0.681) from Lower Granite to McNary Dam and 0.825 (0.707-0.943) from McNary to Bonneville Dam (Tables 25-26; Figures 8-9). The estimate from Lower Granite to McNary was well below the long-term mean of 0.734 and was the lowest estimate since 2001. In contrast, the estimate from McNary to Bonneville was well above the long-term mean of 0.701 and was the highest estimate since 2006. Combining these two estimates, the overall estimate from Lower Granite to Bonneville Dam in 2019 (0.518) was very near the long-term mean of 0.522.

Table 24. Estimated survival probabilities for groups of yearling Chinook released from selected Snake River Basin hatcheries to the tailrace of Lower Granite Dam, 1993-2019. Distance to Lower Granite Dam is shown for each release site (km). Standard errors in parentheses. 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)	0.548 (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)	0.646 (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)
2018	0.744 (0.015)	0.633 (0.030)	0.651 (0.012)	0.651 (0.009)	0.702 (0.011)	0.634 (0.015)	0.519 (0.013)	0.648 (0.026)
2019	0.688 (0.013)	0.571 (0.022)	0.627 (0.024)	0.491 (0.009)	0.616 (0.014)	0.280 (0.008)	0.539 (0.021)	0.544 (0.050)
Mean	**0.768 (0.014)**	**0.659 (0.016)**	**0.656 (0.010)**	**0.698 (0.019)**	**0.602 (0.014)**	**0.532 (0.033)**	**0.474 (0.030)**	**0.627 (0.011)**

* Released at Imnaha River Weir.

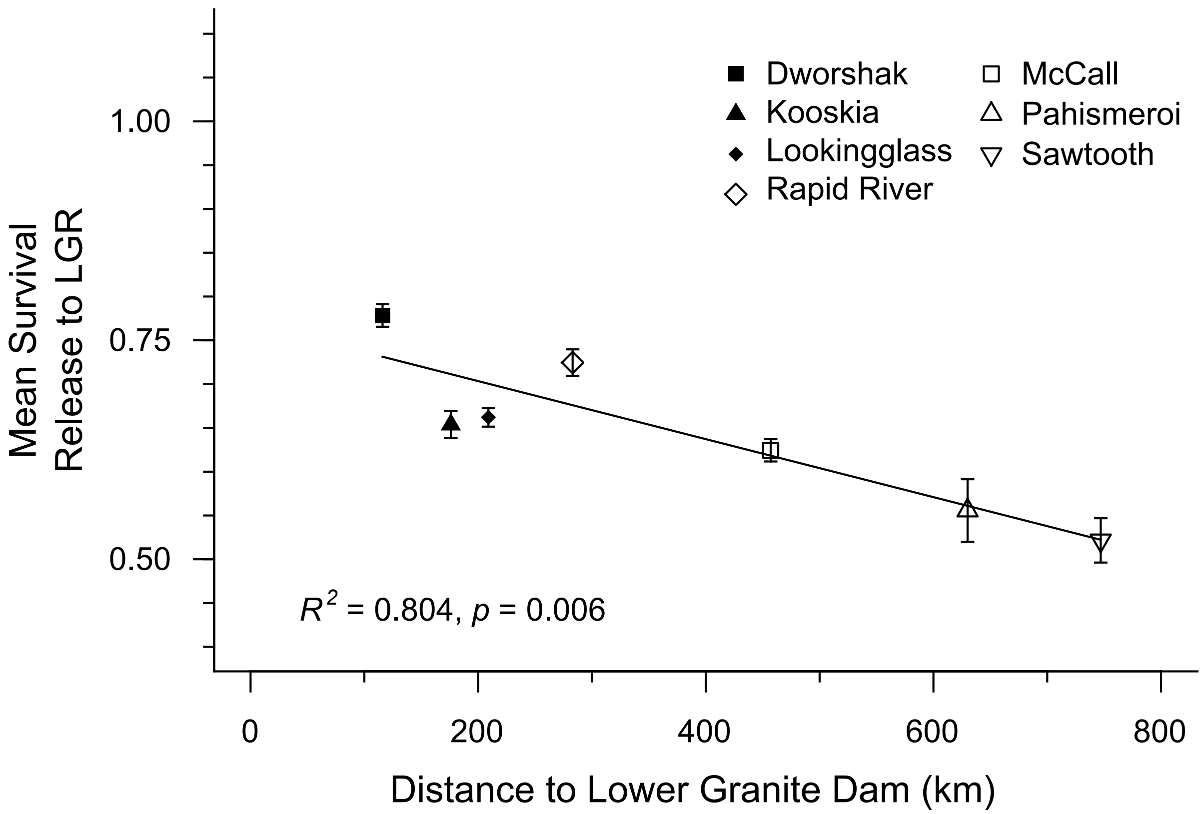


Figure 7. Mean estimated survival probability from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2019 vs. distance (km) to Lower Granite Dam. The coefficient of determination between survival and migration distance is also shown, along with a *P*-value for a test of the null hypothesis of zero correlation. Whiskers extend one standard error above and below point estimates.

Table 25. Annual survival probability estimates for Snake River yearling Chinook salmon (hatchery and wild combined), 1995–2019. 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 single-project estimates. Simple arithmetic means across all available years (1993-2019) are given.

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	0.924 (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)	0.947 (0.005)	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
2018	0.880 (0.022)	0.942 (0.013)	0.917 (0.019)	0.877 (0.036)	0.936	0.770 (0.074)	0.743 (0.100)	0.862
2019	0.785 (0.027)	0.874 (0.015)	0.953 (0.027)	0.792 (0.032)	0.890	1.015 (0.088)	0.798 (0.111)	0.893
Mean	**0.924 (0.010)**	**0.926 (0.006)**	**0.923 (0.008)**	**0.860 (0.011)**	**0.927 (0.006)**	**0.867 (0.019)**	**0.806 (0.023)**	**0.896 (0.013)**

Table 26. Annual hydropower system survival probability estimates derived by combining estimated survival in component reaches for Snake River yearling Chinook salmon (hatchery and wild combined), 1999–2019. Standard errors in parentheses. Simple arithmetic means are given. Years 1993-1998 omitted for space.

	Annual survival estimates for hatchery and wild yearling Chinook (SE)				
Year	Snake River trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Snake River trap to Bonneville Dam
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)	0.784 (0.013)	0.715 (0.107)	0.560 (0.084)	0.507 (0.077)
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
2018	0.880 (0.022)	0.733 (0.025)	0.590 (0.045)	0.432 (0.036)	0.381 (0.033)
2019	0.785 (0.027)	0.628 (0.027)	0.825 (0.060)	0.518 (0.044)	0.407 (0.037)
Mean	**0.924[a] (0.010)**	**0.734[b] (0.012)**	**0.701[c] (0.020)**	**0.522[c] (0.019)**	**0.485[c] (0.019)**

a. Mean for 1993-2019; no estimate possible for 1997.
b. Mean for 1995-2019; no estimate possible for 1993-1994.
c. Mean for 1999-2019; no estimate possible for 1993-1998.

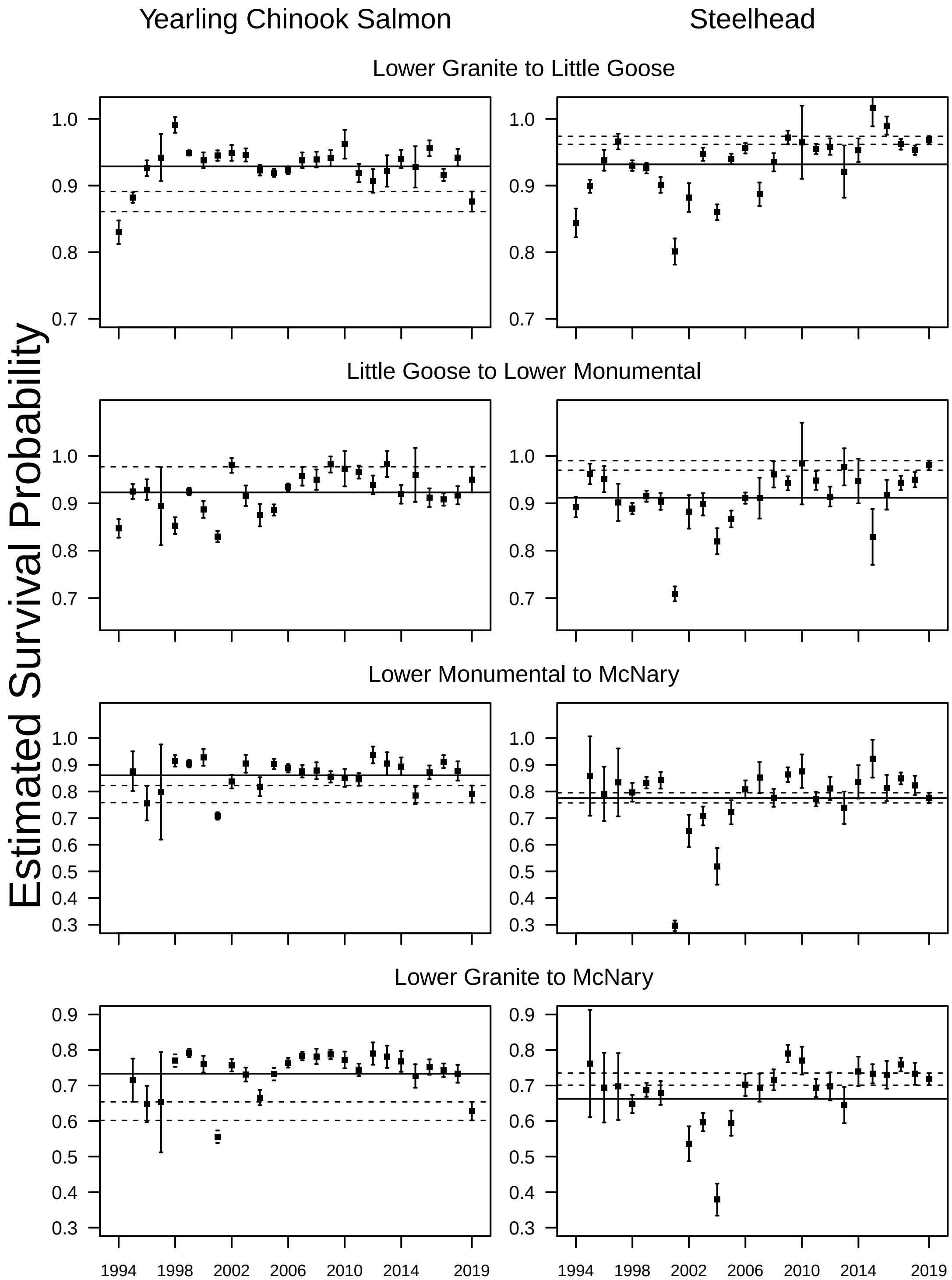


Figure 8. Annual weighted mean survival probability estimates for Snake River yearling Chinook salmon and juvenile steelhead (hatchery and wild combined) through Snake River reaches, 1993-2019. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Dashed horizontal lines indicate 95% CI endpoints for 2019 estimates; solid horizontal lines indicate long-term means (1993-2019).

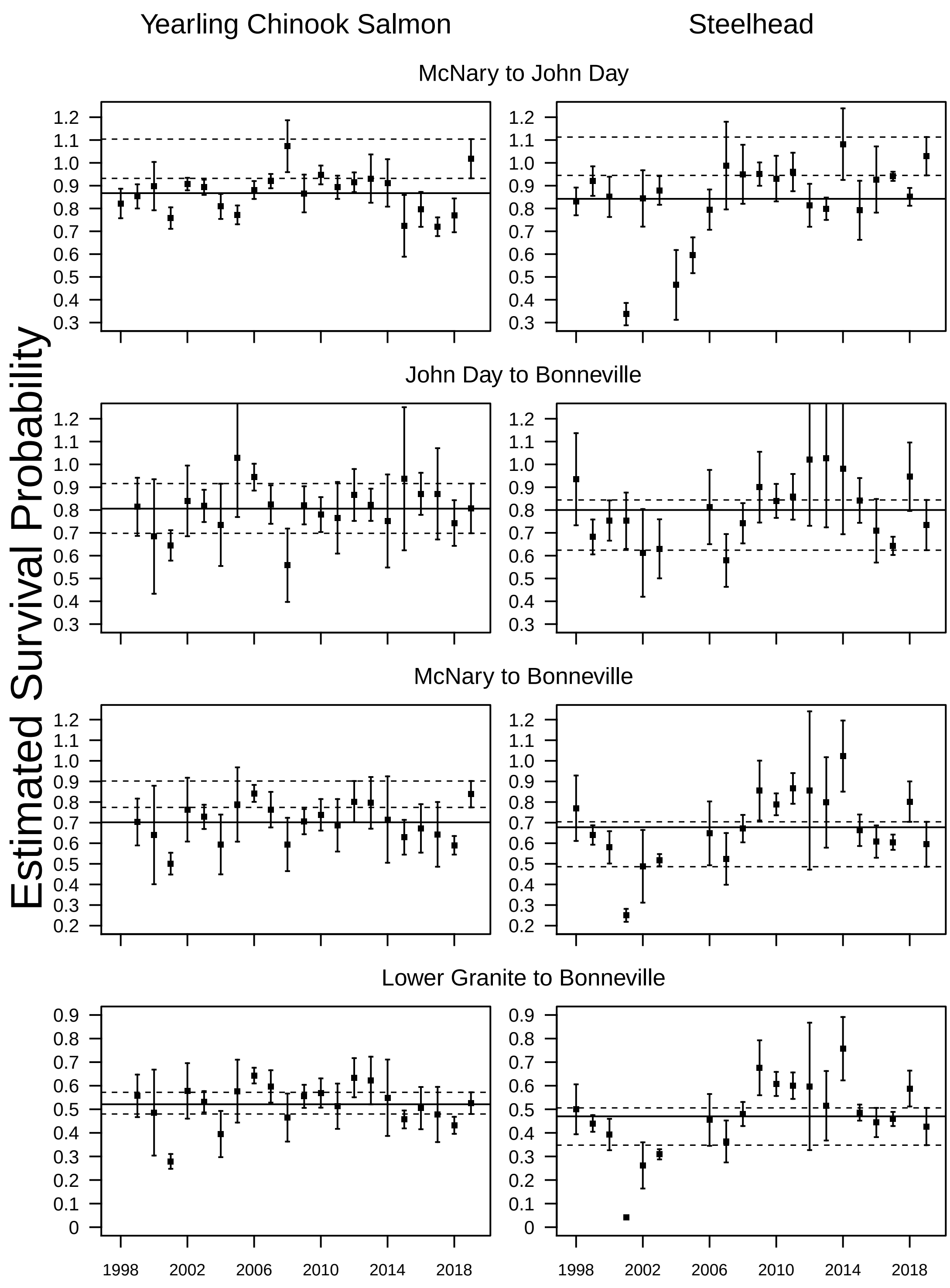


Figure 9. Annual weighted mean survival probability estimates for Snake River yearling Chinook salmon and juvenile steelhead (hatchery and wild combined) through Columbia River reaches and from Lower Granite Dam to Bonneville Dam, 1993-2019. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Dashed horizontal lines indicate 95% CI endpoints for 2019 estimates; solid horizontal lines indicate long-term means (1993-2019).

For combined wild and hatchery yearling Chinook salmon from the Snake River trap to the tailrace of Bonneville Dam in 2019, mean estimated survival was 0.407 (95% CI 0.334-0.479; Table 26). This estimate was lower than the 23-year mean of 0.485, but higher than the estimate from 2018 of 0.381. The difference between estimates in 2018 and 2019 was not significant (P = 0.60).

For wild yearling Chinook salmon in 2019, mean estimated survival was 0.669 (95% CI 0.614-0.724) from Lower Granite to McNary Dam; this estimate was below the long-term average of 0.722 (Table 27). Due to low detections at McNary Dam, we did not have sufficient data to estimate survival for wild Chinook from McNary to Bonneville Dam using our standard methods for fish detected and returned to the river at McNary. Instead, we used a single pooled group of all wild fish released upstream from McNary Dam. Using this method, estimated survival from McNary to Bonneville Dam was 0.813 (0.590-1.036), which was well above the long-term average of 0.663 (Table 27). Estimated survival from the Snake River trap to Bonneville Dam was 0.472 (0.320-0.624), slightly higher than the long-term average of 0.450.

Steelhead—For combined wild and hatchery steelhead, mean estimated survival from Lower Granite to McNary Dam was 0.717 (95% CI 0.684-0.750), lower than the 2018 estimate of 0.733, but higher than the long-term average of 0.660 (Tables 28-29; Figures 8-9). From McNary to Bonneville Dam, mean estimated survival in 2019 was 0.595 (0.381-0.809), substantially lower than both the 2018 estimate of 0.802 and the long-term average of 0.676.

Estimated survival from the Snake River trap to Bonneville Dam for combined wild and hatchery steelhead was 0.412 (0.261-0.562; Table 29), which was lower than the long-term average of 0.457; the estimate in 2019 was the lowest since 2003. The corresponding estimate from 2018 was 0.578; the difference between estimates in 2018 and 2019 was not statistically significant (P = 0.12).

For wild steelhead in 2019, mean estimated survival from Lower Granite to McNary Dam was 0.771 (0.685-0.857), which was higher than the long-term average of 0.657 (Table 30). Due to low detection at McNary Dam, we did not have sufficient data to estimate survival for wild steelhead from McNary to Bonneville Dam using our standard methods for fish detected and returned to the river at McNary. Instead, we used a single pooled group of all wild fish released upstream from McNary Dam. Estimated survival from McNary to Bonneville Dam using this method was 0.640 (0.518-0.762), which was above the long-term average of 0.624. Overall estimated survival from the Snake River trap to Bonneville Dam was 0.480 (0.344-0.616) in 2019, higher than the long-term average of 0.418 but not as high as the estimate in 2018 of 0.513.

Table 27. Annual hydropower system survival probability estimates derived by combining estimated survival in component reaches for Snake River yearling Chinook salmon (wild only), 1999–2019. Standard errors in parentheses. Simple arithmetic means are given. Years 1993-1998 omitted for space.

	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)	0.542 (0.028)	0.437 (0.041)	0.237 (0.025)	0.218 (0.027)
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)	0.722 (0.015)	0.577 (0.074)	0.417 (0.054)	0.372 (0.049)
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
2018	0.871 (0.030)	0.760 (0.031)	0.762 (0.144)	0.579 (0.112)	0.504 (0.099)
2019	0.868 (0.065)	0.669 (0.028)	0.813 (0.114)	0.544 (0.080)	0.472 (0.078)
Mean	**0.915[a] (0.010)**	**0.722[b] (0.014)**	**0.663[c] (0.032)**	**0.486[c] (0.026)**	**0.450[c] (0.024)**

a. Mean for 1993-2019; no estimate possible for 1997.
b. Mean for 1995-2019; no estimate possible for 1993, 1994, or 1997.
c. Mean for 1999-2019; no estimate possible for 1993-1998.

Table 28. Annual survival probability estimates for Snake River juvenile steelhead (hatchery and wild combined), 1995–2019. 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 single-project estimates. Simple arithmetic means across all available years (1993–2019) 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
2018	0.983 (0.025)	0.953 (0.007)	0.950 (0.016)	0.823 (0.036)	0.907	0.851 (0.039)	0.946 (0.150)	0.973
2019	0.965 (0.027)	0.968 (0.006)	0.981 (0.011)	0.774 (0.019)	0.880	1.029 (0.084)	0.734 (0.110)	0.857
Mean	**0.952 (0.010)**	**0.932 (0.009)**	**0.912 (0.012)**	**0.775 (0.026)**	**0.876 (0.017)**	**0.842 (0.037)**	**0.800 (0.031)**	**0.891 (0.017)**

Table 29. Annual hydropower system survival probability estimates derived by combining estimated survival in component reaches for Snake River juvenile steelhead (hatchery and wild combined), 1997–2019. Standard errors in parentheses. Simple arithmetic means are given. Years 1993-1996 omitted for space.

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
2018	0.983 (0.025)	0.733 (0.031)	0.802 (0.098)	0.588 (0.076)	0.578 (0.076)
2019	0.965 (0.025)	0.717 (0.017)	0.595 (0.109)	0.427 (0.079)	0.412 (0.077)
Mean	**0.952[a] (0.010)**	**0.663[b] (0.027)**	**0.676[c] (0.037)**	**0.470[c] (0.033)**	**0.457[c] (0.036)**

a. Mean for 1993-2019.
b. Mean for 1995-2019; no estimate possible for 1993-1994.
c. Mean for 1997-2019; no estimate possible for 1993-1996.

Table 30. Annual hydropower system survival probability estimates derived by combining estimated survival in component reaches for Snake River juvenile steelhead (wild only), 1999–2019. Standard errors in parentheses. Simple arithmetic means are given. Years 1993-1998 omitted for space, but are included means for which they had available estimates.

	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
2018	0.848 (0.060)	0.736 (0.075)	0.822 (0.136)	0.605 (0.118)	0.513 (0.106)
2019	0.973 (0.088)	0.771 (0.044)	0.640 (0.062)	0.493 (0.055)	0.480 (0.069)
Mean	**0.950[a] (0.011)**	**0.657[b] (0.030)**	**0.624[c] (0.044)**	**0.432[c] (0.035)**	**0.418[c] (0.036)**

a. Mean for 1993-2019.

b. Mean for 1998-2019; no estimate available for 1993-1997

c. Mean for 1999-2019; no estimate available for 1993-1998

Sockeye Salmon—For pooled groups of wild and hatchery Snake River sockeye salmon, estimated survival from Lower Granite to McNary Dam was 0.836 in 2019 (95% CI 0.738-0.946; Table 31). This estimate was substantially higher than either the 2018 estimate of 0.684 or the average of 0.637 for 1996-2019. For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.434 (0.377-0.499) in 2019. This estimate was slightly above the 1996-2019 average of 0.407.

Table 31. Annual estimated survival probabilities for sockeye salmon (hatchery and wild combined), from Lower Granite to Bonneville Dam for Snake River fish, and from Rock Island to Bonneville Dam for upper Columbia River fish, 1996–2019. Estimates are from tailrace to tailrace. Simple arithmetic means are given. Standard errors in parentheses.

	Annual survival estimates for 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 (0.115)	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)
2018	0.684 (0.061)	0.940 (0.151)	0.643 (0.088)
2019	0.836 (0.053)	0.520 (0.044)	0.434 (0.031)
Mean	**0.637 (0.034)**	**0.564 (0.066)**	**0.407 (0.049)**

Table 31. Continued.

	Annual survival estimates for 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)
2018	0.927 (0.118)	0.560 (0.112)	0.344 (0.124)
2019	0.941 (0.125)	0.701 (0.120)	0.737 (0.191)
Mean	**0.697 (0.033)**	**0.714 (0.070)**	**0.506 (0.052)**

Upper Columbia River Stocks

Sockeye Salmon—For Upper Columbia River sockeye salmon captured, tagged, and released to the tailrace of Rock Island Dam in 2019, estimated survival to McNary tailrace was 0.941 (95% CI 0.726-1.219; Table 31). This estimate was higher than the long-term average of 0.697 and similar to the 2018 estimate of 0.927 for Upper Columbia sockeye. Estimated survival of sockeye from Rock Island to Bonneville Dam in 2019 was 0.737 (0.447-1.215). This estimate was much higher than both the long-term average of 0.506 and the 2018 estimate of 0.344, but the estimate was also very imprecise.

Yearling Chinook Salmon—For pooled groups of yearling Chinook from Upper Columbia River hatcheries, estimated survival in 2019 from McNary tailrace to Bonneville tailrace was 0.785 (95% CI 0.683-0.903), slightly lower than the 1999-2019 average of 0.812 (Table 32).

Steelhead—For pooled groups of hatchery steelhead from Upper Columbia hatcheries, estimated survival from McNary to Bonneville tailrace in 2019 was 0.606 (95% CI 0.521-0.705). This estimate was below the long-term average of 0.764 (Table 32).

Table 32. Annual estimated survival probabilities for upper Columbia River hatchery yearling Chinook salmon (1999-2019) and hatchery juvenile steelhead (2003-2019). Multiple release sites were used in each year and were not the same in all years. Simple arithmetic means are given with standard errors in parentheses.

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)
2018	0.608 (0.016)	0.914 (0.044)	0.820 (0.096)	0.749 (0.084)
2019	0.506 (0.018)	0.853 (0.042)	0.920 (0.066)	0.785 (0.056)
Mean	**0.557 (0.011)**	**0.897 (0.021)**	**0.900 (0.039)**	**0.812 (0.029)**
	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)
2018	0.416 (0.021)	0.942 (0.062)	1.232 (0.194)	1.161 (0.186)
2019	0.342 (0.016)	0.812 (0.048)	0.746 (0.054)	0.606 (0.047)
Mean	**0.414 (0.014)**	**0.892 (0.028)**	**0.864 (0.054)**	**0.764 (0.048)**

Comparison Between Snake and Columbia River Stocks

In 2019, estimated survival from McNary to Bonneville tailrace was higher for hatchery and wild spring/summer Chinook originating in the Snake River (0.825; 95% CI 0.707-0.943; Table 33) than for those originating in the Upper Columbia River Basin (0.760; 0.664-0.856), but the difference was not statistically significant ($P = 0.40$).

For hatchery and wild steelhead migrating in this same reach during 2019, estimated survival for Snake River fish (0.595; 0.381-0.809; Table 33) was nearly identical to that for Upper Columbia River fish (0.597; 0.511-0.683), and unsurprisingly, the difference was not statistically significant ($P = 0.99$).

For hatchery and wild sockeye salmon, estimated survival from McNary to Bonneville tailrace was lower for stocks originating in the Snake (0.520; 0.441-0.614; Table 31) than in the Upper Columbia River Basin (0.697; 0.500-0.972; Table 33), but the difference was not statistically significant ($P = 0.12$).

Table 33. Annual estimated survival probabilities from McNary Dam tailrace to Bonneville Dam tailrace for various spring-migrating salmonid stocks (hatchery and wild combined) in 2019. Standard errors in parentheses. In shaded rows, the annual estimates are weighted means of estimates for weekly groups. In all other rows, all release cohorts were pooled into a single group for the annual estimate. Release numbers for pooled cohorts are from points upstream from 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	11,175	1.015 (0.088)	0.798 (0.111)	0.825 (0.060)
Upper Columbia Chinook	Upper Columbia sites[a]	209,368	0.867 (0.038)	0.877 (0.057)	0.760 (0.049)
Upper Columbia Chinook	Yakima River sites[b]	86,230	0.859 (0.061)	1.051 (0.163)	0.902 (0.136)
Upper Columbia Coho	Upper Columbia sites[a]	45,859	0.898 (0.094)	0.960 (0.133)	0.863 (0.127)
Upper Columbia Coho	Yakima River sites[b]	18,600	0.915 (0.152)	1.043 (0.376)	0.954 (0.339)
Snake River Sockeye	Snake River sites[c]	62,363	0.717 (0.056)	0.725 (0.061)	0.520 (0.044)
Upper Columbia Sockeye	Upper Columbia sites[a]	13,005	0.636 (0.076)	1.103 (0.185)	0.701 (0.120)
Snake River Steelhead	McNary Dam tailrace	7,987	1.029 (0.084)	0.734 (0.110)	0.595 (0.109)
Upper Columbia Steelhead	Upper Columbia sites[a]	97,244	0.797 (0.044)	0.749 (0.051)	0.597 (0.044)

[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

In the *Results* section of this report, we compare 2019 estimates with historical estimates of survival between the Snake River trap and Bonneville Dam for four Snake River stock groups: combined hatchery and wild yearling Chinook (Table 26), wild yearling Chinook (Table 27), combined hatchery and wild steelhead (Table 29), and wild steelhead (Table 30).

For both Chinook salmon and steelhead in 2019, estimated survival was above average for wild fish groups, but below average for combined hatchery and wild fish groups. For the second consecutive year, survival for combined hatchery and wild yearling Chinook was particularly low; in 2018 and 2019, we estimated the lowest survival for this group since 2004.

In particular, the 2019 estimates for combined hatchery and wild yearling Chinook were below average in the reaches from the Snake River trap to Lower Granite Dam and from Lower Granite to McNary Dam. Estimates for wild yearling Chinook were also below average in these reaches, but not to the same degree. These differences between estimates for wild-only vs. combined stocks suggests that survival for wild and hatchery fish differed in 2019. We investigated a variety of factors that might explain why survival was lower for hatchery than for wild Chinook and why survival was below average between the Snake River trap and McNary Dam.

We observed unusually low survival in 2019 for a number of hatchery stocks of Chinook salmon in reaches upstream from Lower Granite Dam. Survival to Lower Granite Dam was the lowest on record for hatchery Chinook released at both the Snake River trap (first year of record 1993) and Salmon River trap (first year 1998; Figure 10). Estimated survival to Lower Granite Dam in 2019 was also below average for many individual hatchery stocks in the Snake River Basin, with estimates for Pahsimeroi and Rapid River Hatchery fish standing out as especially far below average (Table 24). In addition, survival between Lower Granite and McNary Dam for hatchery Chinook was the lowest since 2001 (Table 34).

Table 34. Annual estimated survival probabilities between Lower Granite and McNary Dam for Snake River yearling Chinook salmon (wild, hatchery, and combined), 1995–2019. Simple arithmetic means are given for 1995-2019, excluding 1997, with standard errors in parentheses.

Annual estimated survival from Lower Granite to MeNary Dam for yearling Chinook (SE)			
Year	**Wild**	**Hatchery**	**Wild and Hatchery**
1995	0.697 (0.097)	0.747 (0.035)	0.715 (0.031)
1996	0.574 (0.059)	0.680 (0.023)	0.648 (0.026)
1997	NA	0.560 (0.066)	0.653 (0.072)
1998	0.771 (0.015)	0.773 (0.012)	0.770 (0.009)
1999	0.791 (0.014)	0.791 (0.007)	0.792 (0.006)
2000	0.775 (0.014)	0.763 (0.026)	0.760 (0.012)
2001	0.542 (0.028)	0.556 (0.019)	0.556 (0.009)
2002	0.768 (0.026)	0.759 (0.008)	0.757 (0.009)
2003	0.729 (0.020)	0.746 (0.019)	0.731 (0.010)
2004	0.667 (0.023)	0.682 (0.013)	0.666 (0.011)
2005	0.661 (0.017)	0.743 (0.019)	0.732 (0.009)
2006	0.754 (0.010)	0.763 (0.009)	0.764 (0.007)
2007	0.773 (0.013)	0.788 (0.013)	0.783 (0.006)
2008	0.786 (0.020)	0.785 (0.016)	0.782 (0.011)
2009	0.765 (0.018)	0.798 (0.006)	0.787 (0.007)
2010	0.744 (0.021)	0.790 (0.022)	0.772 (0.012)
2011	0.743 (0.015)	0.753 (0.016)	0.746 (0.010)
2012	0.798 (0.020)	0.793 (0.034)	0.790 (0.016)
2013	0.778 (0.018)	0.799 (0.033)	0.781 (0.016)
2014	0.722 (0.015)	0.861 (0.017)	0.784 (0.013)
2015	0.647 (0.058)	0.775 (0.082)	0.727 (0.033)
2016	0.703 (0.017)	0.788 (0.018)	0.752 (0.011)
2017	0.709 (0.020)	0.811 (0.032)	0.743 (0.019)
2018	0.760 (0.031)	0.723 (0.046)	0.733 (0.025)
2019	0.669 (0.028)	0.634 (0.040)	0.628 (0.027)
Mean	**0.722 (0.014)**	**0.746 (0.015)**	**0.734 (0.012)**

However, not all stocks of Chinook salmon displayed low survival upstream from Lower Granite Dam in 2019. Comparable wild Chinook stocks had average survival or only slightly below average survival, even when the corresponding hatchery estimate was particularly low (Figure 10). Additionally, not every Chinook stock of hatchery origin had poor survival in 2019; for hatchery Chinook tagged at the Grande Ronde River trap and for those from McCall and Sawtooth Hatcheries, estimated survival to Lower Granite Dam was near the long-term average (Figure 10, Table 24).

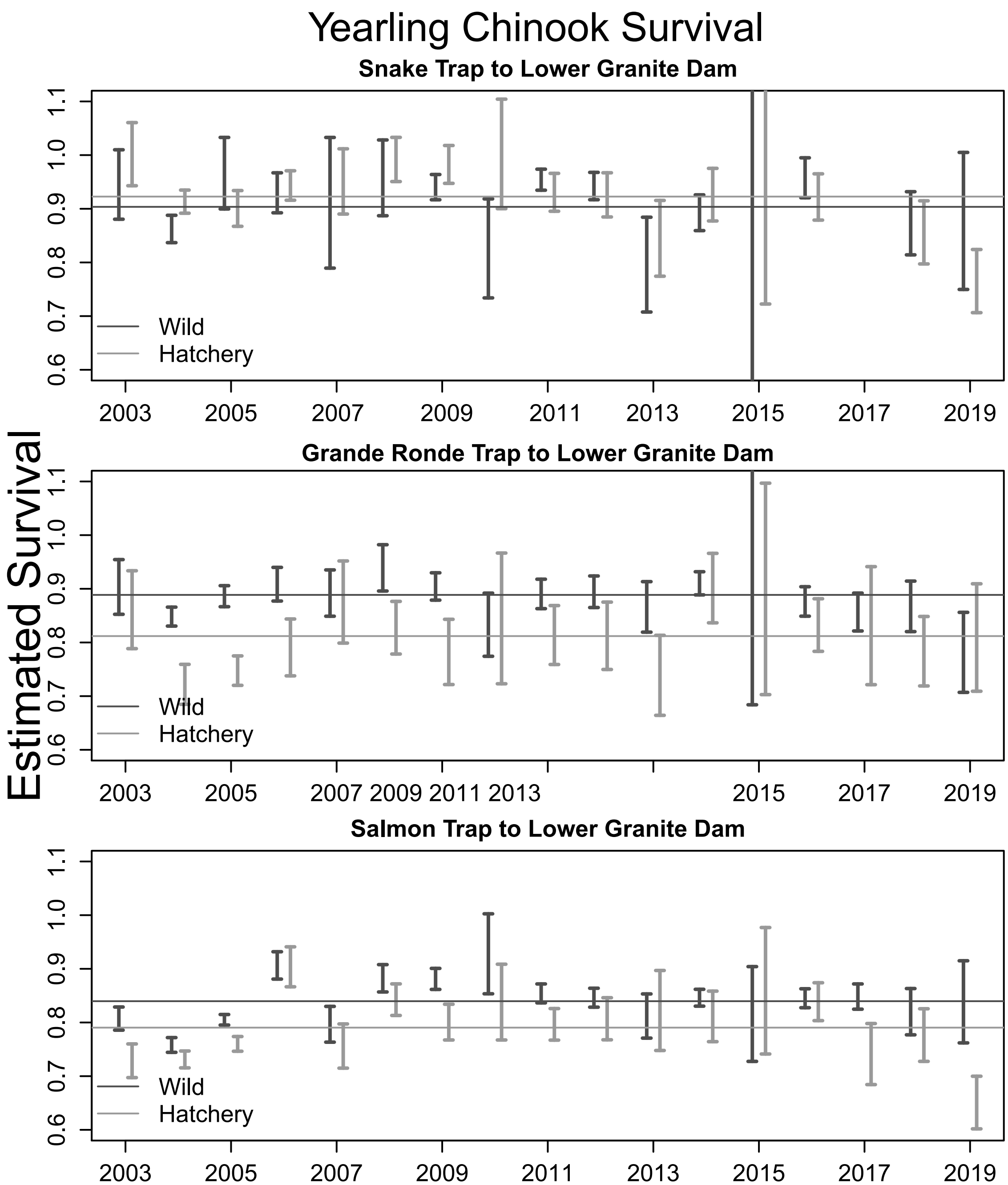


Figure 10. Estimated survival probability between the release location and Lower Granite Dam for fish tagged at traps in the Snake River basin, 2003-2019. Whiskers show 95% confidence intervals. Horizontal lines indicate the 2003-2019 means for each rear type.

We investigated potential explanations for the low survival upstream from Lower Granite Dam demonstrated by many groups of hatchery Chinook in 2019. We closely examined the underlying PIT-tag data used in generating survival estimates for estimates that were unusually low (Snake River trap, Salmon River trap, Pahsimeroi Hatchery, and Rapid River Hatchery), but we did not find any evidence of data omissions or corruption that may have affected these estimates.

We also contacted experts in the region to inquire whether there were any unusual occurrences in 2019 that may have affected the survival of hatchery fish. We learned of an outbreak of bacterial kidney disease (BKD) among yearling Chinook reared at Pahsimeroi Hatchery (Doug Engemann pers. comm. 2019). The timing of this outbreak was not long before the scheduled release date for these fish, and the federal requirements for treatment using an Investigational New Animal Drug (INAD) rendered the outbreak untreatable. Thus, significant numbers of diseased fish were released.

Bacterial kidney disease is both vertically and horizontally transmissible, and ultimately causes high mortality rates in salmonids (Fryer and Sanders 1981). It is possible that the BKD outbreak was responsible for the poor survival of Pahsimeroi Hatchery smolts in 2019. In any case, the diseased fish were not likely representative of the Snake River basin-wide population of hatchery Chinook smolts. Therefore, we removed records of known Pahsimeroi Hatchery yearling Chinook (i.e., those tagged at the hatchery) from datasets used for survival and travel-time estimation between Lower Granite Dam and Bonneville Dam. Estimates in this report reflect the final dataset after the removal of known Pahsimeroi Hatchery fish.

The degree to which other groups of tagged fish included diseased fish from Pahsimeroi Hatchery is not known. It is likely that survival estimates for hatchery Chinook tagged at the Snake and Salmon River traps were influenced to some degree, as non-tagged fish released from Pahsimeroi Hatchery were among the hatchery stocks trapped and tagged at both traps.

While fish tagged at traps can be identified as hatchery-origin by checking for a clipped adipose fin, the specific hatchery of origin cannot be identified. Thus, we could not remove Pahsimeroi fish from groups tagged and released at the traps. Pahsimeroi Hatchery fish were roughly 13% of non-tagged hatchery fish released upstream from the Salmon River trap, and 10% of those released upstream from the Snake River trap (Table 35).

Table 35. Yearling spring/summer Chinook salmon released from hatcheries in the Snake River basin upstream from Lower Granite Dam in 2019. Data from the Fish Passage Center.

Hatchery	Release site	Number Released	Number PIT tagged	Distance (km) to Lower Granite Dam common with Pahsimeroi
Subject to collection and tagging at both Salmon and Snake River traps				
Sawtooth	Salmon River (ID)	1,005,915	19,864	747/630
	Yankee Fork (Salmon R)	94,366	4,597	721/630
Springfield	Yankee Fork (Salmon R)	101,577	4,191	721/630
Pahsimeroi	Pahsimeroi River	794,882	21,890	630/630
McCall	S Fork Salmon River	159,911	26,136	463/345
	S Fork Salmon River	947,076	25,925	463/345
	Johnson Cr Idaho	127,855	2,008	429/345
Rapid River	Rapid River	2,504,018	51,863	283/270
	Little Salmon River	200,000	0	270/270
Total		5,935,600	156,474	
Subject to collection and tagging only at Snake River trap				
Rapid River	Hells Canyon Dam	400,000	0	224/130
Lookingglass	Imnaha River	218,023	55,350	220/130
	Imnaha Acclim. Pond	293,499	0	219/130
	Grande Ronde Accl. P.	250,095	0	418/98
	Catherine Cr Accl. P.	136,458	20,987	378/98
	Lostine Acclim. Pond	132,036	0	292/98
	Lostine Acclim. Pond	130,210	0	292/98
	Lookingglass Creek	136,468	0	235/98
Total		1,696,789	76,337	
Not subject to collection and tagging at either Salmon or Snake River trap				
Clearwater	Powell Acclim. Pond	624,403	25,445	321/51
	Red River	1,180,724	17,077	299/51
	Selway River	402,570	17,068	208/51
	Kooskia Hatchery	691,051	9,746	175/51
	Clearwater River	702,546	17,086	116/51
Dworshak	Kooskia Hatchery	247,263	8,000	175/51
	Dworshak Hatchery	1,724,382	42,000	116/51
Total		5,724,952	136,422	

The degree to which Pahsimeroi Hatchery fish transmitted BKD to other stocks during the juvenile migration is also unknown. Other stocks of both wild and hatchery fish that migrated alongside Pahsimeroi Hatchery smolts in 2019 did not necessarily have unusually low survival to Lower Granite Dam.

Wild fish tagged at the Salmon River trap had average survival, while wild fish tagged at the Snake and Grande Ronde River traps had only slightly below-average survival. Hatchery fish tagged at the Grande Ronde River trap had average survival (Figure 10). Hatchery fish from McCall and Sawtooth hatcheries, which were released nearest in space and time to Pahsimeroi Hatchery fish, had average or above-average survival to Lower Granite Dam (Table 24).

Although survival upstream from Lower Granite Dam may not have been affected by BKD, the disease may still have been transmitted. Bacterial kidney disease can have an incubation period of well over two months (Meyer et al. 2002), which means fish infected during migration might not become symptomatic until after reaching the estuary.

Yearling Chinook salmon smolts from Rapid River Hatchery also had unusually low survival to Lower Granite Dam in 2019. However, unlike Pahsimeroi Hatchery smolts, there were no known concerns about their health. Rapid River Hatchery smolts were released more than one month prior to the release of Pahsimeroi smolts, so it seems unlikely that substantial disease transmission occurred.

Detection of PIT-tagged fish began at Lower Granite Dam on 18 March, while tagged fish were released from Rapid River Hatchery on 11 March. Therefore, any tagged fish that passed Lower Granite Dam before 18 March could not have been detected, and these potential missed detections would have induced bias in the survival estimate. However, the first recorded detection of Rapid River Hatchery fish was on 23 March, so it is unlikely that this type of bias was the cause of low survival estimates.

The large number of non-tagged Rapid River Hatchery fish made up roughly 42% of hatchery fish released upstream from the Salmon River trap, and 33% of hatchery fish released upstream from the Snake River trap (Table 35). If survival in the reaches upstream from Lower Granite Dam was equal between non-tagged Rapid River fish and their tagged counterparts, then Rapid River Hatchery fish could have had a large influence on the unusually low survival estimates we observed from the Snake and Salmon River traps to Lower Granite Dam.

On the other hand, Rapid River hatchery fish did not appear to contribute to the low overall survival estimate between Lower Granite and McNary Dam. Although Rapid River Hatchery fish presumably made up a large component of the cohort migrating in that reach, they did not themselves have a low survival estimate in the reach (Appendix Table B1).

Because we removed known Pahsimeroi Hatchery smolts from the dataset, the low survival estimates we found between Lower Granite and McNary Dam in 2019 were not likely to have been solely the result of BKD effects. Another possible explanation is predation on Chinook smolts by piscivorous fish. Several species of piscivorous fish reside in Snake River reservoirs, including northern pikeminnow *Ptychocheilus oregonensis*, walleye *Sander vitreus*, and smallmouth bass *Micropterus dolomieu*.

Northern pikeminnow is the focus of a predator control program that has operated in the Columbia River basin since 1991 with the objective of reducing predation on salmonid smolts. Since the inception of the program, indices of northern pikeminnow abundance and consumption of juvenile salmon have decreased (Porter 2012, Storch et al. 2014). We have no evidence that this pattern changed in 2019. No predator control program currently exists for walleye or smallmouth bass, but recreational fishing restrictions such as bag and size limits were relaxed in 2017.

The population of smallmouth bass in Snake River reservoirs does not appear to have changed in a consistent direction in recent years (Table 36, Erhardt et al. 2018), but estimated consumption of subyearling Chinook salmon by smallmouth bass was fifteen times higher in 2013-2015 than in 1996-1997 (Naughton et al. 2004, Erhardt et al. 2018).

Erhardt et al. (2018) note that yearling spring Chinook salmon are less vulnerable to smallmouth bass predation than subyearling fall Chinook, because yearlings are larger and they migrate when water temperatures are cooler. However, Erhardt et al. also found that yearling Chinook were the most common prey item in the stomachs of large smallmouth bass in April, and Storch et al. (2014) estimated spring indices of smallmouth bass predation on salmonids that generally increased over the period 1991-2013.

Walleye density and predation rates on juvenile salmon have not been estimated with confidence in the Snake River (Storch et al. 2014), but collection counts of walleye have increased substantially since 2013, particularly at Lower Monumental Dam (Table 36). These sources suggest the possibility that juvenile salmonids have faced increased predation from smallmouth bass and walleye in Snake River reservoirs during recent years, but it is uncertain if a link can be made between piscivorous fish predation and the below-average survival of Chinook salmon in that reach in 2019.

Table 36. Collection counts of notable incidental species at the fish bypass facilities of Snake River dams. Counts shown are from the expanded sample plus the total number of individuals observed in the separator at Lower Granite. Data from USACE juvenile fish collection and bypass reports.

Year	Smallmouth Bass	Walleye	Siberian Prawn
		Lower Granite Dam	
2010	1,024	0	11,711
2011	682	1	3,400
2012	620	1	3,831
2013	445	0	6,634
2014	2,037	0	9,839
2015	2,160	1	20,979
2016	4,819	3	25,848
2017	1,604	1	4,148
2018	3,625	5	43,434
		Little Goose Dam	
2008	15,503	32	5,213
2009	5,092	19	6,327
2010	4,150	20	38,676
2011	3,691	8	15,743
2012	2,442	7	23,183
2013	1,279	9	45,015
2014	3,528	14	81,310
2015	2,102	27	464,586
2016	2,992	65	51,518
2017	8,977	110	31,668
2018	2,939	170	11,159
		Lower Monumental Dam	
2010	12,171	10	8,599
2011	393	19	2,818
2012	10,984	8	2,219
2013	428	9	12,969
2014	1,457	92	18,388
2015	779	337	48,243
2016	848	608	10,527
2017	1,764	733	9,020
2018	1,046	352	1,557

Activity of predacious fish is related to water temperature and turbidity, with higher temperature and lower turbidity associated with greater predation rates. However, in 2019 the lowest survival estimates between Lower Granite and McNary Dam were in late March and early April (Tables 2 and 4), when water temperature was relatively low and turbidity relatively high (Appendix Figure C1, Table 37).

Table 37. Secchi depths recorded at Little Goose Dam in 2019. Data from USACE fish facility weekly reports. No weekly report was available for 5-11 April.

	Secchi depth (ft)	
Period	Max	Min
22-28 Mar	4.9	3.2
29 Mar-4 Apr	1.9	1.3
5-11 Apr	-	-
12-18 Apr	1.7	0.7
19-25 Apr	2.0	1.1
26 Apr-2 May	2.6	1.8
3-9 May	3.6	3.0
10-16 May	4.0	2.8
17-23 May	2.9	2.4
24-30 May	3.6	3.0
31 May-6 Jun	3.5	2.5
7-13 Jun	3.6	3.0

Predacious fish are not the only taxa that prey upon migrating smolts. Avian piscivores are abundant along the Columbia River downstream from its confluence with the Snake River, and their populations and consumption rates have been intensively monitored (Collis et al. 2002, Ryan et al. 2001, 2003; Roby et al. 2008, Evans et al. 2012, Collis et al. 2020).

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 had large populations of gulls *Larus* spp. Other avian piscivores in this area include the American white pelican *Pelecanus erythrorhynchos,* double-crested cormorant *Phalacrocorax auritus*, great egret *Ardea alba*, and herons *A. herodias* and *Nycticorax nycticorax.*

Starting in 2015 and continuing through 2019, passive and active dissuasion measures were employed on the Crescent Island Caspian tern colony. These efforts have resulted in elimination of nesting at that location since 2015. However, terns displaced from this colony have attempted to relocate or join other colonies within the mid-Columbia Basin.

Relocation of Caspian terns to the Blalock Islands colony in John Day pool has increased the number of predators in that reach (Collis et al. 2020). In 2019 the Blalock Islands tern colony was only slightly smaller than the original colony on Crescent Island (Collis et al. 2020). Additionally, several large colonies of gulls were seen in the mid-Columbia region in 2019 on Island 20, Badger Island, and Miller Rocks Island. These colonies were all estimated to have substantial predation rates on juvenile steelhead and sockeye salmon in 2019 (Collis et al. 2020).

Eliminating nesting on Crescent Island would be expected to decrease avian predation on migrating smolts in McNary Dam pool, with a corresponding increase in smolt survival between Ice Harbor and McNary Dam. An increase in nesting on the Blalock Islands would be expected to increase predation in John Day pool, with a corresponding decrease in smolt survival between McNary and John Day Dam.

We routinely estimate survival within both of these reaches. However, statistical issues related to low detection rates and/or smolt sample sizes lead us to examine estimates in the reaches from Lower Monumental to McNary and from McNary to Bonneville Dam for evidence of survival impacts from changing avian predation.

Avian predation rates on steelhead smolts are considerably higher than on yearling Chinook salmon (Evans et al. 2012, Hostetter et al. 2012). Many mid-Columbia bird colonies in 2019 were found to have consumption rates of 3% or more on Snake River steelhead, but consumption rates of 0.8% or less on Snake River yearling Chinook salmon (Collis et al. 2020).

Survival estimates for Snake River steelhead between McNary and Bonneville Dam have been below average in almost every year since 2015. This drop in estimated survival coincides with the 2015 relocation of much of the Crescent Island tern colony to islands below McNary Dam (Table 29). Moreover, estimated survival for steelhead between Lower Monumental and McNary Dam was above average during 2015-2019. These patterns indicate the possibility that avian predators have been influencing survival rates of Snake River steelhead.

Snake River yearling Chinook salmon have not displayed as consistent a pattern in estimates of survival; in particular, estimates in 2019 showed a reverse pattern to what we would expect if avian predators were a major contributor to Chinook mortality. Perhaps this is not surprising, given the low estimated consumption rates of juvenile Chinook by avian predators. Further investigation is needed to determine whether Chinook survival estimates between McNary and Bonneville Dam for 2015-2018 were biased low due to violations of CJS model assumptions that cannot be detected with our present tests of assumption violations, or whether the survival seen in 2019 was biased high for a similar reason.

Another factor that has potentially influenced survival of juvenile salmon in Snake River reservoirs in 2019 and other recent years is a population explosion of an invasive crustacean that may compete with salmonid smolts. Siberian prawn *Palaemon modestus* was first documented in the Snake River in 1998 (Haskell et al. 2006). Collection counts of Siberian prawn were low in the 2000s, but have increased significantly in recent years, reaching a peak of 464,586 at Little Goose Dam in 2015 (Table 36, Erhardt and Tiffan 2016).

Siberian prawn consumes the same types of prey as juvenile salmonids, and the competition may result in depressed growth rates of juvenile salmon in Snake River reservoirs (Tiffan et al. 2014, Tiffan and Hurst 2016). However, collection counts of Siberian prawn have generally declined since the peak in 2015. Collection counts for 2019 are not yet available, but by extrapolating trends in the data, it seems likely that Siberian prawn was not more abundant in 2019 than in the previous four years (Table 36).

Survival of juvenile Chinook between Lower Granite and Bonneville Dam has not perfectly tracked the trends in Siberian prawn collection counts. Survival of combined hatchery and wild smolts was generally above average during 2014-2018, despite very high Siberian prawn counts in several of those years (Tables 26 and 36). Wild Chinook smolts did have below-average survival in the Snake River during 2014-2017, indicating a possible relationship with Siberian prawn counts, yet hatchery Chinook salmon had above-average survival in all those years (Table 34). Competition with Siberian prawn may be a contributing factor, but it is likely not the sole reason for below-average survival of Snake River Chinook salmon in 2019.

Environmental conditions and management actions in 2019 resulted in a year with average water temperatures but above-average flow and spill during most of the migration season. Mean flow in the Snake River was well above average except for a short period in late May and after the beginning of June.

Spill discharge levels and percentages were well above the post-2006 average for nearly the entire migration season. High spill resulted in very low detection probabilities at McNary, John Day, and Bonneville Dam, which reduced the precision of our survival estimates for the lower Columbia River. High spill also resulted in above-average total dissolved gas (TDG).

Water temperatures in the Snake River were close to average during the migration season overall, but daily water temperatures fluctuated above and below the long-term daily means. After the beginning of June, daily mean temperatures rose to about one degree (C) above the long-term mean.

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 generally decreased, more so for steelhead than for Chinook smolts. Travel times are not as strongly influenced by flow as they once were: since 2006, travel time in low-flow years has been more similar to that in medium and high-flow years for both yearling Chinook and steelhead. For yearling Chinook, day of the year is now a stronger predictor of travel time than either flow or spill.

Before the new spill regime in 2006, some of the lowest flow years were also low spill years. Therefore, the effect of average flow on travel time was difficult to separate from that of spill. Flow and spill also vary within seasons, so comparisons of annual flow or spill among years did not provide much insight into differences in travel time, although they did allow for simple visual comparison of overall annual differences. Decreased forebay delays and overall shortened travel times can potentially decrease exposure to the elevated water temperatures that may occur late in spring or early summer.

In 2019, median travel time between Lower Granite and Bonneville Dam was similar to that in other high-flow years under the present spill regime during May for yearling Chinook salmon and throughout the migration season for steelhead. However, April median travel times were longer for yearling Chinook salmon in 2019 than in other recent high-flow years. High spill volumes in 2019 induced notable eddies in the tailrace at some dams. It is possible that tailrace egress times were longer for yearling Chinook salmon smolts because of these eddies.

It is also possible that yearling Chinook salmon smolts traveled more slowly through the hydrosystem early in the season because fish in the reservoirs were less smolted than usual. These fish may have been swept downstream early by the very large freshet in the second week of April. It is not possible to resolve these two hypotheses using just one year of data from 2019; however, this issue is worth monitoring as elevated spill continues to be used in future migration seasons.

In 2019, estimated percentages of transported yearling Chinook and steelhead were substantially higher than estimated percentages from 2014 to 2017, though not quite as high as the estimate from 2018. Percentages of transported fish increased in 2018 and 2019 because the transportation program began earlier in those years than in other years since 2006. In most years since 2006, collection for transportation began within 1-2 d of 1 May, while in 2018 and 2019, collection began a full week earlier, on 23 and 24 April, respectively.

Detection probability at dams has been lower in general since 2007, when programs were instituted at most dams to encourage spillway passage by increasing spill and using surface-passage structures. These programs have been successful, and there is evidence that surface spill is disproportionately attractive to fish at lower flow levels. Greater use of spill results in a higher proportion of fish passing through spillways, as intended. However, higher proportions of spillway passage result in lower proportions of tagged fish entering bypass systems, where PIT tags can be detected.

For survival estimates based on PIT-tag data, sample size is effectively proportional to number of detections, which is the result of both total numbers of migrating PIT-tagged fish and detection probabilities. Reduced sample sizes have become common in recent years, as reliance on spillway 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.

At present, the emphasis on spillway passage 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 have been 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 by 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 for the furthest downstream reaches within the migration corridor: from McNary to John Day and from John Day to Bonneville Dam.

Smaller effective sample sizes also heighten uncertainty in estimates of travel time and smolt-to-adult return ratios, thus reducing 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. This option is not feasible, as it 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 developing PIT-tag monitoring systems for additional fish-passage routes.

A new detection system has been installed in Spillbay 1 at Lower Granite Dam and will be operational during the 2020 migration season. Given the large number of smolts that pass this dam via the removeable spillway weir (RSW), spillbay detection has the potential to greatly increase overall detection efficiency at Lower Granite Dam, and we have high hopes for the success of this new system.

Location of the new detection system in a spillway passage route is important for other reasons as well. 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 survival and detection probability estimates from mark-recapture models and can also 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. Fish that passed Lower Granite Dam via different routes on the same day can be subsequently tracked to provide direct comparisons of survival between dam-passage routes.

Finally, the ability to detect PIT-tagged fish in additional passage routes will increase the precision and accuracy of annual survival estimates. Higher rates of detection at Lower Granite Dam will provide larger effective sample sizes for reaches that include the dam, yielding greater statistical power without additional marking. Furthermore, detection of fish passing multiple routes will reduce the possibility of bias introduced by differing rates of survival between detected and non-detected fish.

If the new spillbay detector at Lower Granite Dam is successful, we believe that the action agencies should prioritize installation of similar PIT-tag monitoring systems in the spillway(s) at Bonneville Dam and the surface-passage structures at McNary Dam. 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, trawl detection rates are relatively low. A stationary PIT-monitoring barge was deployed ~8 km below Bonneville Dam in 2019, but is still in the feasibility testing stage.

The ability to estimate survival to Bonneville Dam would be greatly improved if detection efficiencies at the dam could be increased or if additional tagged fish could be detected downstream from the dam. However, until such technology becomes available, we believe that adding detection capability at Bonneville Dam should be the greatest priority.

McNary Dam is also an important “starting point” for estimates of PIT-tagged smolt survival and is the most important detection site for survival estimates of upper Columbia River stocks. Given the shortage of detection available at mid-Columbia River dams, the key reach for monitoring survival of upper Columbia River salmon is the reach from McNary to Bonneville Dam. However, the quality of our estimates in that reach has been consistently poor for these stocks during the past 10 years.

Increased detection rates at both McNary and Bonneville Dam are necessary to improve our ability to monitor upper Columbia River salmon, but increasing the number of detections at McNary Dam will also increase precision of estimates and modeling of in-season trends and patterns for Snake River stocks. Lastly, detections at both McNary and Bonneville Dam are critical for the investigation of relationships among juvenile migration timing, passage history, downstream survival, and smolt-to-adult return rates.

The PIT tag is an essential research tool that yields a great deal of valuable information that cannot be obtained using any other tagging method. Because of its low cost and long life, the PIT tag allows large numbers of individual fish to be monitored through both the juvenile and adult migration. At present, there is no other tagging method that allows direct comparison of smolt-to-adult return ratios (SARs) 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 existing 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 at Bonneville Dam and McNary Dam 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 quality 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 enhance survival estimation. We recommend installation of PIT-tag detection systems at The Dalles Dam and at upper Columbia River dams.

Acknowledgements

We express our appreciation to all who assisted both directly and indirectly with this research. Staff of the Pacific States Marine Fisheries Commission provided valuable assistance in data acquisition. Fish Ecology Division staff from several research stations participated in the study: M. Morris and his crew tirelessly operated the towed PIT-tag detection arrays in the estuary. A. Barenberg and K. McIntyre helped coordinate and supervise tagging at Lower Granite Dam. B. Sandford provided PIT-tag data from avian bird colonies. We thank K. Tiffan for providing published and unpublished data about smallmouth bass and Siberian prawn abundance and ecology. We thank K. Anderson for assistance in acquiring unpublished dam bypass reports. We thank Doug Engemann for providing information about the disease outbreak at Pahsimeroi Hatchery. We thank J. Butzerin for editorial advice and assistance to improve the quality of this report. We also thank all tagging staff and coordinators for their efforts in PIT-tag data collection and for making these data publicly available. Support for this research came from NOAA and from the region's electrical ratepayers through the Bonneville Power Administration.

References

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5:1-437.

Collis, K. D., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537-550.

Collis, K., A. Evans, J. Tennyson, A. Turecek, Q. Payton, and R. Bhatt. 2020. Avian Predation in the Columbia Plateau Region: Management, Monitoring, and Evaluation in 2019. Report to Grant County Public Utility District No. 2.

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika 51:429-438.

Columbia River DART (Data Access in Real Time). 1996-. Columbia Basin Research, School of Aquatic & Fisheries Sciences, University of Washington, Seattle, Washington. Available at www.cbr.washington.edu/dart/dart.html. (August 2018).

Crawford, B. A., and S. M. Rumsey. 2011. Guidance for Monitoring Recovery of Pacific Northwest Salmon and Steelhead Listed under the Federal Endangered Species Act. National Marine Service, Northwest Region.

Erhardt, J. M., K. F. Tiffan and W. P Connor. 2018. Juvenile Chinook Salmon Mortality in a Snake River Reservoir: Smallmouth Bass Predation Revisited. Transactions of the American Fisheries Society 147:316-328.

Erhardt, J. M. and K. F. Tiffan. 2016. Ecology of nonnative Siberian prawn (*Palaemon modestus*) in the lower Snake River, Washington, USA. Aquatic Ecology 50:607-621.

Evans, A. F., N. J. Hostetter, D. D. Roby, K. Collis, D. E. Lyons, B. P. Sanford, R. D. Ledgerwood, and S. Sebring. 2012. Systemwide evaluation of avian predation on juvenile salmonids from the Columbia River based on recoveries of passive integrated transponder tags. Transactions of the American Fisheries Society 141:975-989.

Faulkner, J. R., S. G. Smith, W. D. Muir, T. M. Marsh, and J. G. Williams. 2007. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2006. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, W. D. Muir, T. M. Marsh, and J. G. Williams. 2008. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2007. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, W. D. Muir, T. M. Marsh, and J. G. Williams. 2009. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2008. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, W. D. Muir, T. M. Marsh, and J. G. Williams. 2010. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2009. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, W. D. Muir, T. M. Marsh, and J. G. Williams. 2011. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2010. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, W. D. Muir, T. M. Marsh, and R. W. Zabel. 2012. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2011. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, T. M. Marsh, and R. W. Zabel. 2013. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2012. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, D. L. Widener, T. M. Marsh, and R. W. Zabel. 2014. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2013. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., S. G. Smith, D. L. Widener, T. M. Marsh, and R. W. Zabel. 2015. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2014. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R. , D. L. Widener, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2016. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2015. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R. , D. L. Widener, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2017. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2016. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Faulkner, J. R., D. L. Widener, B. L. Bellerud, and R. W. Zabel. 2019. Associations among fish length, dam passage history, and survival to adulthood in two at-risk species of Pacific salmon. Transactions of the American Fisheries Society 148:1069–1087.

Fryer, J. L. and J. E. Sanders. 1981. Bacterial Kidney Disease of Salmonid Fish. Annual Review of Microbiology 35:273-298.

Haskell, C. A., R. D. Baxter, and K. F. Tiffan. 2006. Range expansion of an Exotic Siberian Prawn to the Lower Snake River. Northwest Science 80:311-316.

Hockersmith, E. E., S. G. Smith, W. D. Muir, B. P. Sandford, J. G. Williams, and J. R. Skalski. 1999. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1997. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Hostetter, N. J., A. F. Evans, D. D. Roby, and K. Collis. 2012. Susceptibility of juvenile steelhead to avian predation: the influence of individual fish characteristics and river conditions. Transactions of the American Fisheries Society 141:1586-1599.

Iwamoto, R. N., W. D. Muir, B. P. Sandford, K. W. McIntyre, D. A. Frost, J. G. Williams, S. G. Smith, and J. R. Skalski. 1994. Survival estimates for the passage of juvenile chinook salmon through Snake River dams and reservoirs, 1993. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and Immigration--stochastic model. Biometrika 52:225-247.

Lady, J., P. Westhagen, and J.R. Skalski. 2013. SURPH 3.5 Manual. SURvival under Proportional Hazards. Report of Columbia Basin Research to the Bonneville Power Administration, Portland, Oregon. (Available from Columbia Basin Research, University of Washington http://www.cbr.washington.edu/analysis/apps/surph)

Ledgerwood, R. D., B. A. Ryan, E. M. Dawley, E. P. Nunnallee, and J. W. Ferguson. 2004. A surface trawl to detect migrating juvenile salmonids tagged with passive integrated transponder tags. North American Journal of Fisheries Management 24:440-451.

Marsh, D. M., G. M. Matthews, S. Achord, T. E. Ruehle, and B. P. Sandford. 1999. Diversion of salmonid smolts tagged with passive integrated transponders from an untagged population passing through a juvenile collection system. North American Journal of Fisheries Management 19:1142-1146.

McCann, J., B. Chockley, E. Cooper, B. Hsu, H. Schaller, S. Haeseker, R. Lessard, C. Petrosky, T. Copeland, E. Tinus, E. Van Dyke, A. Storch, and D. Rawding. 2017. Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye: 2017 Annual Report. Report of the Comparative Survival Study Oversight Committee and Fish Passage Center to the Bonneville Power Administration, Portland, Oregon. Available: www.fpc.org/documents/CSS.html

Meyer, F. P., J. W. Warren and T. G. Carey, editors. 2002. A Guide to Integrated Fish Health Management in the Great Lakes Basin, Revision One. Ann Arbor (MI): Great Lakes Fishery Commission.

Muir, W. D., S. G. Smith, E. E. Hockersmith, S. Achord, R. F. Absolon, P. A. Ocker, B. M. Eppard, T. E. Ruehle, J. G. Williams, R. N. Iwamoto, and J. R. Skalski. 1996. Survival estimates for the passage of yearling chinook salmon and steelhead through Snake River dams and reservoirs, 1995. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Muir, W. D., S. G. Smith, R. N. Iwamoto, D. J. Kamikawa, K. W. McIntyre, E. E. Hockersmith, B. P. Sandford, P. A. Ocker, T. E. Ruehle, J. G. Williams, and J. R. Skalski. 1995. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1994. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

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

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001b. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River Dams. North American Journal of Fisheries Management 21:135-146.

Muir, W. D., S. G. Smith, R. W. Zabel, D M. Marsh, J. G. Williams, and J. R. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2002. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Naughton, G. P., D. H. Bennet and K. B. Newman. 2004. Predation on Juvenile Salmonids by Smallmouth Bass in the Lower Granite Reservoir System, Snake River. North American Journal of Fisheries Management 24:534-544.

Porter, R. 2012. Report on the predation index, predator control fisheries, and program evaluation for the Columbia River Basin experimental northern pikeminnow management program, 2012 annual report. Report of the Northern Pikeminnow Management Program to the Bonneville Power Administration, Portland, Oregon.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990c. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335-340.

PSMFC (Pacific States Marine Fisheries Commission). 1996-present. PIT tag information system. Interactive database maintained by the Pacific States Marine Fisheries Commission, Portland, Oregon. Available: www.ptagis.org. (August 2013).

Roby, D. D., K. Collis, D. E. Lyons, Y. Suzuki, J. Y. Adkins, L. Reinalda, N. Hostetter, and L. Adrean. 2008. Research, monitoring, and evaluation of avian predation on salmonid smolts in the lower and mid-Columbia River. Draft 2007 Season Summary. Report to the Bonneville Power Administration, Portland, OR.

Roby, D. D., K. Collis, D. E. Lyons, Y. Suzuki, P. J. Loschl, T. J. Lawes, K. S. Bixler, A. Piggott, A. Evans, B. Cramer, A. Turecek, Q. Payton, M. Hawbecker, and D. Kuligowski. 2016. Avian predation on juvenile salmonids: evaluation of the Caspian Tern management plan in the Columbia River estuary. 2015 Final Annual Report. Report to the Bonneville Power Administration, Portland, OR.

RTR (Real Time Research, Inc.). 2017. Bird Research Northwest. Cooperative program of the Oregon State University, Real Time Research Inc., U. S. Geological Survey, and Oregon Cooperative Fish and Wildlife Research Unit. Available from www.birdresearchnw.org. (December 2017).

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River Basin. North American Journal of Fisheries Management 21:417-421.

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary, 1998-2000. Transactions of the American Fisheries Society 132:275-288.

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

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R. 1998. Estimating season-wide survival rates of outmigrating salmon smolt in the Snake River, Washington. Canadian Journal of Fisheries and Aquatic Sciences 55:761-769.

Skalski, J. R., A. Hoffmann, and S. G. Smith. 1993. Testing the significance of individual and cohort-level covariates in animal survival studies. Pages 1-17 *In* J. D. Lebreton and P. M. North (editors), The use of marked individuals in the study of bird population dynamics: Models, methods, and software. Birkhauser Verlag, Basel.

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:1484-1493.

Smith, S. G., W. D. Muir, S. Achord, E. E. Hockersmith, B. P. Sandford, J. G. Williams, and J. R. Skalski. 2000a. Survival estimates for the passage of juvenile salmonids through Snake and Columbia River dams and reservoirs, 1998. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Smith, S. G., W. D. Muir, G. Axel, R. W. Zabel, J. G. Williams, and J. R. Skalski. 2000b. Survival estimates for the passage of juvenile salmonids through Snake and Columbia River dams and reservoirs, 1999. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Smith, S. G., W. D. Muir, E. E. Hockersmith, S. Achord, M. B. Eppard, T. E. Ruehle, J. G. Williams, and J. R. Skalski. 1998. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1996. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Smith, S. G., W. D. Muir, R. W. Zabel, D. M. Marsh, J. G. Williams, R. A. McNatt, and J. R. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2003. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Smith, S. G., W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2005. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2004. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Smith, S. G., W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2006. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2005. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Smith, S. G., J. R. Skalski, W. Schlechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH.1 Manual. (Available from Center for Quantitative Science, HR-20, University of Washington, Seattle, WA 98195.)

Storch, A. J., C. Mallette, and S. Williams. 2014. Evaluate predator control fisheries and establish an index of predation by Northern Pikeminnow and other piscivorous fishes on juvenile salmonids in the lower Columbia and Snake rivers. Annual Report to the Bonneville Power Administration, Project 199007700, Portland, Oregon.

Tiffan, K. F., J. M. Erhardt, and S. J. St. John, 2014. Prey availability, consumption, and quality contribute to variation in growth of subyearling Chinook salmon rearing in riverine and reservoir habitats. Transactions of the American Fisheries Society, 143: 219-229.

Tiffan, K. F. and W. R. Hurst, 2016. Feeding Ecology of Non-native Siberian Prawns *Palaemon modestus* (Heller, 1862) (Decapoda, Palaemonidae), in the lower Snake River, Washington, USA. Crustaceana, 89:721-736.

Widener, D. L., J. R. Faulkner, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2018. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2017. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Widener, D. L., J. R. Faulkner, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2019. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2018. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Williams, J. G., and G. M. Matthews. 1995. A review of flow survival relationships for spring and summer chinook salmon, *Oncorhynchus tshawytscha*, from the Snake River Basin. Fish. Bull., U.S. 93:732-740.

Williams, J. G., S. G. Smith, and W. D. Muir. 2001. Survival estimates for downstream migrant yearling juvenile salmonids through the Snake and Columbia Rivers hydropower system, 1996-1980 and 1993-1999. North American Journal of Fisheries Management 21:310-317.

Zabel, R. W., T. Wagner, J. L. Congleton, S. G. Smith, and J. G. Williams. 2005. Survival and selection of migrating salmon from capture-recapture models with individual traits. Ecological Applications 15:1427-1439.

Zabel, R. W., S. G. Smith, W. D. Muir, D. M. Marsh, and J. G. Williams. 2002. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2001. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Zabel, R. W., S. G. Smith, W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2001. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2000. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Appendix A: Evaluation of Model Assumptions

Background

Using the Cormack-Jolly-Seber (CJS), or single-release (SR) model, 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, with probabilities considered "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").

Thus, the detection history is a record of outcomes in a series of events, although it is an imperfect record, since detection history cannot always distinguish between mortality and survival without detection. For a given group of tagged fish, the SR model represents detection history data as a multinomial distribution, with each multinomial cell probability (detection history probability) 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 non-detected 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 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 or biweekly 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, a developed preference for a particular passage route is a behavioral response, while a size-related difference in passage-route selection is 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 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 count 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 expressed 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 proportions as those for fish first detected at John Day or below, the difference could indicate 1. behavioral response to detection at Lower Monumental, 2. inherent differences in detectability (i.e., guidability) among tagged fish in the group, or 3. 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 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 from 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	Detected at Trawl	
df = 1	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 release groups from Lower Granite in 2019, there were more significant tests than expected by chance alone (5%) for steelhead and also for yearling Chinook salmon ($\alpha = 0.05$; Appendix Table A1). There were 10 weekly groups of yearling Chinook salmon, and the overall sum of χ^2 test statistics was significant for one group (10%). For 11 steelhead groups, the overall test was significant 3 times (27%).

Counting all individual component tests (i.e., 2.C2, 3.SR3, etc.), 3 tests out of 49 (6%) were significant for yearling Chinook salmon and 8 out of 54 (15%) were significant for steelhead (Appendix Tables A1-A3). There is a 45% chance of 3 or more tests out of 49 being significant if the true test-wise probability of a "false positive" result is $\alpha = 0.05$, and a 0.5% chance of 8 or more significant tests out of 54. This provides evidence that the number of positive tests for Chinook could be simply due to chance, but the results for steelhead indicate a number of significant assumption violation tests that is not likely explained by chance alone.

We diagnosed 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 steelhead released from Lower Granite Dam, 5 of the 8 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 steelhead released from Lower Granite Dam, there were 2 significant Test 2.C2 results and 3 significant Test2.C3 results. Both of the significant Test 2.C2 tests showed that fish detected at Little Goose Dam were less likely to be next detected below McNary Dam, and all three of the significant Test 2.C3 tests showed fish detected at Lower Monumental Dam were more likely to be detected again at McNary Dam.

For biweekly groups from McNary Dam, there were no significant contingency table test results for yearling Chinook; however, one of the four tests for steelhead had a highly significant χ^2 test statistic (Appendix Tables A4-A6). The significant test result for steelhead was for Test 2.C2, and the result indicated that fish detected passing John Day Dam were less likely to be detected at the trawl. Given the small number of tests we were able to perform and the highly significant test statistic for the one significant test result, it is likely that model assumptions were violated for one or more biweekly cohorts of steelhead.

Discussion

We believe that inherent differences in detectability (guidability) of fish within a release group are the most likely cause of the patterns we observed in contingency table tests in 2019, as in previous years. Zabel et al. (2002, 2005) and Faulkner et al. (2019) provided evidence of inherent differences related to length of fish at tagging, and similar observations were made in 2019 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 suggested that the heterogeneity was inherent, and not a behavioral response (Zabel et al. 2005). Probability of detection at Little Goose Dam afforded the best insight into the relationship between fish size and detection, as Little Goose was the first dam encountered after release by fish included in these datasets (all fish included in the dataset 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 were not consistently more likely to be detected downstream offers evidence against the proposition that size selection is the only mechanism driving these 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 percentage 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 later migrants from the cohort: they will encounter low spill and have higher 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 did 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 at the site of interest and downstream. The fate of fish not detected at the site of interest is only known for fish detected 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, 2019.

Test		Species		Total
		Chinook	Steelhead	
Test 2.C2	Tests (n)	10	11	21
	Significant tests (n)	0	2	2
Test 2.C3	Tests (n)	10	11	21
	Significant tests (n)	1	3	4
Test 3.SR3	Tests (n)	10	11	21
	Significant tests (n)	0	0	0
Test 3.Sm3	Tests (n)	9	10	19
	Significant tests (n)	1	2	3
Test 3.SR4	Tests (n)	10	11	21
	Significant tests (n)	1	1	2
Test 2 sum	Tests (n)	10	11	21
	Significant tests (n)	1	3	4
Test 3 sum	Tests (n)	10	11	21
	Significant tests (n)	1	1	2
Test 2 + 3	Tests (n)	10	11	21
	Significant tests (n)	1	3	4

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 2019.

	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
23–29 Mar	2.27	0.893	1.37	0.712	1.35	0.509	0.02	0.876
30 Mar–5 Apr	2.41	0.879	2.08	0.556	2.05	0.360	0.04	0.851
6–12 Apr	6.75	0.344	0.91	0.824	0.84	0.657	0.07	0.798
13–19 Apr	9.33	0.156	0.95	0.813	0.94	0.624	0.01	0.930
20–26 Apr	3.56	0.736	2.68	0.444	0.94	0.626	1.74	0.187
27 Apr–3 May	6.28	0.393	5.34	0.149	5.34	0.069	0.00	0.960
4 –10 May	9.13	0.167	1.62	0.655	1.01	0.605	0.62	0.432
11–17 May	16.21	**0.013**	12.62	**0.006**	4.43	0.109	8.19	**0.004**
18–24 May	2.59	0.858	0.68	0.877	0.68	0.712	0.00	0.955
25–31 May	3.99	0.551	3.17	0.366	1.53	0.466	1.64	0.200
Total (df)	62.52 (59)	0.352	31.42 (30)	0.395	19.09 (20)	0.516	12.33 (10)	0.264

	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
23–29 Mar	0.90	0.826	0.00	0.986	0.34	0.558	0.55	0.457
30 Mar–5 Apr	0.33	0.955	0.31	0.578	0.01	0.904	0.00	0.960
6–12 Apr	5.85	0.119	1.58	0.209	2.77	0.096	1.50	0.220
13–19 Apr	8.38	**0.039**	0.18	0.675	4.82	**0.028**	3.39	0.066
20–26 Apr	0.89	0.829	0.00	0.967	0.77	0.382	0.12	0.730
27 Apr–3 May	0.94	0.817	0.49	0.482	0.30	0.586	0.15	0.702
4 –10 May	7.51	0.057	0.87	0.352	2.24	0.134	4.40	**0.036**
11–17 May	3.59	0.309	1.02	0.313	0.50	0.478	2.07	0.150
18–24 May	1.91	0.592	1.71	0.192	0.20	0.657	0.01	0.936
25–31 May	0.82	0.663	0.37	0.543	-	-	0.45	0.501
Total (df)	33.10 (29)	0.361	6.51 (10)	0.771	11.95 (9)	0.216	12.64 (10)	0.244

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 2019.

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
23–29 Mar	8.70	0.191	6.56	0.087	6.56	0.038	0.00	0.978
30 Mar–5 Apr	4.54	0.604	1.74	0.628	1.73	0.422	0.01	0.912
6–12 Apr	10.00	0.125	7.24	0.065	3.06	0.217	4.18	**0.041**
13–19 Apr	20.65	**0.002**	19.31	**<0.001**	10.93	**0.004**	8.38	**0.004**
20–26 Apr	43.09	**<0.001**	26.14	**<0.001**	2.00	0.369	24.15	**<0.001**
27 Apr–3 May	8.09	0.231	5.77	0.124	3.45	0.178	2.32	0.128
4–10 May	3.06	0.802	2.36	0.501	1.21	0.545	1.15	0.284
11–17 May	13.85	**0.031**	8.69	**0.034**	8.63	**0.013**	0.06	0.802
18–24 May	8.62	0.196	4.66	0.199	3.42	0.181	1.23	0.267
25–31 May	7.87	0.248	5.59	0.134	5.29	0.071	0.30	0.586
1–7 Jun	4.81	0.440	3.38	0.337	0.49	0.782	2.89	0.089
Total (df)	133.28 (65)	**<0.001**	91.43 (33)	**<0.001**	46.76 (22)	**0.002**	44.67 (11)	**<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
23–29 Mar	2.14	0.544	1.11	0.293	0.63	0.426	0.40	0.527
30 Mar–5 Apr	2.80	0.424	0.00	0.981	0.03	0.872	2.77	0.096
6–12 Apr	2.76	0.430	0.06	0.811	0.50	0.481	2.20	0.138
13–19 Apr	1.34	0.719	0.25	0.620	0.10	0.755	1.00	0.318
20–26 Apr	16.95	**0.001**	0.13	0.720	8.87	**0.003**	7.94	**0.005**
27 Apr–3 May	2.33	0.507	0.80	0.371	0.74	0.388	0.78	0.376
4–10 May	0.69	0.875	0.01	0.932	0.17	0.684	0.52	0.470
11–17 May	5.16	0.160	0.00	0.965	4.19	**0.041**	0.97	0.325
18–24 May	3.97	0.265	0.87	0.351	2.79	0.095	0.31	0.579
25–31 May	2.28	0.516	1.03	0.311	1.20	0.273	0.05	0.822
1–7 Jun	1.43	0.489	1.06	0.303	-	-	0.37	0.544
Total (df)	41.85 (32)	0.114	5.31 (11)	0.915	19.22 (10)	**0.038**	17.32 (11)	0.099

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, 2019.

	Test 2.C2		Test 3.SR3		Test 2 + 3	
Species	No.	sig.	No.	sig.	No.	sig.
Chinook	4	0	1	0	5	0
Steelhead	2	1	2	0	4	1
Total	6	1	3	0	9	1

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 2019.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
6–19 Apr	0.73	0.394	0.73	0.394	-	-
20 Apr–3 May	2.09	0.351	0.22	0.640	1.87	0.171
4–17 May	0.00	0.968	0.00	0.968	-	-
18–31 May	0.25	0.619	0.25	0.619	-	-
Total (df)	3.07 (5)	0.690	1.19 (4)	0.879	1.87 (1)	0.171

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 2019.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
6–19 Apr	4.24	0.120	2.16	0.141	2.07	0.150
20 Apr–3 May	14.12	**0.001**	11.31	**0.001**	2.81	0.093
4–17 May	-	-	-	-	-	-
18–31 May	-	-	-	-	-	-
1–14 Jun	-	-	-	-	-	-
Total (df)	18.36 (4)	**0.001**	13.47 (2)	**0.001**	4.89 (2)	0.087

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 2019. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Release to McNary Dam
			Yearling Chinook salmon			
Clearwater Hatchery						
Clear Creek	9,741	0.679 (0.017)	0.889 (0.044)	1.100 (0.100)	0.799 (0.099)	0.531 (0.048)
Powell Pond	25,388	0.551 (0.012)	0.860 (0.034)	1.003 (0.062)	1.014 (0.097)	0.482 (0.038)
Red River Pond	8,460	0.262 (0.013)	0.882 (0.077)	1.005 (0.140)	1.132 (0.273)	0.263 (0.054)
Selway River	17,028	0.452 (0.009)	0.894 (0.031)	1.083 (0.065)	0.788 (0.073)	0.344 (0.025)
N Fork Clearwater R	25,662	0.648 (0.010)	0.949 (0.026)	1.003 (0.047)	0.852 (0.061)	0.525 (0.030)
Dworshak Hatchery						
N Fork Clearwater R	41,813	0.688 (0.013)	0.850 (0.026)	0.946 (0.041)	0.842 (0.050)	0.466 (0.021)
Kooskia Hatchery						
Kooskia	7,908	0.571 (0.022)	0.870 (0.056)	0.962 (0.101)	0.737 (0.112)	0.352 (0.041)
Lookingglass Hatchery						
Catherine Creek Pond	20,909	0.454 (0.018)	1.008 (0.073)	0.899 (0.083)	0.953 (0.129)	0.392 (0.044)
Grande Ronde Pond	1,991	0.465 (0.038)	0.966 (0.127)	0.950 (0.169)	0.593 (0.171)	0.253 (0.064)
Imnaha River	8,954	0.551 (0.025)	1.165 (0.111)	0.917 (0.129)	1.056 (0.221)	0.622 (0.107)
Imnaha Weir	11,917	0.626 (0.024)	0.919 (0.066)	1.037 (0.108)	0.768 (0.106)	0.458 (0.048)
Lookingglass Hatchery	5,986	0.549 (0.025)	0.852 (0.063)	0.930 (0.096)	0.694 (0.104)	0.302 (0.038)
Lostine Pond	5,962	0.559 (0.022)	0.938 (0.058)	0.957 (0.079)	0.824 (0.121)	0.414 (0.054)
McCall Hatchery						
Knox Bridge	51,684	0.616 (0.014)	0.945 (0.041)	0.985 (0.054)	0.920 (0.064)	0.528 (0.029)
Johnson Creek	2,014	0.490 (0.051)	0.860 (0.140)	1.004 (0.203)	0.639 (0.198)	0.271 (0.072)
Pahsimeroi Hatchery						
Pahsimeroi Pond	21,849	0.280 (0.008)	0.968 (0.067)	0.799 (0.084)	0.742 (0.114)	0.161 (0.020)
Rapid River Hatchery						
Rapid River Hatchery	51,426	0.491 (0.009)	0.920 (0.033)	1.045 (0.053)	0.918 (0.065)	0.433 (0.024)
Sawtooth Hatchery						
Alturas Lake Creek	953	0.486 (0.053)	1.037 (0.189)	0.844 (0.193)	0.678 (0.235)	0.288 (0.088)
Sawtooth Hatchery	18,863	0.539 (0.021)	0.902 (0.062)	1.027 (0.094)	0.717 (0.084)	0.358 (0.032)
Yankee Fork	4,587	0.438 (0.021)	0.947 (0.070)	0.980 (0.090)	1.062 (0.232)	0.432 (0.089)

Appendix Table B2. Estimated survival probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2019. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ 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
			Juvenile steelhead			
Clearwater Hatchery						
Meadow Creek	10,590	0.776 (0.010)	0.970 (0.023)	1.034 (0.045)	0.751 (0.059)	0.585 (0.040)
Newsome Creek	2,535	0.671 (0.021)	1.114 (0.073)	0.715 (0.067)	1.025 (0.218)	0.548 (0.110)
S Fork Clearwater R	4,678	0.923 (0.015)	0.928 (0.030)	1.051 (0.058)	0.789 (0.083)	0.710 (0.066)
Dworshak Hatchery						
S Fork Clearwater R	15,598	0.743 (0.006)	0.987 (0.013)	1.016 (0.025)	0.715 (0.036)	0.533 (0.024)
Dworshak NFH	17,049	0.798 (0.006)	0.965 (0.012)	0.928 (0.021)	0.690 (0.038)	0.493 (0.025)
Hagerman Hatchery						
East Fork Salmon R	8,519	0.433 (0.025)	1.031 (0.113)	0.918 (0.134)	0.554 (0.156)	0.227 (0.058)
Sawtooth Hatchery	29,750	0.738 (0.006)	0.990 (0.013)	0.916 (0.018)	0.937 (0.047)	0.627 (0.030)
Irrigon Hatchery						
Big Canyon Facility	6,767	0.770 (0.020)	1.000 (0.048)	1.038 (0.077)	0.593 (0.082)	0.474 (0.057)
Little Sheep Facility	14,912	0.733 (0.011)	0.969 (0.027)	0.949 (0.038)	0.832 (0.077)	0.561 (0.048)
Wallowa Hatchery	10,000	0.780 (0.012)	1.009 (0.029)	0.906 (0.038)	0.893 (0.087)	0.637 (0.058)
Lyons Ferry Hatchery						
Cottonwood Pond	3,996	0.844 (0.072)	0.989 (0.247)	0.882 (0.323)	NA	NA

Appendix Table B2. Continued.

Hatchery/ 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
			Juvenile steelhead			
Magic Valley Hatchery						
Little Salmon R	4,365	0.870 (0.025)	1.116 (0.075)	0.958 (0.103)	0.705 (0.172)	0.656 (0.147)
Pahsimeroi R Trap	11,300	0.710 (0.011)	1.081 (0.035)	0.932 (0.053)	0.691 (0.106)	0.495 (0.071)
Sawtooth Hatchery	5,660	0.584 (0.019)	1.036 (0.058)	0.951 (0.082)	0.804 (0.171)	0.463 (0.091)
Yankee Fork	13,204	0.359 (0.013)	1.050 (0.073)	0.826 (0.079)	0.629 (0.123)	0.196 (0.035)
Niagara Springs Hatchery						
Hells Canyon Dam	8,571	0.842 (0.008)	0.940 (0.017)	1.019 (0.029)	1.013 (0.078)	0.817 (0.059)
Little Salmon R	5,081	0.845 (0.014)	1.022 (0.035)	1.022 (0.068)	0.736 (0.132)	0.650 (0.108)
Pahsimeroi R Trap	8,958	0.813 (0.010)	0.979 (0.021)	0.902 (0.030)	0.895 (0.094)	0.642 (0.065)

Appendix Table B3. Estimated survival probabilities for PIT-tagged juvenile sockeye and coho salmon from Snake River Basin hatcheries released for migration year 2019. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ 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
				Sockeye salmon				
Sawtooth Hatchery								
Redfish Lake Cr Trap	9 May 2019	6,860	0.786 (0.039)	0.966 (0.086)	0.727 (0.071)	0.853 (0.106)	0.598 (0.071)	0.470 (0.051)
Springfield Hatchery								
Redfish Lake Cr Trap	7-8 May 2019	52,404	0.603 (0.040)	1.342 (0.171)	0.781 (0.104)	0.666 (0.068)	0.698 (0.067)	0.421 (0.028)
				Coho salmon				
Cascade Hatchery								
Lostine River	28 March 2019	1,964	0.351 (0.087)	0.559 (0.205)	1.317 (0.545)	0.904 (0.441)	0.665 (0.306)	0.234 (0.086)
Eagle Creek Hatchery								
Kooskia Hatchery	28 March 2019	4,997	0.300 (0.045)	1.034 (0.283)	0.646 (0.205)	1.018 (0.361)	0.680 (0.218)	0.204 (0.057)
N Lapwai Valley Pnd	27 March 2019	4,996	0.447 (0.030)	0.986 (0.117)	0.991 (0.188)	1.022 (0.279)	0.998 (0.227)	0.446 (0.097)
Kooskia Hatchery								
Kooskia Hatchery	28 March 2019	4,986	0.456 (0.143)	0.600 (0.282)	1.385 (0.890)	0.225 (0.148)	0.187 (0.091)	0.085 (0.031)

Appendix Table B4. Estimated detection probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2019. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Yearling Chinook salmon			
Clearwater Hatchery					
Clear Creek	9,741	0.254 (0.008)	0.225 (0.011)	0.156 (0.013)	0.096 (0.010)
Powell Pond	25,388	0.235 (0.006)	0.211 (0.008)	0.191 (0.010)	0.071 (0.006)
Red River Pond	8,460	0.256 (0.015)	0.243 (0.020)	0.209 (0.026)	0.062 (0.014)
Selway River	17,028	0.275 (0.007)	0.278 (0.009)	0.230 (0.013)	0.117 (0.010)
N Fk Clearwater R	25,662	0.240 (0.005)	0.244 (0.007)	0.209 (0.009)	0.094 (0.006)
Dworshak Hatchery					
N Fk Clearwater R	41,813	0.136 (0.003)	0.190 (0.005)	0.176 (0.007)	0.095 (0.005)
Kooskia Hatchery					
Kooskia	7,908	0.194 (0.009)	0.244 (0.014)	0.208 (0.020)	0.123 (0.016)
Lookingglass Hatchery					
Catherine Cr Pond	20,909	0.196 (0.009)	0.153 (0.010)	0.193 (0.014)	0.056 (0.007)
Grande Ronde P.	1,991	0.194 (0.020)	0.164 (0.022)	0.201 (0.032)	0.087 (0.025)
Imnaha River	8,954	0.219 (0.011)	0.156 (0.014)	0.164 (0.019)	0.054 (0.010)
Imnaha Weir	11,917	0.216 (0.010)	0.177 (0.011)	0.168 (0.015)	0.082 (0.010)
Lookingglass H.	5,986	0.210 (0.012)	0.176 (0.013)	0.165 (0.016)	0.109 (0.015)
Lostine Pond	5,962	0.209 (0.010)	0.185 (0.011)	0.202 (0.015)	0.078 (0.012)
McCall Hatchery					
Knox Bridge	51,684	0.189 (0.005)	0.126 (0.005)	0.162 (0.007)	0.065 (0.004)
Pahsimeroi Hatchery					
Pahsimeroi Pond	21,849	0.354 (0.012)	0.226 (0.014)	0.230 (0.020)	0.106 (0.015)
Rapid River Hatchery					
Rapid River Hatch	51,426	0.239 (0.005)	0.169 (0.006)	0.178 (0.008)	0.071 (0.004)
Sawtooth Hatchery					
Alturas Lake Cr	953	0.197 (0.028)	0.153 (0.028)	0.204 (0.040)	0.081 (0.030)
Sawtooth H.	18,863	0.199 (0.009)	0.161 (0.010)	0.181 (0.013)	0.089 (0.009)
Yankee Fork	4,587	0.215 (0.013)	0.189 (0.014)	0.258 (0.021)	0.052 (0.012)

Appendix Table B5. Estimated detection probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2019. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Juvenile steelhead			
Clearwater Hatchery					
Meadow Creek	10,590	0.360 (0.007)	0.323 (0.009)	0.297 (0.012)	0.097 (0.008)
Newsome Creek	2,535	0.345 (0.015)	0.274 (0.019)	0.376 (0.028)	0.054 (0.013)
S Fork Clearwater R	4,678	0.376 (0.009)	0.300 (0.011)	0.299 (0.016)	0.092 (0.010)
Dworshak Hatchery					
S Fork Clearwater R	15,598	0.449 (0.005)	0.406 (0.006)	0.417 (0.010)	0.144 (0.008)
Dworshak NFH	17,049	0.431 (0.005)	0.442 (0.006)	0.478 (0.010)	0.123 (0.008)
Hagerman Hatchery					
East Fork Salmon R	8,519	0.220 (0.014)	0.164 (0.016)	0.255 (0.029)	0.032 (0.010)
Sawtooth Hatchery	29,750	0.338 (0.004)	0.344 (0.005)	0.416 (0.007)	0.069 (0.004)
Irrigon Hatchery					
Big Canyon Facility	6,767	0.255 (0.009)	0.235 (0.011)	0.253 (0.016)	0.049 (0.007)
Little Sheep Facility	14,912	0.295 (0.006)	0.245 (0.007)	0.303 (0.011)	0.048 (0.005)
Wallowa Hatchery	10,000	0.302 (0.007)	0.288 (0.009)	0.354 (0.013)	0.057 (0.006)
Lyons Ferry Hatchery					
Cottonwood Pond	3,996	0.301 (0.027)	0.188 (0.042)	0.303 (0.076)	0.011 (0.006)
Magic Valley Hatchery					
Little Salmon R	4,365	0.337 (0.012)	0.230 (0.015)	0.295 (0.027)	0.041 (0.010)
Pahsimeroi R Trap	11,300	0.354 (0.008)	0.318 (0.010)	0.361 (0.018)	0.042 (0.007)
Sawtooth Hatchery	5,660	0.273 (0.011)	0.296 (0.015)	0.332 (0.025)	0.042 (0.010)
Yankee Fork	13,204	0.282 (0.012)	0.218 (0.014)	0.318 (0.024)	0.044 (0.009)
Niagara Springs Hatchery					
Hells Canyon Dam	8,571	0.430 (0.007)	0.370 (0.008)	0.425 (0.012)	0.079 (0.007)
Little Salmon R	5,081	0.387 (0.010)	0.369 (0.013)	0.376 (0.023)	0.050 (0.010)
Pahsimeroi Trap	8,958	0.344 (0.007)	0.353 (0.009)	0.458 (0.013)	0.047 (0.006)

Appendix Table B6. Estimated detection probabilities for PIT-tagged juvenile sockeye and coho salmon from Snake River Basin hatcheries released for migration year 2019. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Release date	Number released	Detection probability: Lower Granite	Little Goose	Lower Monumental	McNary
			Sockeye salmon			
Sawtooth Hatchery						
Redfish Lk Cr Trp	9 May	6,860	0.134 (0.008)	0.090 (0.008)	0.152 (0.011)	0.066 (0.008)
Springfield Hatchery						
Redfish Lk Cr Trp	7-8 May	52,404	0.060 (0.004)	0.032 (0.004)	0.064 (0.005)	0.044 (0.003)
			Coho salmon			
Cascade Hatchery						
Lostine River	28 March	1,964	0.142 (0.038)	0.213 (0.055)	0.155 (0.049)	0.054 (0.023)
Eagle Creek Hatchery						
Kooskia Hatchery	28 March	4,997	0.119 (0.019)	0.116 (0.027)	0.140 (0.031)	0.042 (0.014)
N Lapwai Val Pd	27 March	4,996	0.168 (0.014)	0.187 (0.020)	0.118 (0.020)	0.042 (0.010)
Kooskia Hatchery						
Kooskia Hatchery	28 March	4,986	0.053 (0.017)	0.085 (0.030)	0.055 (0.029)	0.040 (0.018)

Appendix Table B7. Estimated survival probabilities by reach between dams for juvenile salmonids released from traps in Snake River Basin in 2019. Estimates based on the single-release model. Standard errors in parentheses.

Trap	Release dates	Distance to LGR (km)	Number released	Release to Lower Granite	Lower Granite to Little Goose	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Release to McNary Dam
				Wild Chinook salmon				
Snake	20 Mar-15 May	52	503	0.868 (0.065)	0.963 (0.134)	1.148 (0.312)	0.647 (0.252)	0.621 (0.176)
Grande Ronde	20 Mar-26 May	100	1,629	0.778 (0.038)	0.983 (0.103)	1.078 (0.188)	0.649 (0.160)	0.535 (0.101)
Imnaha	01 Feb-30 May	142	1,784	0.811 (0.037)	0.866 (0.062)	0.988 (0.110)	0.779 (0.149)	0.540 (0.088)
Lolo Creek	28 Mar-31 May	159	511	0.597 (0.107)	NA	NA	NA	NA
Salmon	13 Mar-07 May	233	901	0.835 (0.039)	0.844 (0.063)	1.143 (0.165)	0.810 (0.235)	0.653 (0.162)
Lookingglass Cr	01 Feb-08 May	235	266	0.558 (0.084)	0.887 (0.264)	0.681 (0.304)	0.660 (0.339)	0.222 (0.074)
Minam	14 Mar-23 May	246	755	0.682 (0.062)	0.820 (0.138)	1.072 (0.276)	0.532 (0.198)	0.318 (0.094)
Lostine	31 Mar-23 May	274	525	0.617 (0.073)	0.736 (0.134)	1.164 (0.341)	0.795 (0.438)	0.420 (0.201)
Catherine Creek	12 Mar-31 May	362	562	0.278 (0.087)	0.333 (0.122)	NA	NA	NA
U. Grande Ronde	02 Apr-31 May	397	663	0.314 (0.055)	1.607 (0.726)	0.845 (0.616)	0.380 (0.275)	0.162 (0.060)
Johnson Creek	07 Mar-30 Apr	436	606	0.548 (0.047)	1.067 (0.144)	0.757 (0.141)	0.861 (0.320)	0.381 (0.132)
Big Creek	31 Mar-05 May	489	437	0.677 (0.123)	1.250 (0.524)	1.010 (0.892)	NA	NA
Lower Lemhi R.	01 Mar-31 May	553	1,458	0.637 (0.041)	0.914 (0.113)	1.361 (0.307)	0.922 (0.381)	0.730 (0.261)
Upper Lemhi R.	12 Mar-23 May	595	152	0.493 (0.121)	NA	NA	NA	NA
Pahsimeroi	12 Mar-31 May	621	224	0.526 (0.074)	0.992 (0.288)	0.475 (0.178)	NA	NA
Marsh Creek	24 Mar-07 May	630	207	0.566 (0.126)	0.916 (0.395)	NA	NA	NA
Sawtooth	22 Mar-16 May	747	1,288	0.561 (0.059)	1.125 (0.249)	0.611 (0.167)	0.644 (0.200)	0.248 (0.058)
				Wild sockeye salmon				
Redfish Lake Cr	10 Apr-31 May	748	2,713	0.503 (0.023)	1.017 (0.089)	0.708 (0.089)	0.733 (0.174)	0.265 (0.058)

Appendix Table B7. Continued.

Trap	Release dates	Distance to LGR (km)	Number released	Release to Lower Granite	Lower Granite to Little Goose	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Release to McNary Dam
				Wild steelhead				
Snake	31 Mar-15 May	52	112	0.973 (0.088)	0.764 (0.105)	1.084 (0.298)	0.603 (0.338)	0.486 (0.237)
Asotin Creek	09 Mar-31 May	64	4,647	0.779 (0.019)	0.902 (0.039)	0.978 (0.067)	0.789 (0.140)	0.542 (0.090)
Big Bear Creek	19 Mar-31 May	99	1,181	0.482 (0.053)	0.827 (0.165)	1.300 (0.488)	0.408 (0.272)	0.211 (0.116)
Grande Ronde	21 Mar-26 May	100	945	0.968 (0.050)	1.144 (0.138)	0.614 (0.101)	NA	NA
Imnaha	04 Feb-29 May	142	3,593	0.819 (0.027)	0.908 (0.054)	0.895 (0.077)	0.742 (0.144)	0.494 (0.089)
Lolo Creek	28 Mar-31 May	159	614	0.628 (0.058)	0.942 (0.222)	1.188 (0.516)	0.644 (0.576)	0.453 (0.338)
Salmon	25 Mar-07 May	233	75	0.826 (0.109)	1.011 (0.256)	0.675 (0.256)	NA	NA
Lookingglass Cr	06 Feb-31 May	235	230	0.637 (0.090)	0.692 (0.130)	1.111 (0.282)	0.544 (0.224)	0.267 (0.087)
Minam	21 Mar-30 May	246	170	0.642 (0.112)	NA	NA	NA	NA
Lostine	23 Mar-22 May	274	180	0.878 (0.358)	0.735 (0.456)	NA	NA	NA
Catherine Creek	12 Mar-30 May	362	162	0.385 (0.078)	1.283 (0.595)	0.810 (0.678)	NA	NA
Upper Grande Ronde	02 Apr-21 May	397	431	0.480 (0.082)	0.859 (0.239)	NA	NA	NA
Panther Creek	16 Mar-31 May	468	468	0.643 (0.069)	0.985 (0.183)	0.670 (0.177)	NA	NA
North Fork Salmon	20 Mar-13 May	512	267	0.486 (0.088)	0.627 (0.183)	NA	NA	NA
Lower Lemhi R.	27 Feb-31 May	553	778	0.624 (0.072)	1.333 (0.504)	0.411 (0.184)	NA	NA
Hayden Creek	21 Mar-31 May	596	296	0.460 (0.218)	NA	NA	NA	NA
				Hatchery Chinook salmon				
Snake	19 Mar-15 May	52	2,467	0.763 (0.030)	1.130 (0.078)	0.956 (0.098)	0.791 (0.138)	0.652 (0.100)
Grande Ronde	20 Mar-21 May	100	1,399	0.803 (0.051)	0.846 (0.083)	1.091 (0.150)	0.808 (0.199)	0.599 (0.130)
Salmon	13 Mar-07 May	233	3,995	0.649 (0.025)	0.923 (0.063)	0.905 (0.082)	0.732 (0.099)	0.397 (0.046)
				Hatchery steelhead				
Snake	24 Mar-11 May	52	970	0.962 (0.028)	0.929 (0.039)	0.958 (0.060)	0.613 (0.086)	0.525 (0.067)
Grande Ronde	28 Mar-26 May	100	3083	0.919 (0.022)	0.969 (0.040)	0.959 (0.057)	0.866 (0.143)	0.739 (0.116)
Salmon	08 Apr-07 May	233	762	0.937 (0.042)	0.883 (0.059)	0.894 (0.081)	1.447 (0.534)	1.070 (0.387)

Appendix Table B8. Estimated detection probabilities at dams for juvenile salmonids released from fish traps in Snake River Basin in 2019. Estimates based on the single-release model. Standard errors in parentheses.

Trap	Release dates	Distance to LGR (km)	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
Wild Chinook salmon							
Snake	20 Mar-15 May	52	503	0.320 (0.032)	0.340 (0.044)	0.225 (0.059)	0.163 (0.053)
Grande Ronde	20 Mar-26 May	100	1,629	0.344 (0.021)	0.259 (0.026)	0.241 (0.037)	0.122 (0.027)
Imnaha	01 Feb-30 May	142	1,784	0.271 (0.017)	0.325 (0.022)	0.276 (0.030)	0.142 (0.026)
Lolo Creek	28 Mar-31 May	159	511	0.400 (0.076)	NA	NA	NA
Salmon	13 Mar-07 May	233	901	0.335 (0.023)	0.407 (0.030)	0.331 (0.047)	0.132 (0.037)
Lookingglass Cr	01 Feb-08 May	235	266	0.357 (0.064)	0.254 (0.074)	0.249 (0.102)	0.182 (0.082)
Minam	14 Mar-23 May	246	755	0.313 (0.034)	0.231 (0.038)	0.238 (0.055)	0.117 (0.041)
Lostine	31 Mar-23 May	274	525	0.324 (0.045)	0.366 (0.054)	0.197 (0.060)	0.071 (0.040)
Catherine Creek	12 Mar-31 May	362	562	0.212 (0.072)	0.217 (0.061)	0.054 (0.052)	0.044 (0.042)
U. Grande Ronde	02 Apr-31 May	397	663	0.269 (0.054)	0.098 (0.044)	0.099 (0.062)	0.132 (0.060)
Johnson Creek	07 Mar-30 Apr	436	606	0.271 (0.032)	0.265 (0.038)	0.338 (0.057)	0.136 (0.052)
Big Creek	31 Mar-05 May	489	437	0.284 (0.057)	0.198 (0.073)	0.180 (0.143)	NA
Lower Lemhi R.	01 Mar-31 May	553	1,458	0.302 (0.024)	0.264 (0.031)	0.170 (0.035)	0.047 (0.019)
Upper Lemhi R.	12 Mar-23 May	595	152	0.240 (0.074)	0.167 (0.084)	NA	NA
Pahsimeroi	12 Mar-31 May	621	224	0.374 (0.065)	0.320 (0.092)	0.421 (0.116)	0.077 (0.074)
Marsh Creek	24 Mar-07 May	630	207	0.265 (0.070)	0.191 (0.078)	0.127 (0.112)	0.091 (0.087)
Sawtooth	22 Mar-16 May	747	1,288	0.264 (0.032)	0.181 (0.036)	0.277 (0.054)	0.124 (0.036)
Wild sockeye salmon							
Redfish Lake Cr	10 Apr-31 May	748	2,713	0.323 (0.019)	0.216 (0.020)	0.281 (0.031)	0.104 (0.025)

Appendix Table B8. Continued.

Trap	Release dates	Distance to LGR (km)	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Wild steelhead				
Snake	31 Mar-15 May	52	112	0.413 (0.060)	0.585 (0.074)	0.348 (0.106)	0.105 (0.070)
Asotin Creek	09 Mar-31 May	64	4,647	0.346 (0.011)	0.310 (0.013)	0.338 (0.022)	0.061 (0.012)
Big Bear Creek	19 Mar-31 May	99	1,181	0.274 (0.035)	0.286 (0.049)	0.239 (0.080)	0.038 (0.026)
Grande Ronde	21 Mar-26 May	100	945	0.326 (0.023)	0.231 (0.028)	0.390 (0.049)	0.011 (0.011)
Imnaha	04 Feb-29 May	142	3,593	0.290 (0.013)	0.269 (0.015)	0.326 (0.025)	0.058 (0.012)
Lolo Creek	28 Mar-31 May	159	614	0.459 (0.048)	0.398 (0.078)	0.447 (0.153)	0.034 (0.034)
Salmon	25 Mar-07 May	233	75	0.404 (0.079)	0.365 (0.101)	0.366 (0.130)	NA
Lookingglass Cr	06 Feb-31 May	235	230	0.307 (0.056)	0.432 (0.068)	0.352 (0.095)	0.167 (0.076)
Minam	21 Mar-30 May	246	170	0.321 (0.069)	0.112 (0.070)	0.377 (0.127)	0.062 (0.060)
Lostine	23 Mar-22 May	274	180	0.165 (0.073)	0.125 (0.062)	NA	NA
Catherine Creek	12 Mar-30 May	362	162	0.368 (0.089)	0.182 (0.089)	0.353 (0.260)	NA
Upper Grande Ronde	02 Apr-21 May	397	431	0.261 (0.052)	0.270 (0.066)	0.122 (0.079)	NA
Panther Creek	16 Mar-31 May	468	468	0.269 (0.038)	0.244 (0.045)	0.314 (0.074)	NA
North Fork Salmon	20 Mar-13 May	512	267	0.316 (0.068)	0.377 (0.093)	0.270 (0.148)	0.100 (0.095)
Lower Lemhi R.	27 Feb-31 May	553	778	0.311 (0.041)	0.124 (0.046)	0.330 (0.081)	NA
Hayden Creek	21 Mar-31 May	596	296	0.206 (0.103)	0.130 (0.110)	0.333 (0.226)	NA
			Hatchery Chinook salmon				
Snake	19 Mar-15 May	52	2,467	0.238 (0.013)	0.198 (0.014)	0.190 (0.018)	0.080 (0.014)
Grande Ronde	20 Mar-21 May	100	1,399	0.218 (0.018)	0.211 (0.021)	0.193 (0.026)	0.084 (0.020)
Salmon	13 Mar-07 May	233	3,995	0.256 (0.013)	0.178 (0.013)	0.200 (0.017)	0.101 (0.014)
			Hatchery steelhead				
Snake	24 Mar-11 May	52	970	0.320 (0.018)	0.482 (0.022)	0.433 (0.030)	0.113 (0.020)
Grande Ronde	28 Mar-26 May	100	3,083	0.309 (0.011)	0.263 (0.012)	0.318 (0.018)	0.048 (0.009)
Salmon	08 Apr-07 May	233	762	0.300 (0.022)	0.379 (0.026)	0.411 (0.037)	0.041 (0.016)

Appendix Table B9. Estimated survival probabilities by reach for PIT-tagged yearling Chinook, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2019. 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			
Chiwawa Hatchery						
Chiwawa Pond	10,082	0.437 (0.049)	1.013 (0.165)	0.630 (0.121)	0.638 (0.120)	0.279 (0.042)
Cle Elum Hatchery						
Clark Flat Pond	16,009	0.326 (0.024)	0.823 (0.098)	NA	NA	NA
Easton Pond	12,000	0.241 (0.021)	0.896 (0.127)	0.799 (0.207)	0.716 (0.178)	0.173 (0.040)
Jack Creek Pond	12,000	0.176 (0.016)	1.080 (0.180)	0.749 (0.259)	0.809 (0.265)	0.142 (0.045)
East Bank Hatchery						
Carlton Pond	5,034	0.552 (0.113)	0.995 (0.304)	0.866 (0.381)	0.862 (0.369)	0.476 (0.179)
Chelan River	10,399	0.904 (0.110)	0.570 (0.096)	0.994 (0.188)	0.566 (0.109)	0.512 (0.076)
Dryden Pond	20,723	0.621 (0.055)	0.842 (0.107)	0.997 (0.216)	0.840 (0.181)	0.522 (0.103)
Nason Acclimation F.	18,278	0.220 (0.025)	0.962 (0.162)	0.532 (0.121)	0.511 (0.114)	0.112 (0.022)
Entiat Hatchery						
Entiat Hatchery	19,885	0.565 (0.053)	0.886 (0.120)	1.353 (0.307)	1.199 (0.270)	0.678 (0.139)
Leavenworth Hatchery						
Leavenworth NFH	19,813	0.515 (0.035)	0.805 (0.079)	1.155 (0.219)	0.930 (0.176)	0.479 (0.085)
Methow Hatchery						
Chewuch Pond	4,997	0.684 (0.188)	0.961 (0.349)	0.737 (0.285)	0.708 (0.291)	0.485 (0.148)
Methow Hatchery	4,993	0.372 (0.078)	NA	NA	NA	NA
Twisp Pond	4,983	0.444 (0.102)	0.809 (0.248)	1.103 (0.423)	0.892 (0.356)	0.397 (0.129)
Winthrop Hatchery						
Winthrop NFH	19,376	0.490 (0.055)	0.708 (0.103)	1.285 (0.306)	0.910 (0.224)	0.446 (0.098)
		Steelhead				
Chiwawa Hatchery						
Chiwawa River	31,256	0.271 (0.025)	0.609 (0.067)	0.735 (0.112)	0.448 (0.075)	0.121 (0.017)

Appendix Table B9. Continued.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Steelhead			
Wells Hatchery						
Omak Pond	9,989	0.397 (0.050)	0.760 (0.118)	0.866 (0.160)	0.658 (0.135)	0.262 (0.042)
Salmon Creek	4,997	0.314 (0.060)	1.358 (0.379)	0.402 (0.113)	0.546 (0.147)	0.171 (0.033)
Similkameen Pond	4,999	0.332 (0.052)	1.083 (0.249)	0.679 (0.199)	0.735 (0.209)	0.244 (0.058)
Wells Hatchery	10,688	0.516 (0.045)	0.930 (0.114)	0.951 (0.166)	0.885 (0.155)	0.456 (0.069)
Winthrop NFH	2,470	0.236 (0.067)	1.357 (0.548)	0.459 (0.204)	0.623 (0.274)	0.147 (0.050)
Winthrop Hatchery						
Twisp Pond	4,531	0.381 (0.120)	0.676 (0.253)	1.160 (0.572)	0.785 (0.431)	0.299 (0.135)
Winthrop NFH	20,037	0.370 (0.044)	0.775 (0.111)	0.676 (0.100)	0.539 (0.086)	0.194 (0.024)
			Coho salmon			
Cascade Hatchery						
Beaver Creek Pond	2,474	0.341 (0.078)	0.768 (0.222)	0.948 (0.570)	0.727 (0.449)	0.248 (0.143)
Mid-Valley Pond	4,477	0.354 (0.065)	1.096 (0.278)	0.868 (0.283)	0.952 (0.313)	0.337 (0.092)
Eagle Hatchery						
Natches River	5,011	0.118 (0.050)	1.019 (0.543)	1.121 (0.798)	1.142 (0.870)	0.134 (0.085)
Yakima R (rkm 325)	5,088	0.102 (0.036)	1.130 (0.602)	0.417 (0.291)	0.471 (0.315)	0.048 (0.027)
Leavenworth Hatchery						
Leavenworth NFH	4,489	0.315 (0.106)	0.407 (0.151)	1.026 (0.362)	0.418 (0.194)	0.132 (0.042)
Prosser Hatchery						
Prosser Hatchery	2,533	0.278 (0.033)	0.717 (0.131)	1.561 (1.040)	1.120 (0.741)	0.311 (0.203)
Willard Hatchery						
Beaver Creek Pond	2,423	0.221 (0.108)	1.177 (0.736)	NA	NA	NA
Butcher Pond	4,985	0.157 (0.033)	NA	NA	NA	NA
Chewuch Pond	4,441	0.292 (0.127)	0.839 (0.443)	NA	NA	NA
Early Winters Pond	4,485	0.126 (0.057)	NA	NA	NA	NA
Mid-Valley Pond	4,450	0.543 (0.136)	0.898 (0.280)	0.578 (0.172)	0.519 (0.177)	0.282 (0.066)
Twisp Pond	4,411	0.205 (0.071)	0.898 (0.390)	1.420 (0.977)	1.275 (0.922)	0.261 (0.166)
Winthrop Hatchery						
Winthrop NFH	4,921	0.323 (0.055)	0.976 (0.219)	1.072 (0.342)	1.046 (0.345)	0.338 (0.096)

Appendix Table B10. Estimated detection probabilities at dams for PIT-tagged yearling Chinook salmon, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2019. 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		
Chiwawa Hatchery				
Chiwawa Pond	10,082	0.056 (0.007)	0.072 (0.009)	0.236 (0.036)
Cle Elum Hatchery				
Clark Flat Pond	16,009	0.109 (0.009)	0.110 (0.011)	0.106 (0.032)
Easton Pond	12,000	0.127 (0.012)	0.114 (0.014)	0.213 (0.050)
Jack Creek Pond	12,000	0.152 (0.015)	0.107 (0.017)	0.184 (0.059)
East Bank Hatchery				
Carlton Pond	5,034	0.041 (0.009)	0.044 (0.011)	0.137 (0.052)
Chelan River	10,399	0.045 (0.006)	0.054 (0.007)	0.164 (0.025)
Dryden Pond	20,723	0.053 (0.005)	0.081 (0.008)	0.089 (0.018)
Nason Acclimation F.	18,278	0.065 (0.008)	0.092 (0.012)	0.245 (0.048)
Entiat Hatchery				
Entiat Hatchery	19,885	0.044 (0.004)	0.055 (0.006)	0.105 (0.022)
Leavenworth Hatchery				
Leavenworth NFH	19,813	0.075 (0.006)	0.098 (0.008)	0.143 (0.025)
Methow Hatchery				
Chewuch Pond	4,997	0.022 (0.006)	0.038 (0.010)	0.141 (0.044)
Methow Hatchery	4,993	0.039 (0.009)	0.036 (0.010)	0.211 (0.050)
Twisp Pond	4,983	0.039 (0.010)	0.066 (0.015)	0.120 (0.040)
Winthrop Hatchery				
Winthrop NFH	19,376	0.041 (0.005)	0.080 (0.008)	0.115 (0.026)
		Steelhead		
Chiwawa Hatchery				
Chiwawa River	31,256	0.052 (0.005)	0.160 (0.011)	0.270 (0.038)
Wells Hatchery				
Omak Pond	9,989	0.042 (0.006)	0.099 (0.010)	0.296 (0.049)
Salmon Creek	4,997	0.043 (0.010)	0.058 (0.013)	0.354 (0.069)
Similkameen Pond	4,999	0.058 (0.011)	0.064 (0.012)	0.300 (0.072)
Wells Hatchery	10,688	0.060 (0.006)	0.082 (0.008)	0.218 (0.034)
Winthrop NFH	2,470	0.041 (0.014)	0.057 (0.018)	0.417 (0.142)
Winthrop Hatchery				
Twisp Pond	4,531	0.025 (0.009)	0.071 (0.016)	0.175 (0.080)
Winthrop NFH	20,037	0.034 (0.004)	0.087 (0.008)	0.293 (0.037)

Appendix Table B10. Continued.

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Coho Salmon		
Cascade Hatchery				
Beaver Creek Pond	2,474	0.052 (0.014)	0.093 (0.020)	0.333 (0.192)
Mid-Valley Pond	4,477	0.035 (0.008)	0.046 (0.010)	0.312 (0.086)
Eagle Hatchery				
Natches River	5,011	0.026 (0.013)	0.055 (0.020)	0.182 (0.116)
Yakima R (rkm 325)	5,088	0.052 (0.021)	0.058 (0.025)	0.336 (0.193)
Leavenworth Hatchery				
Leavenworth NFH	4,489	0.027 (0.010)	0.103 (0.020)	0.376 (0.121)
Prosser Hatchery				
Prosser Hatchery	2,533	0.203 (0.028)	0.246 (0.040)	0.133 (0.088)
Willard Hatchery				
Beaver Creek Pond	2,423	0.020 (0.012)	0.040 (0.017)	NA
Butcher Pond	4,985	0.058 (0.014)	0.036 (0.012)	0.200 (0.126)
Chewuch Pond	4,441	0.014 (0.007)	0.030 (0.010)	0.078 (0.074)
Early Winters Pond	4,485	0.014 (0.008)	0.032 (0.013)	0.201 (0.127)
Mid-Valley Pond	4,450	0.021 (0.006)	0.041 (0.009)	0.394 (0.092)
Twisp Pond	4,411	0.026 (0.010)	0.046 (0.014)	0.182 (0.117)
Winthrop Hatchery				
Winthrop NFH	4,921	0.041 (0.008)	0.067 (0.012)	0.265 (0.076)

Appendix C: Environmental Conditions and Salmonid Passage Timing

Methods

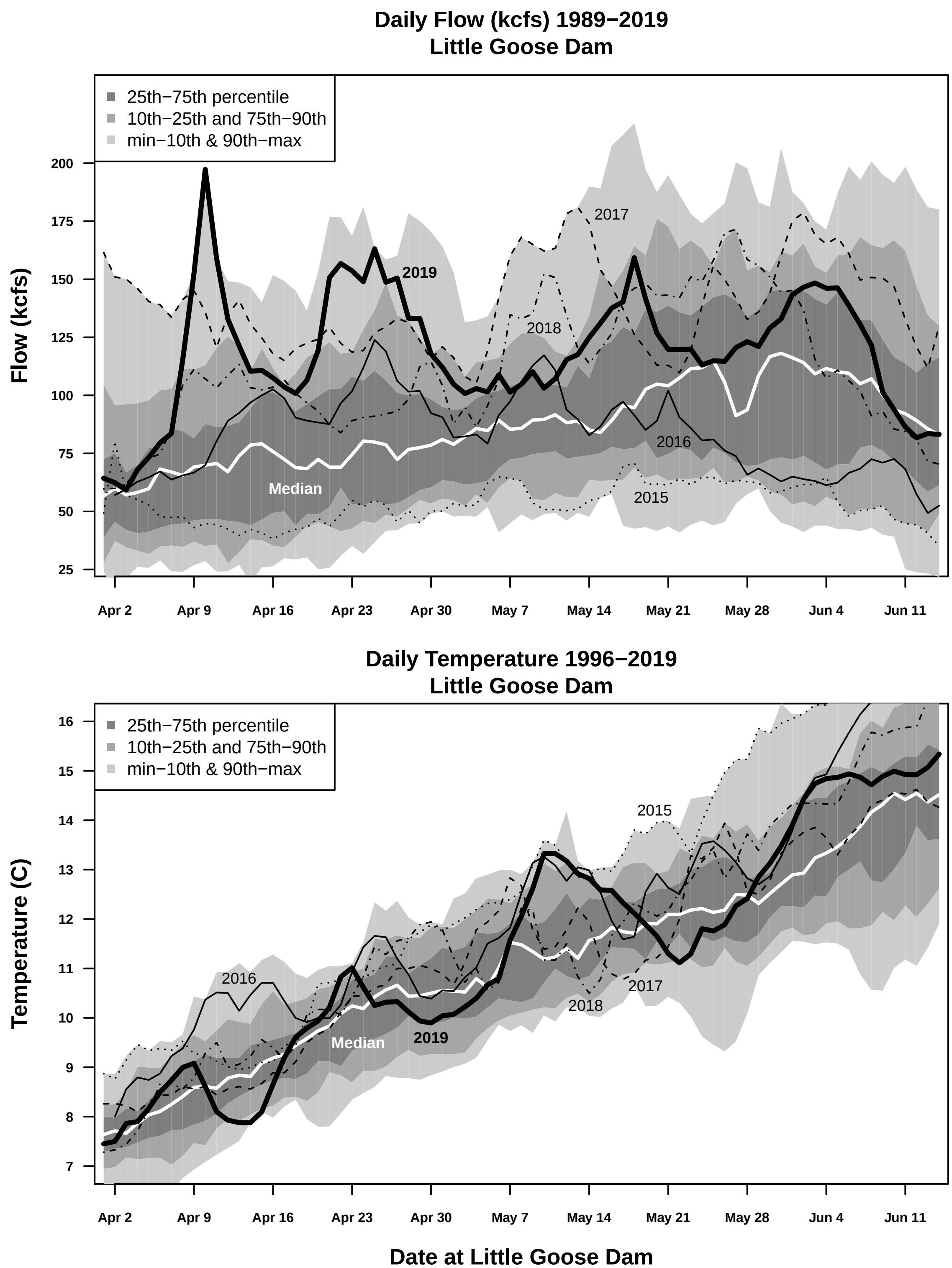
In August 2019 we obtained data on daily flow, temperature, spill, and total dissolved gas saturation (TDG) at Snake River dams from Columbia River DART (1996-). We also obtained collection counts of yearling Chinook salmon and steelhead (hatchery and wild combined) compiled by the Smolt Monitoring Program from fpc.org (Fish Passage Center). We created plots to compare daily measures of flow, temperature, spill, and TDG in 2019 to those during 2015-2018, and to long-term daily quantiles from values during 1989-2019 for flow, 1996-2019 for temperature, and 2006-2019 for spill and TDG.

We combined collection count data with daily estimates of the proportion of fish using the juvenile bypass system (equivalent to daily estimates of PIT-tag detection probabilities) to calculate daily estimates of the number of smolts passing Lower Granite Dam. For visual comparison, we normalized the daily estimates by dividing by the annual total, and created plots of these daily passage proportions to compare with those during 2015-2018 and with long-term daily quantiles

In addition, for each daily group of PIT-tagged yearling Chinook salmon and steelhead detected at or released from Lower Granite Dam, we calculated an index of Snake River flow exposure. For each daily group, the index was equal to average daily flow at Lower Monumental Dam during the period between the 25th and 75th passage percentiles based on dates 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 to McNary Dam tailrace (results shown in Figure 5).

Results

Environmental conditions and management actions in 2019 resulted in a year with average water temperatures but above-average flow and spill during most of the migration season. Mean flow in the Snake River was well above average except for a short period in late May and after the beginning of June (Appendix Figure C1). Mean daily flow at Little Goose Dam during the main migration period (1 April-15 June) was 118.4 kcfs, which was well above the long-term mean of 93.5 kcfs.



Appendix Figure C1. Upper panel shows daily mean Snake River flow as indexed at Little Goose Dam from April to mid-June. Lines show daily values for 2015-2019 and the daily median for 1998-2019. Shading indicates quantiles for 1998-2019. Lower panel shows same annual statistics for temperature at the dam, with median and other quantiles based on data from 1996-2019.

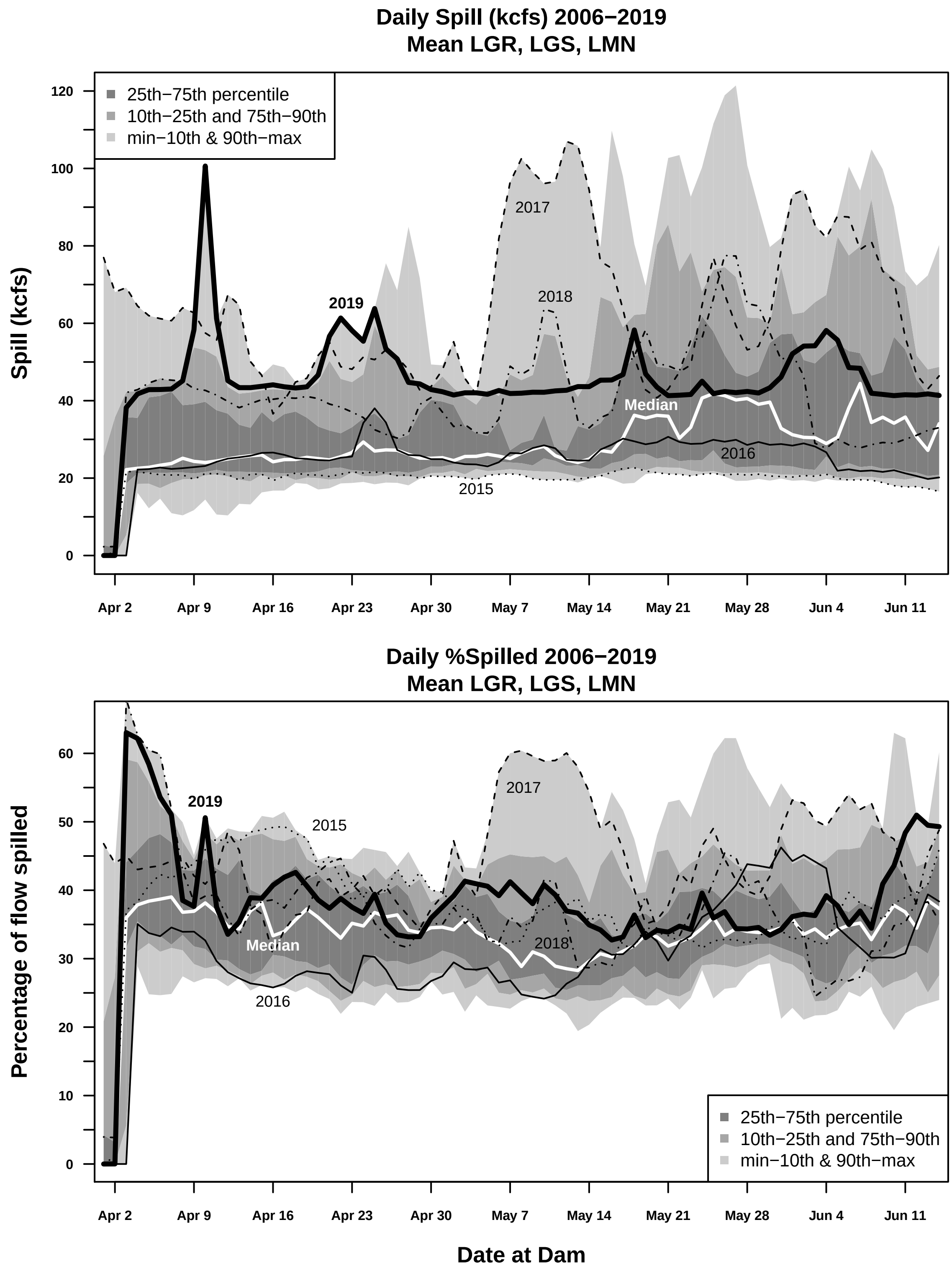
Mean daily water temperature at Little Goose Dam was 11.4°C during the 2019 migration period, which was near the long-term mean of 11.2°C. However, daily water temperatures varied substantially through the season(Appendix Figure C1). Water temperature fluctuated from more than one degree below the daily mean during spikes in flow in April and late May to nearly two degrees (C) warmer than the mean during periods in early May and early June, when flow was not as high.

Mean spill discharge at Snake River dams during the 2019 migration was 45.5 kcfs, which was significantly above the long-term mean of 34.3 kcfs (2006-2019), and the third highest average spill discharge of our time series. Daily spill discharges remained above the long-term daily mean for the entire season, with peaks in early and late April (Appendix Figure C2).

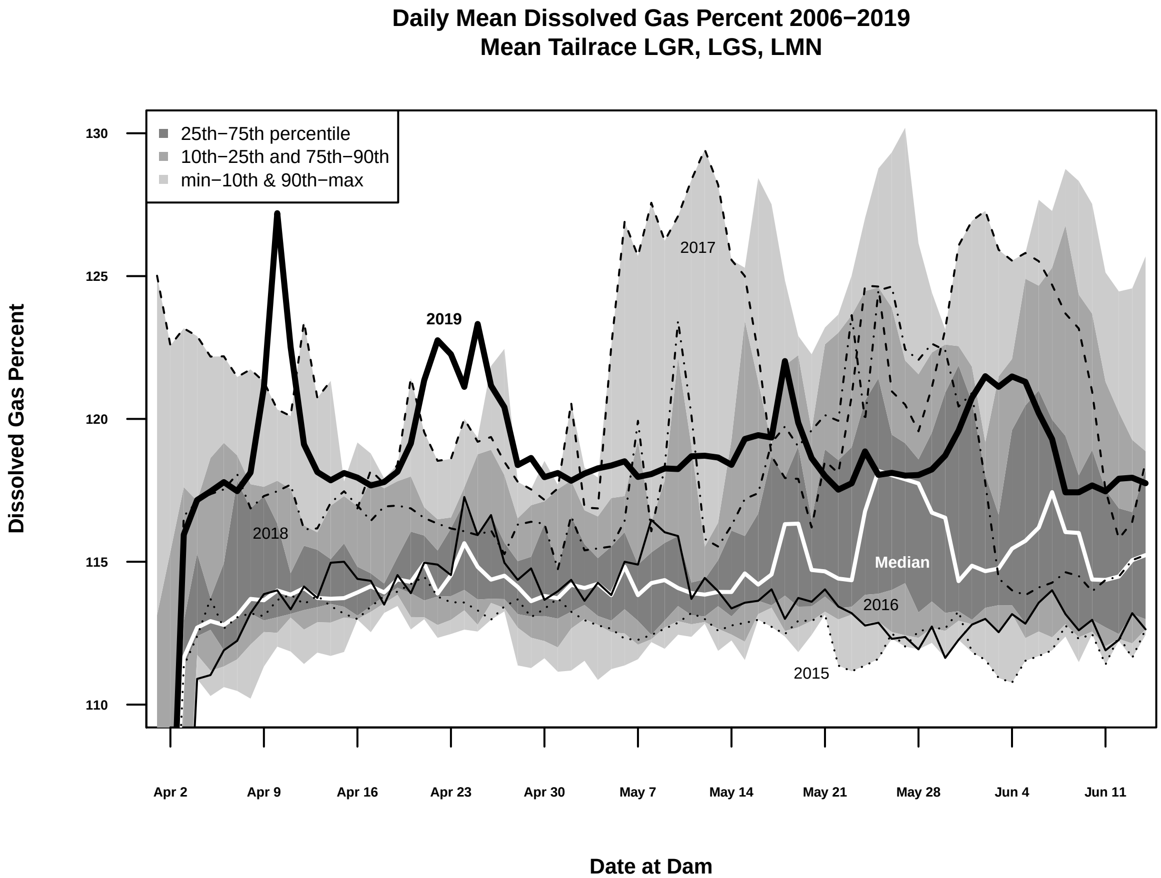
Spill as a percentage of flow at Snake River dams averaged 38.5% in 2019, which was above the long-term mean of 34.6% (2006-2019) and was the second highest mean spill percentage in our time series, exceeded only in 2017. Daily mean spill percentages in 2019 were above the long-term daily means for the majority of the migration period (Appendix Figure C2), and well above average during early April and the first two weeks of May. Daily mean spill percentages were extremely high for the first few days of April, , while flow volume was still relatively low, because the spill program featuring a fixed spill volume was started (Appendix Figure C1).

Total dissolved gas (TDG) was higher in 2019 than in most years in the 2006-2019 period, particularly in April (Appendix Figure C3). Daily TDG was generally between 115 and 120%, except for spikes above 120% in mid-April, mid-May, and early June; additionally, there was an unusually large spike above 125% TDG in early April.

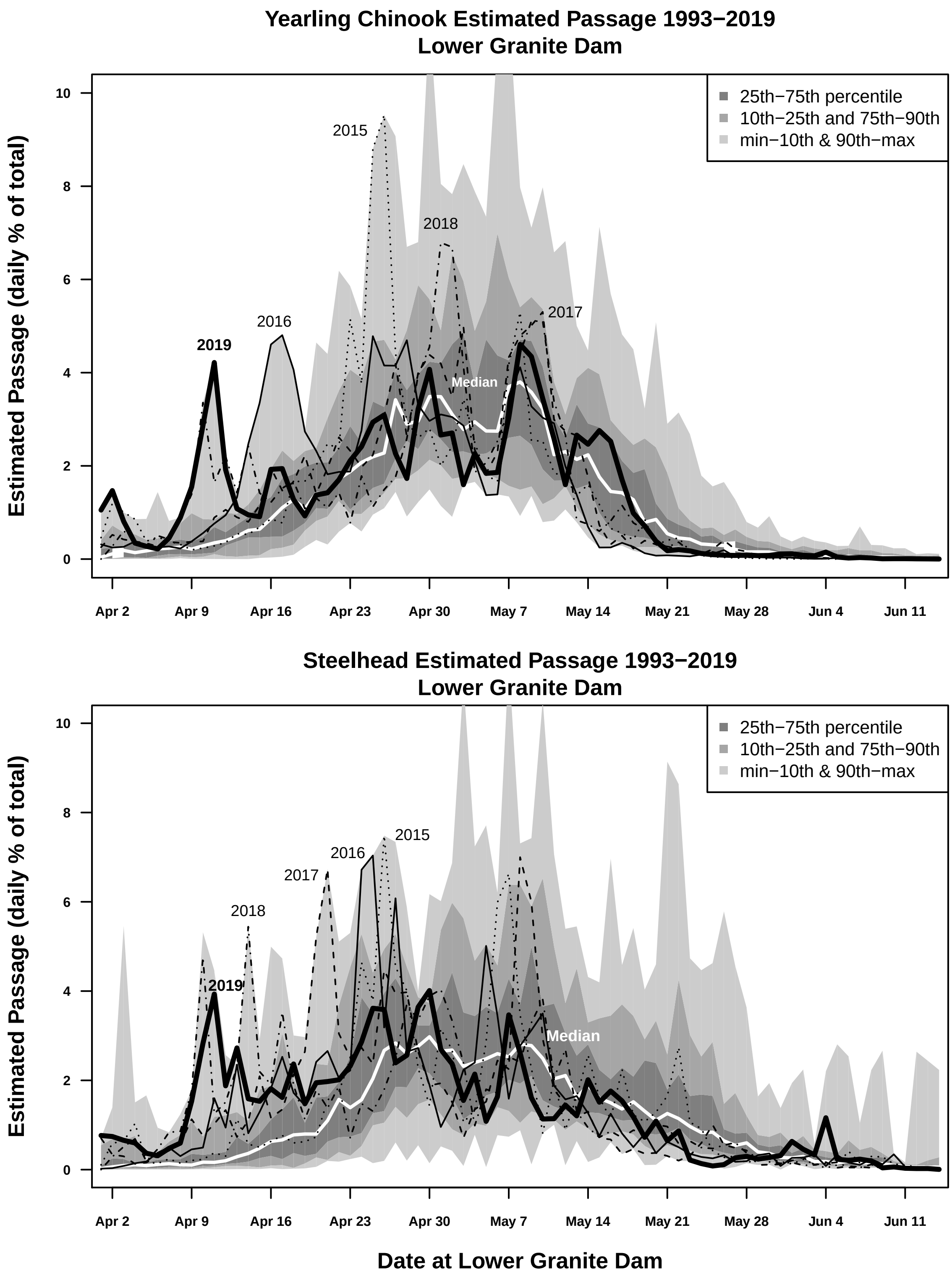
A significant spike in flow occurred during 9-11 April 2019, and this spike was associated with a decrease in water temperature (Appendix Figure C1), an increase in spill (Appendix Figure C2), and an increase in dissolved gas (Appendix Figure C3). This large freshet also promoted smolt passage; both yearling Chinook salmon and steelhead had spikes in passage at Lower Granite Dam during this freshet (Appendix Figure C4). This timing was unusually early for such large passage numbers of both species, and resulted in unusually early passage timing overall.



Appendix Figure C2. Daily mean spill (upper panel) and spill as a percentage of total flow (lower panel) averaged across Lower Granite, Little Goose and Lower Monumental Dams from April to mid-June. Lines show daily values for 2015-2019 and the daily median for 2006-2019. Shading indicates quantiles for 2006-2019.



Appendix Figure C3. Daily mean percentage of dissolved gas averaged across Lower Granite, Little Goose and Lower Monumental Dam from April to mid-June. Lines show daily values for 2015-2019 and the daily median for 2006-2019. Shading indicates quantiles for 2006-2019.



Appendix Figure C4. Estimated daily smolt passage at Lower Granite Dam for yearling Chinook salmon and steelhead. Daily passage expressed as percentage of the total for the year. Lines show daily values for 2015-2019 and the daily median for 2006-2019. Shading indicates quantiles for 1993-2019.