NOAA Contract Report NMFS-NWFSC-CR-2023-10

https://doi.org/10.25923/qmmp-pz37

Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs, 2022

Project **1993-029-00**, Contract **83639 REL 28**

October 2023

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

NOAA Contract Report Series NMFS-NWFSC-CR

Recommended citation:

(Widener et al. 2023)[1]

[1] Widener, D. L., J. R. Faulkner, S. G. Smith, and T. M. Marsh. 2023. Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs, 2022. U.S. Department of Commerce, NOAA Contract Report NMFS-NWFSC-CR-2023-10.

https://doi.org/10.25923/qmmp-pz37

Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs, 2022

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

https://doi.org/10.25923/qmmp-pz37

October 2023

Fish Ecology Division
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, Washington 98112

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

Executive Summary

In 2022, we completed the 30th year of a study to estimate survival and travel time for 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.

During the 2022 migration season, we tagged and released a total of 21,758 hatchery steelhead *O. mykiss,* 9,350 wild steelhead, and 6,285 wild 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 agencies at various hatcheries, traps, and other sites upstream from Lower Granite Dam on the Snake and upstream from McNary Dam on the Columbia River.

As a consequence of high spill levels, low numbers of fish passed Lower Granite Dam via the juvenile bypass systems in 2020-2022, resulting in small sample sizes of detected fish for survival estimation. Without additional data from the new spillway detection system at Lower Granite Dam, which first became operational in 2020, most survival estimates for wild fish in 2020, 2021, and 2022 would not have been possible.

Other than the bypass and spillway systems at Lower Granite, detection sites in 2022 included the juvenile bypass systems at Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dam, as well as the Bonneville Dam corner collector. Detection data from all of these sites have been used in previous years.

In 2020, operation of the Columbia River estuary trawl detection system was suspended, and we used alternative sources of detection information below Bonneville Dam for survival estimation. In 2022, trawl system operation resumed, but we continued to use all available data sources downstream of Bonneville Dam, including those from alternative sources. We anticipate continuing this approach in future years, as well as revisiting past years when only data from the trawl was used. Four sources of data downstream from Bonneville Dam were available in 2022:

1) Detections by the estuary trawl
2) Detections by PIT-tag monitoring systems installed on pile dikes in the Columbia River estuary

3) Recoveries of tags from multiple avian nesting and roosting areas in the Columbia River estuary
4) Detections of precocious juvenile fish as they ascended the adult fish ladder at Bonneville Dam

Primary research objectives in 2022 were:

1) Estimate reach survival and travel time throughout the spring 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 2022, we estimated reach survival and travel time for yearling Chinook salmon, steelhead, and sockeye *O. nerka* of both wild and hatchery origin. We also estimated survival and travel time for coho salmon *O. kisutch* of hatchery origin. Survival estimates were calculated using a statistical model for mark-recapture data from single-release groups.

During most of the migration season, detection probabilities at dams downstream from Lower Granite Dam were extremely low because of very high rates of spill and correspondingly low proportions of fish passing via juvenile bypass systems. Due to these low detection probabilities, we were unable to use our customary approach of pooling "virtual" release groups of fish detected or released at Lower Granite Dam during the same daily or weekly period. Instead, we estimated survival and detection probabilities by pooling virtual release groups over biweekly periods.

Because detection rates were also low at McNary Dam, no survival estimates were possible from McNary for groups pooled over any detection period (daily, weekly, or biweekly). Instead, for survival estimation between McNary and Bonneville Dam, we used the same biweekly groups used for estimates in the reaches from Lower Granite to McNary. This change from customary methods was also necessary in 2020 and 2021 because of low detection rates at McNary.

Hatchery and wild fish were combined in some analyses. Among PIT-tagged fish detected at Lower Granite Dam, 90.5% of yearling Chinook and 90.7% of steelhead were of hatchery origin. In the run at large, which includes both tagged and non-tagged fish, our corresponding estimates of the hatchery-origin component were 84% of yearling Chinook and 88% of steelhead.

All survival probability estimates between dams refer to the reach from the tailrace of the upstream dam to the tailrace of the downstream dam. Estimates of average survival and associated standard errors 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 2022. Standard errors in parentheses.

	Yearling Chinook salmon	Steelhead
Snake River Smolt Trap to Lower Granite Dam	0.963 (0.072)	0.940 (0.023)
Lower Granite to Little Goose Dam	0.823 (0.035)	0.881 (0.027)
Little Goose to Lower Monumental Dam	1.014 (0.059)	0.992 (0.043)
Lower Monumental to McNary Dam[a]	0.869 (0.138)	0.681 (0.043)
Lower Monumental to Ice Harbor Dam	0.921 (0.104)	1.036 (0.078)
Ice Harbor to McNary Dam	0.929 (0.172)	0.672 (0.052)
McNary to John Day Dam	0.806 (0.087)	1.265 (0.198)
John Day to Bonneville Dam[b]	0.892 (0.077)	0.737 (0.091)
Snake River Smolt Trap to Bonneville Dam[c]	0.508 (0.044)	0.520 (0.038)

[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 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 (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 fish from the Snake River, average estimated survival through the entire hydropower system was 0.508 (95% CI 0.423-0.594) for yearling Chinook and 0.520 (0.446-0.594) 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 Bonneville Dam ranged from 0.674 (SE 0.163) for Entiat Hatchery fish released from the hatchery to 0.106 (0.056) for Methow Hatchery fish released from Goatwall Pond. For Upper Columbia River steelhead, estimated survival from release to Bonneville Dam ranged from 0.380 (0.209) for Wells Hatchery fish released from Similkameen Pond to 0.097 (0.090) for Wells Hatchery fish released to the Twisp River.

Of the run at large that arrived at Lower Granite Dam, we estimated that 27.3% of yearling Chinook and 31.4% of steelhead were transported from a Snake River collector dam (means of combined wild and hatchery estimates). These estimates were slightly below the 2007-2022 average.

Two factors determine the ultimate proportion of fish transported: passage timing of the population relative to the transportation period and the proportion of the population collected during the transportation period. In 2022, proportions of fish collected during transport operations were below average. However, the run was very late for both Chinook and steelhead. These two factors offset one another to result in overall transportation rates that were only slightly below average.

We also calculated travel time over individual reaches between dams and over combined reaches between Lower Granite and Bonneville Dam (461 km) for yearling Chinook and steelhead. Over the last several years, we have noted a trend toward shorter smolt travel times relative to levels of flow and spill. However, in 2022 we saw unusually long travel times despite very high levels of spill.

For much of the migration season, travel times for both yearling Chinook and steelhead were far longer in 2022 than in other recent years. Only in mid-May did travel times begin to shorten, becoming similar to timing in other recent years by the beginning of June. The longest travel times in 2022 were observed during the first half of the migration season, when flow was low and water was unusually cold.

At dams where PIT-tag detection was possible only in the juvenile bypass system, detection probabilities were again very low in 2022. This reduced the quality of survival estimates and required use of alternative methods in an attempt to compensate for low detection numbers. The quality of survival estimates has suffered from low detection probabilities in other recent years, but the issue has been especially acute from 2020 through 2022.

With the exception of Lower Granite Dam, which acquired a spillway detection system in 2020, every dam had a detection rate far below the 2007-2021 average in 2022. These extremely low detection rates resulted in highly imprecise survival estimates for most single-project component reaches.

In recent years, spill levels have been increased in an attempt to boost juvenile salmonid survival through the hydropower system. Unfortunately, a side effect of increased spill since 2006 has been a persistent decline in detection rates at Snake and Columbia River dams, and this decline has been exacerbated with further increases in spill since 2020. Detection probabilities in 2022 were not quite as low as those seen in 2021, but were still among the lowest on record.

Given a fixed number of tagged smolts, these lower detection probabilities greatly reduce the precision of survival estimates from PIT-tag data. In light of present operations, we believe the need is increasingly urgent to develop PIT-tag detection capability for passage routes other than bypass systems. Specifically, we recommend that the region place high priority on development and installation of PIT-monitoring systems for conventional spillways, as well as for surface-passage structures.

The spillway detection system at Lower Granite Dam continued to be highly effective in 2022. Without it, survival estimation for Snake River fish would have been seriously impaired. From 2007 to 2019, when detection was possible only in the juvenile bypass system at Lower Granite Dam, the overall estimated mean annual percentage of tagged fish detected was 26.1% for yearling Chinook. In 2022, the estimated overall percentage of tagged yearling Chinook detected was 40.2%, with only 9.2% detected in the bypass system and 31.0% detected on the spillway system. We urge regional managers to take note of the success of the new system and to prioritize installation of similar systems at other major dams.

Because of its low cost, ease of implantation, low biological impact, and long life, the PIT tag continues to be the preferred marking technique for the Columbia Basin fisheries community. Throughout the basin, nearly 2 million individual fish are PIT-tagged annually. However, as we have reported in recent years, higher rates of detection are necessary if we are to enhance or even maintain the precision of juvenile survival estimates based on PIT-tag data.

A PIT-tagged fish can be monitored throughout its life, during both the juvenile and adult migrations. However, the amount of information gathered per tagged fish is proportional to the rate of detection after release. Thus, in terms of informational value, reduced detection rates considerably decrease the rate of return on investment in the entire PIT tagging program.

The management regime of increased spill rates may improve salmonid survival, but it also hinders the ability to identify and evaluate that improvement. Similarly, we are also less likely to recognize potential inadvertent harm resulting from increases in spill or from other management decisions.

Despite recent declines in the quality and quantity of smolt migration data, there is still no marking technology other than the PIT tag that allows direct comparison of smolt-to-adult return ratios between groups of fish. 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

Executive Summary iii

Introduction 1

Survival from Release to Bonneville Dam 3
    Methods 3
        Experimental Design 3
        Study Fish 6
        Data Analysis 10
    Results 13
        Snake River Yearling Chinook Salmon 13
        Snake River Steelhead 19
        Survival Between Lower Monumental and Ice Harbor Dam 24
        Survival and Detection from Hatcheries and Smolt Traps 25

Travel Time and Migration Rates 27
    Methods 27
    Results 28

Proportion of Transported Spring Migrants 37
    Methods 37
    Results 40

Comparisons Among Annual Estimates 44
    Comparison Among Years 44
        Snake River Stocks 44
        Upper Columbia River Stocks 65
        Detection Probabilities 68
    Comparison Between Snake and Columbia River Stocks 70

Discussion 72

Conclusions and Recommendations 89

Acknowledgements 90

References 91

Appendix A: Evaluation of Model Assumptions 101

Appendix B: Survival and Detection Data from Individual Hatcheries and Traps 113

Appendix C: Environmental Conditions and Salmonid Passage Timing 132

Introduction

Accurate and precise estimates of survival are critical for recovery of depressed stocks of Pacific salmon *Oncorhynchus* spp. that migrate through Snake and Columbia River reservoirs, dams, and free-flowing reaches. 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 2022, the National Marine Fisheries Service (NMFS) has estimated annual 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, 2019; Widener et al. 2018-2021, 2023). 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 2022, the 30th year of the study. Research objectives in 2022 were:

1) Estimate reach survival and travel time throughout the yearling Chinook salmon and steelhead migration season.
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 Cormack-Jolly-Seber (CJS) mark-recapture model for single-release groups, otherwise known as the single-release model (Cormack 1964; Jolly 1965; Seber 1965; Skalski 1998; Skalski et al. 1998; Muir et al. 2001a). In our application of the model, detection of a PIT-tagged fish is equivalent to "recapture." Further background information and underlying statistical theory pertaining to the single-release model is detailed by Iwamoto et al. (1994).

During the 2022 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 our analyses were released in the Snake River upstream from Lower Granite Dam for the annual multi-agency *Comparative Survival Study* (McCann et al. 2022).

Generally, tagged fish are detected at dams with monitoring facilities only if they are diverted into the juvenile bypass systems at those dams (Figure 1). The exceptions are Lower Granite, which has a spillway detection system (active since 2020) and Bonneville, which has a detection system located in the corner collector of Powerhouse 2 (active since 2006). In 2022, the following twelve sites were equipped with automated monitoring facilities or were monitored by hand (Figure 1; Prentice et al. 1990a,b,c):

Dams with detection systems

- Lower Granite Dam (rkm[1] 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)

Estuary sites of detection or recovery

- Astoria-Megler Bridge (rkm 12)
- Avian colonies (rkm 8-32)
- Pile dike detection systems (rkm 68-70)
- Troutdale transmission towers (rkm 190)
- Pair-trawl system (rkm 65-84)

---

[1] River kilometer from the mouth of the Columbia River

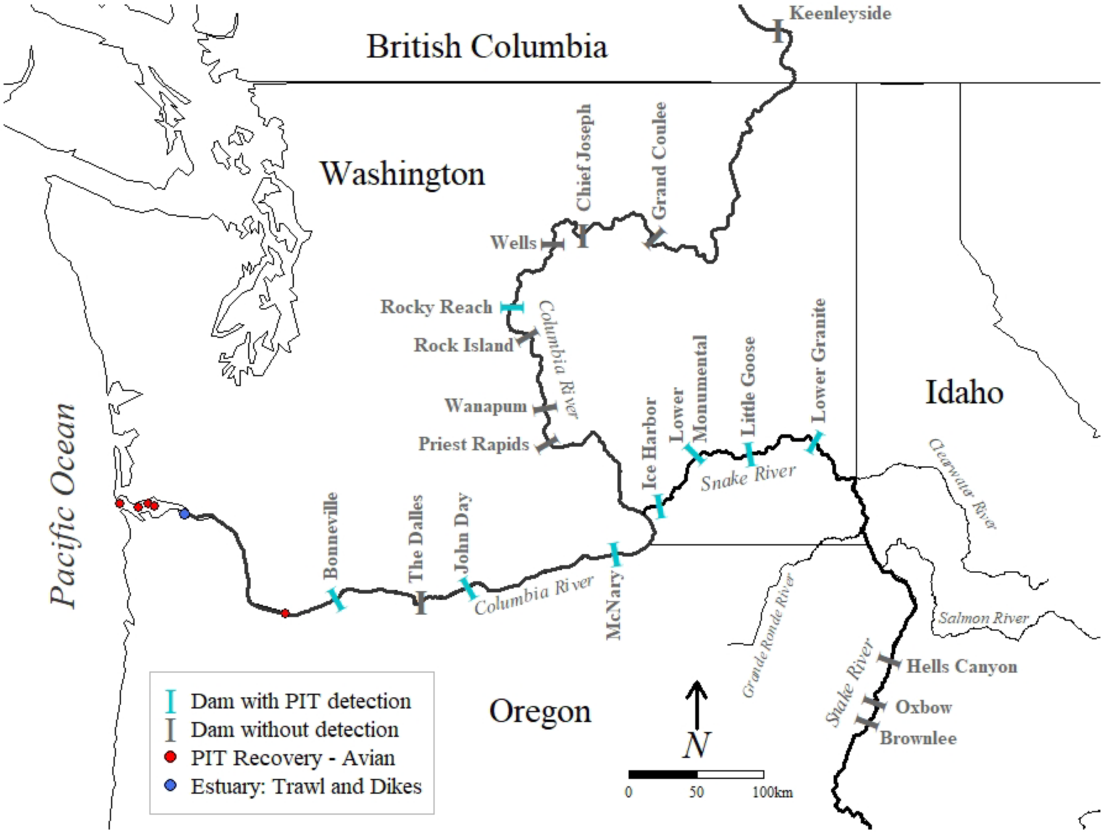


Figure 1. Study area showing PIT-tag detection sites in the Columbia River Basin, 2022. Dams with detection capability are represented by turquoise bars, and those without are represented by gray bars. Pair-trawl operation and pile dikes are in close proximity and represented by a single blue dot. Sites of recovery from avian nesting and roosting areas are represented by red dots.

If Bonneville Dam were the final detection site in the series, the single-release model could not produce separate estimates of the probabilities of survival from John Day to Bonneville Dam and of detection at Bonneville Dam; only the joint probability of survival and detection could be estimated. To separate the two estimates requires detection of fish after they pass Bonneville Dam.

We used four sources of detection data from fish that had passed Bonneville Dam in 2022. These included detections of migrating fish in the estuary by the NMFS pair-trawl system (Ledgerwood et al. 2004) and by the stationary systems on pile dikes 6 and 7. A third source was recoveries of PIT tags deposited by predaceous birds on nesting colonies or roosting areas such as the Astoria-Megler Bridge and the transmission towers near Troutdale, OR (Evans et al. 2023). Our fourth and final data source was detections of precocious juveniles (known as “mini-jacks”) migrating upstream through the fish ladders at Bonneville Dam. We grouped detections from all four data sources to form a single composite “final detection site.”

In 2022, detection probabilities were far below average for Bonneville Dam and low for the composite final detection site. Although data were sufficient to estimate survival from John Day to Bonneville Dam for most stocks, many of the resulting estimates were extremely imprecise.

At Snake and Columbia River dams, most tagged fish were returned to the river after detection, which allowed for the possibility of additional detection at one or more sites downstream (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 reaches 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, a PIT-tag detection system was first operated in the juvenile bypass facility in 2005. Since 2006, detections at Ice Harbor have been sufficient to partition the two-project survival estimate from Lower Monumental to McNary Dam. However, in 2022, detections at Ice Harbor and McNary were extremely low, and detections at Lower Monumental were also far below average. These low detection rates resulted in small samples with very poor precision in the resulting survival estimates.

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 2022, we collected hatchery and wild steelhead *O. mykiss* and wild yearling Chinook 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 numbers arriving in the bypass system at Lower Granite Dam except during the early and late periods of the migration season. During those periods, we tagged more fish than proportionate to numbers arriving to ensure adequate sample sizes for early and late-season estimates.

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

For both yearling Chinook salmon and steelhead, we created virtual daily "release groups" from fish tagged and released upstream from Lower Granite Dam and subsequently detected passing the dam. Virtual release groups included fish detected in either the juvenile bypass or spillway detection systems. We created a virtual daily group for each day that had detections between 14 March and 31 July 2022.

At Lower Granite Dam, each virtual daily group of fish detected and returned to the river was combined with fish tagged and released from the dam on the same date. These combined daily groups were then pooled into weekly and biweekly groups. We considered hatchery and wild fish and in both combined and separated groups.

For each species and origin, we attempted to estimate survival in individual reaches between Lower Granite and McNary Dam. However, extremely poor detection rates at every dam downstream from Lower Granite rendered results for all daily and weekly groups unusable. For all species, we were able to obtain survival estimates of sufficient quality only by using a series of biweekly groups, and only for hatchery groups alone or for combined hatchery and wild groups.

In the earliest part of the migration season, even biweekly groups were sometimes not sufficient. In these cases, we pooled all daily groups up to a certain date for an early cohort that included detections from more than two weeks. Similarly, in the last part of the migration, it was necessary in some cases to pool all daily groups after a certain date into a late cohort that contained detections from more than two weeks.

For wild-only groups, data was not sufficient to estimate survival for any type of within-season cohorts, and we were able to estimate survival only by pooling all wild-origin smolts into a single group for the entire season.

We PIT tagged and released 21,758 hatchery steelhead, 9,350 wild steelhead, and 6,285 wild yearling Chinook salmon at Lower Granite Dam from 6 April through 18 June 2022 (Table 1). From these numbers, respective total tagging mortalities were 20, 2, and 30 for hatchery steelhead, wild steelhead, and wild yearling Chinook salmon. 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.

At Lower Granite Dam, a total of 108,807 yearling Chinook salmon (91,404 hatchery, 17,403 wild) were either collected, tagged, and released to the tailrace or detected and returned to the tailrace. A total of 111,450 steelhead (97,729 hatchery, 13,721 wild) were tagged and released or detected and returned to the tailrace.

We estimated that 90.5% of the overall run of yearling Chinook and 90.7% of the steelhead run was of hatchery origin in 2022. These estimates were 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). The distinction of hatchery-origin yearling chinook was based on clipped fins (FPC 2021a). Fin-clip data is not as reliable for steelhead, so instead we used fin erosion as a marker to distinguish hatchery origin (unpublished data from Jerry McCann, Fish Passage Center, personal communication).

For combined hatchery and wild groups used to estimate survival, estimated proportions of hatchery fish were 84% for yearling Chinook and 88% for steelhead. Thus, the composition of our sample contained a slightly greater proportion of wild fish compared to the composition of the overall run.

When we tag fish at Lower Granite Dam for this study, we intentionally emphasize tagging of wild fish to ensure adequate sample sizes for separate estimates of survival. Our tagging goals for wild fish have been difficult to meet in nearly all study years, and in 2022, the small number of wild smolts entering the bypass system at Lower Granite Dam increased the difficulty of meeting these goals. Although more wild Chinook and steelhead were tagged in 2022 than in either 2020 or 2021, tagging numbers were still below the 10-year average from 2010 to 2020.

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 2022. Also included are numbers of tagging mortalities and shed tags.

	Hatchery Steelhead			**Wild Steelhead**			**Wild Yearling Chinook**		
Release date	Number released	Mortalities	Shed tags	Number released	Mortalities	Shed tags	Number released	Mortalities	Shed tags
6 Apr	231	-	1	23	-	-	99	1	-
7 Apr	595	1	-	81	-	-	148	-	-
13 Apr	796	-	-	76	-	-	345	3	-
14 Apr	766	-	-	58	-	-	226	4	-
20 Apr	1,185	1	-	55	-	-	98	1	-
21 Apr	623	2	-	23	-	-	63	1	-
26 Apr	785	1	-	69	-	-	150	-	-
27 Apr	750	-	-	63	-	-	112	2	-
28 Apr	758	-	-	73	-	-	105	-	-
29 Apr	762	-	1	120	-	-	140	-	-
30 Apr	407	1	-	76	-	-	131	-	-
3 May	822	1	-	150	-	-	90	-	-
4 May	764	-	-	112	-	-	91	-	-
5 May	763	-	-	91	-	-	132	1	-
6 May	730	-	1	199	-	-	95	-	-
7 May	582	1	-	124	-	-	156	3	-
10 May	739	-	1	497	-	1	341	2	-
11 May	722	-	1	383	-	-	165	-	-
12 May	737	-	-	326	-	-	236	-	-
13 May	682	-	-	440	-	1	226	-	-
14 May	484	-	-	436	-	-	139	1	-
17 May	531	-	-	229	-	-	183	-	-
18 May	561	-	-	271	-	-	186	1	-
19 May	557	-	1	291	-	3	152	-	1
20 May	544	1	-	470	-	-	478	1	-
21 May	446	-	-	567	-	-	292	2	1
24 May	375	-	-	189	-	-	84	-	-
25 May	476	1	-	174	1	-	96	-	-
26 May	346	-	-	453	-	-	167	2	-
27 May	411	-	-	357	-	-	293	-	1
28 May	313	1	-	153	-	1	181	2	1
1 Jun	341	1	-	401	-	-	90	-	-
2 Jun	337	1	-	449	1	-	137	-	1
3 Jun	338	-	-	463	-	-	152	-	-
4 Jun	171	-	-	211	-	-	152	-	2
7 Jun	199	2	-	186	-	-	84	1	-
8 Jun	176	1	-	252	-	-	85	-	-
9 Jun	148	-	1	83	-	-	46	-	-
10 Jun	172	-	-	189	-	-	62	-	-
11 Jun	148	-	1	99	-	-	77	2	-
14 Jun	143	3	-	125	-	-			
15 Jun	142	1	-	78	-	-			
16 Jun	93	-	-	47	-	-			
17 Jun	90	-	-	57	-	-			
18 Jun	17	-	-	81	-	-			
	21,758	20	8	9,350	2	6	6,285	30	7

As a result of lower tagging and detection rates at Lower Granite Dam, overall sample sizes for wild fish in 2022 were slightly lower than average, though not as low as those in 2020 or 2021. Below-average numbers in virtual release groups compounded the difficulties imposed by low detection rates at downstream sites. These reductions in sample size contributed to poor precision in survival estimates for wild fish.

Releases from McNary Dam**—**To estimate survival downstream of McNary Dam, our standard methodology in previous years has been to create virtual daily "release groups" at McNary. Virtual groups are formed using yearling Chinook and steelhead released from locations throughout the Columbia and Snake River Basin according to day of detection at McNary. However, in 2022 detection rates at McNary were too low to generate sample sizes sufficient for survival estimation using this method.

In total, only 4,093 yearling Chinook and 2,228 steelhead of Snake River origin were detected passing McNary Dam in 2022. These detection numbers resulted in very small sample sizes that were similar to those in 2020 and 2021. From 2020 through 2022, the combination of small sample sizes, low detection rates below Bonneville Dam, and extremely low detection rates at John Day Dam have made survival estimation impossible for virtual groups made from fish detected at McNary Dam.

Therefore, in 2022 we again used the alternative method devised in 2020 for survival estimation of Snake River Basin fish between McNary and Bonneville Dam. This alternative method uses virtual release groups based on day of detection at Lower Granite Dam for survival estimation between McNary and Bonneville Dam. This method provides adequate sample sizes for survival estimation because far more Snake River fish are detected at Lower Granite than at McNary.

The main drawback of this method is that it results in greater overlap in downstream passage timing among adjacent virtual release groups due to dispersion during migration. When release groups are followed all the way from Lower Granite to Bonneville Dam, a large degree of overlap is expected in passage timing at the furthest downstream sites. This overlap impairs the ability to distinguish changes in survival that may result from river conditions, which change across the season.

Protracted dispersal within virtual groups is also likely to increase variation among individuals in survival and detection probability at each reach and detection site. This variation presumably increases as fish move downstream, potentially violating the model assumption of homogeneous survival and detection probabilities across individuals within a release group. If this violation is of sufficient magnitude, it can potentially bias survival estimates (Appendix A). Despite this risk, the method is the most stable among available approaches, producing estimates of acceptable quality for comparison with estimates from the method used in previous years.

Releases in the upper Columbia River—Groups of tagged yearling Chinook and steelhead were released from locations throughout the Columbia River Basin upstream from the confluence of the Columbia and Snake Rivers. For these fish, we estimated survival from release to McNary Dam and to dams downstream using release groups based on species, tagging site, and release location. We also pooled fish of a given species from all release locations into a single overall group for the entire year. We used these pooled groups for estimates between McNary and Bonneville Dam.

Releases from Hatcheries and Smolt Traps—In 2022, most hatcheries in the Snake and upper Columbia River Basins released PIT-tagged fish as part of research independent of our 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 the respective release sites 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 sites 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, wild and hatchery steelhead, and wild sockeye. These fish were PIT tagged and released at traps throughout the Snake River Basin, including the Salmon River (White Bird), Snake River, and Lower Grand Ronde Smolt Traps.

Data Analysis

Tagging and detection data were downloaded 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 first downloaded on 2 August 2022, and we published a memorandum of preliminary survival estimates on 20 October 2022. At the time that memo was published, data from PIT-tag recoveries on avian colonies throughout the basin were not yet available.

By early December 2022, recovery data from the avian colonies had been uploaded to the PTAGIS database, significantly expanding detection data from below Bonneville Dam (Evans et al. 2023). Accordingly, on 13 December we again downloaded tagging and detection data for the 2022 migration year. Data were examined for erroneous records, inconsistencies, and anomalies. Records were eliminated where appropriate, and all eliminated PIT-tag codes were recorded with the reasons for their elimination. Very few records were eliminated (<0.1%).

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

All analyses reported here were from data downloaded on 13 December 2022. It is possible that data in the PTAGIS database may have been updated or corrected after this date. Thus, estimates we may provide in the future, or data used for future analyses, may differ slightly from those presented here.

Tests of Assumptions—We evaluated assumptions of the single-release 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 past study years, some sample sizes have been large enough that these tests had sufficient power to detect small violations of model assumptions. However, in 2022 statistical power was likely low for most tests due to small sample sizes and low detection probabilities. Very small violations have only marginal effects on survival estimates, but large violations can result in biased parameter estimates. Appendix A contains a detailed discussion of these tests of assumptions, the extent of assumption violations and their implications in 2022, and possible reasons for these violations.

Survival Estimates—All of our survival estimates were calculated from a release point or from the tailrace of a dam to the tailrace of a downstream dam. All estimates of survival and detection were computed using the statistical computer program SURPH (Survival with Proportional Hazards) for analyzing mark-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).

Our survival estimates are based on information from migrating fish that are either detected in juvenile bypass systems and returned to the river or pass dams via turbines or spillways (including surface-passage structures). Detections of fish that are ultimately collected for transportation are used for survival information only to the point where they are removed from the river.

Estimates of survival probability under the single-release model are random variables, subject to sampling variability, and the 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 estimates of survival probability 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 entire migration season. When a series extended across all or most of the season, we considered this weighted average to be the seasonal average for the year. For each survival estimate in such a series, the weight applied was proportional to the inverse of its estimated relative variance (coefficient of variation squared).

We used the inverse of estimated *relative* variance rather than *absolute* variance because the variance of a survival probability estimate from the single-release 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 River, 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 for the shorter component reaches.

Estimated survival from the Snake River Smolt Trap to Bonneville Dam provides important information on survival through an extended reach containing eight hydroelectric projects. The Snake River Smolt 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 two components:

1) Estimated survival to Lower Granite Dam for fish tagged and released at the Snake River Smolt Trap using a single estimate for all fish pooled across the migration season
2) Weighted mean estimated survival from Lower Granite to Bonneville Dam for virtual biweekly groups of fish released from Lower Granite Dam

In past years, when detection rates were higher, and virtual release group sizes at McNary Dam were sufficient, we calculated the annual mean estimated survival from Lower Granite to Bonneville Dam as the product of two independent weighted means: (1) estimated survival from Lower Granite to McNary Dam and (2) estimated survival from McNary to Bonneville Dam. This method does not produce estimates to Bonneville Dam for virtual groups formed at Lower Granite Dam. However, the alternative method used from 2020 through 2022 does produce such estimates, and we have reported them here.

We performed statistical tests to compare pairs of survival estimates between years or stocks or to compare an estimate to its estimated long-term mean. For each of these comparisons, we calculated the difference between survival estimates and used the estimated variances of the estimates to calculate a variance of the difference. Resulting variances were then used to calculate a z-statistic, which we compared to a standard normal distribution to obtain two-sided p-values. We considered differences between estimates to be statistically significant at the $\alpha = 0.05$ level.

Results

Snake River Yearling Chinook Salmon

Survival Probabilities—For yearling Chinook salmon, we estimated survival probability from the tailrace of Lower Granite Dam downstream through multiple Snake River dams. We produced estimates for five biweekly groups over ten consecutive weeks during 23 March-31 May and for a single pooled cohort including all remaining detected fish in the season, covering the period from 1 June to 26 July (Table 2). Mean estimated survival was 0.823 (SE 0.035) from Lower Granite to Little Goose, 1.014 (0.059) from Little Goose to Lower Monumental, and 0.869 (0.138) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.709 (0.077).

Table 2. Survival probability estimates from Lower Granite to McNary Dam for combined wild and hatchery Snake River yearling Chinook in 2022. Weighted means are of independent estimates for biweekly 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 Mar-5 Apr	1,381	0.558 (0.100)	0.654 (0.202)	2.185 (1.061)	0.797 (0.331)
6-19 Apr	5,160	0.747 (0.160)	1.328 (0.633)	0.629 (0.325)	0.624 (0.183)
20 Apr-3 May	45,204	0.756 (0.091)	1.182 (0.227)	1.021 (0.220)	0.913 (0.140)
4-17 May	40,546	0.833 (0.043)	1.060 (0.095)	0.880 (0.139)	0.778 (0.108)
18-31 May	14,287	0.763 (0.080)	0.815 (0.136)	0.696 (0.164)	0.433 (0.085)
1 Jun-26 Jul	2,082	0.922 (0.073)	0.998 (0.149)	0.585 (0.136)	0.538 (0.104)
Weighted mean		**0.823 (0.035)**	**1.014 (0.059)**	**0.869 (0.138)**	**0.709 (0.077)**

In 2022, detection rates of yearling Chinook at McNary Dam were too low to create virtual release groups of sufficient sample size. Thus, we estimated survival and detection probabilities downstream of McNary Dam using biweekly groups formed from fish detected or tagged and released at Lower Granite Dam; the same groups that were used for estimates in Snake River reaches (Table 3).

While these virtual groups were identified by date of passage at Lower Granite Dam, their dates of passage at McNary were later. Detection probabilities were low at McNary and extremely low at John Day Dam. Consequently, survival estimates were generally imprecise (Table 3). Mean estimated survival was 0.806 (SE 0.087) from McNary to John Day, 0.892 (0.077) from John Day to Bonneville, and 0.689 (0.066) for the combined reach from McNary to Bonneville Dam.

Table 3. Survival probability estimates from McNary to Bonneville Dam and for the overall reach from Lower Granite to Bonneville Dam for combined wild and hatchery Snake River yearling Chinook in 2022. Weighted means are of independent estimates for biweekly groups. Standard errors in parentheses.

Estimated survival of yearling Chinook salmon groups from Lower Granite Dam (SE)					
Date at Lower Granite Dam	Number Released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam
23 Mar-5 Apr	1,381	0.704 (0.550)	0.652 (0.554)	0.459 (0.310)	0.366 (0.195)
6-19 Apr	5,160	0.645 (0.307)	0.973 (0.453)	0.628 (0.254)	0.392 (0.109)
20 Apr-3 May	45,204	0.947 (0.210)	0.644 (0.118)	0.609 (0.108)	0.556 (0.050)
4-17 May	40,546	0.666 (0.112)	1.028 (0.145)	0.685 (0.119)	0.532 (0.055)
18-31 May	14,287	1.124 (0.280)	0.943 (0.271)	1.060 (0.331)	0.459 (0.111)
1 Jun-26 Jul	2,082	0.595 (0.186)	0.744 (0.717)	0.443 (0.421)	0.238 (0.222)
Weighted mean		**0.806 (0.087)**	**0.892 (0.077)**	**0.689 (0.066)**	**0.528 (0.022)**

For combined wild and hatchery Snake River yearling Chinook, the overall survival estimate from Lower Granite to Bonneville Dam was 0.528 (SE 0.022). For wild and hatchery yearling Chinook released from the Snake River Smolt Trap, estimated survival to Lower Granite Dam was 0.963 (0.072). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River yearling Chinook salmon was 0.508 (0.044).

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for hatchery vs. wild yearling Chinook (Table 4). Sample sizes were adequate to estimate survival for most biweekly groups of hatchery yearling Chinook, although low detection rates compelled us to pool the first two cohorts into a four-week cohort, and the final cohort was pooled with all remaining fish in the season.

Table 4. Survival probability estimates from Lower Granite to McNary Dam for Snake River yearling Chinook salmon in 2022. For hatchery fish, daily groups were pooled for biweekly estimates; wild fish were pooled into a single group for the full season. Weighted means are of the independent estimates for biweekly groups. Standard errors in parentheses.

		Estimated survival of biweekly 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 Mar-19 Apr	5,135	0.606 (0.093)	0.784 (0.241)	1.299 (0.471)	0.617 (0.152)
20 Apr-3 May	40,128	0.778 (0.113)	0.990 (0.219)	1.191 (0.284)	0.917 (0.156)
4-17 May	35,087	0.828 (0.050)	1.067 (0.111)	0.967 (0.177)	0.854 (0.138)
18-31 May	10,452	0.945 (0.192)	1.145 (0.416)	0.362 (0.142)	0.391 (0.098)
1 Jun-11 Jul	454	0.787 (0.166)	1.370 (0.762)	0.930 (1.011)	1.003 (0.953)
Weighted mean		**0.803 (0.038)**	**1.044 (0.048)**	**1.007 (0.126)**	**0.770 (0.094)**
		Wild yearling Chinook			
24 Mar-26 Jul	**21,404**	**0.750 (0.032)**	**0.985 (0.071)**	**0.855 (0.102)**	**0.631 (0.066)**

Sample sizes for wild Chinook were too low to estimate survival for any type of within-season cohort, and we were able to estimate survival only by pooling all wild-origin smolts into a single group. Annual estimated survival across the season was higher for hatchery than for wild Chinook salmon, but the difference was not significant ($P = 0.23$).

We were unable to estimate survival probabilities for daily groups of yearling Chinook salmon in 2022. Even for pooled biweekly groups, the precision of nearly all survival estimates was poor (Table 2). Consequently, it was impossible to assess any potential within-season trends in survival during 2022.

Detection Probabilities—Detection probability estimates in 2022 were extremely low at almost every dam downstream of Lower Granite Dam (Tables 5-7). In marked contrast, because of the spillway detection system, detection probability estimates at Lower Granite Dam were above average (Appendix Tables B4, B8, B10). Detection probability estimates at Snake River dams were generally higher for wild than for hatchery Chinook salmon (Table 7).

Table 5. Detection probability estimates at Little Goose, Lower Monumental, and McNary Dam for combined wild and hatchery Snake River yearling Chinook salmon in 2022. Standard errors in parentheses.

	Detection probability estimates for 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 Mar-5 Apr	1,381	0.139 (0.028)	0.094 (0.027)	0.056 (0.024)
6-19 Apr	5,160	0.069 (0.015)	0.019 (0.008)	0.032 (0.010)
20 Apr-3 May	45,204	0.027 (0.003)	0.021 (0.003)	0.010 (0.002)
4-17 May	40,546	0.078 (0.004)	0.076 (0.006)	0.013 (0.002)
18-31 May	14,287	0.070 (0.008)	0.071 (0.009)	0.021 (0.005)
1 Jun-26 Jul	2,082	0.183 (0.017)	0.178 (0.024)	0.115 (0.024)

Table 6. Detection probability estimates at John Day and Bonneville Dam for combined wild and hatchery Snake River yearling Chinook salmon in 2022. Standard errors in parentheses.

	Detection probability estimates for yearling Chinook salmon groups from Lower Granite Dam (SE)		
Date at Lower Granite Dam	Number released	John Day Dam	Bonneville Dam
23 Mar-5 Apr	1,381	0.027 (0.019)	0.088 (0.049)
6-19 Apr	5,160	0.022 (0.009)	0.097 (0.028)
20 Apr-3 May	45,204	0.010 (0.002)	0.104 (0.010)
4-17 May	40,546	0.032 (0.003)	0.112 (0.012)
18-31 May	14,287	0.051 (0.008)	0.091 (0.022)
1 Jun-26 Jul	2,082	0.198 (0.051)	0.113 (0.106)

Table 7. Detection probability estimates at Little Goose, Lower Monumental, and McNary Dam for Snake River yearling Chinook salmon in 2022. For hatchery fish, daily groups were pooled for biweekly estimates; wild fish were pooled into a single group for the full season. Standard errors in parentheses.

		Detection probability estimates for 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 Mar-19 Apr	5,135	0.100 (0.016)	0.042 (0.012)	0.042 (0.011)
20 Apr-3 May	40,128	0.024 (0.004)	0.021 (0.004)	0.009 (0.002)
4-17 May	35,087	0.073 (0.005)	0.072 (0.006)	0.012 (0.002)
18-31 May	10,452	0.044 (0.009)	0.031 (0.009)	0.019 (0.005)
1 Jun-11 Jul	454	0.213 (0.050)	0.114 (0.060)	0.053 (0.051)
		Wild yearling Chinook		
24 Mar-26 Jul	21,404	0.109 (0.005)	0.100 (0.006)	0.030 (0.003)

Snake River Steelhead

Survival Probabilities**—**For steelhead, we estimated survival probabilities from the tailrace of Lower Granite Dam through multiple downstream dams. We produced estimates for five biweekly groups over ten consecutive weeks during 23 March-31 May as well as for a single pooled cohort that included all remaining fish detected from 1 June to 19 July. Mean estimated survival was 0.881 (SE 0.027) from Lower Granite to Little Goose, 0.992 (0.043) from Little Goose to Lower Monumental, and 0.681 (0.034) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, estimated survival averaged 0.610 (0.055).

Table 8. Survival probability estimates from Lower Granite to McNary Dam for combined wild and hatchery Snake River juvenile steelhead in 2022. Weighted means are of independent estimates for biweekly 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 Mar-5 Apr	2,634	0.964 (0.175)	1.191 (0.504)	0.389 (0.167)	0.447 (0.087)
6-19 Apr	10,656	1.152 (0.178)	0.737 (0.191)	0.662 (0.169)	0.562 (0.082)
20 Apr-3 May	38,514	0.919 (0.049)	1.061 (0.123)	0.708 (0.101)	0.691 (0.068)
4-17 May	36,519	0.925 (0.038)	1.097 (0.077)	0.766 (0.103)	0.777 (0.095)
18-31 May	16,089	0.875 (0.085)	0.965 (0.141)	0.715 (0.281)	0.603 (0.228)
1 Jun-19 Jul	7,037	0.829 (0.026)	0.910 (0.055)	0.623 (0.072)	0.470 (0.049)
Weighted mean		**0.881 (0.027)**	**0.992 (0.043)**	**0.681 (0.034)**	**0.610 (0.055)**

In 2022, detection rates at McNary Dam were too low to create virtual release groups of sufficient sample size from fish detected at the dam. Thus, we estimated survival and detection probabilities downstream of McNary Dam using biweekly groups formed from fish detected at Lower Granite Dam—the same groups used for estimates in Snake River reaches (Table 9).

While these virtual groups were identified by date of passage at Lower Granite Dam, their dates of passage at McNary were later. Detection probabilities were extremely low at both McNary and John Day Dams. Consequently, survival estimates were generally imprecise (Table 9). Mean estimated survival was 1.265 (SE 0.198) from McNary to John Day, 0.737 (0.091) from John Day to Bonneville, and 0.757 (0.047) for the entire reach from McNary to Bonneville Dam (Table 9).

Table 9. Survival probability estimates from McNary to Bonneville Dam and for the overall reach from Lower Granite to Bonneville Dam for combined wild and hatchery Snake River juvenile steelhead in 2022. Weighted means are of independent estimates for biweekly groups. Standard errors in parentheses.

		Estimated survival of steelhead groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number Released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam
23 Mar-5 Apr	2,634	0.946 (0.424)	0.661 (0.330)	0.625 (0.219)	0.280 (0.082)
6-19 Apr	10,656	0.686 (0.194)	0.757 (0.225)	0.519 (0.117)	0.292 (0.050)
20 Apr-3 May	38,514	1.196 (0.185)	0.703 (0.095)	0.842 (0.099)	0.581 (0.037)
4-17 May	36,519	1.186 (0.209)	0.637 (0.091)	0.756 (0.103)	0.588 (0.037)
18-31 May	16,089	0.688 (0.278)	1.192 (0.261)	0.820 (0.338)	0.495 (0.082)
1 Jun-19 Jul	7,037	2.161 (0.486)	0.305 (0.123)	0.660 (0.239)	0.310 (0.108)
Weighted mean		**1.265 (0.198)**	**0.737 (0.091)**	**0.757 (0.047)**	**0.553 (0.038)**

For wild and hatchery Snake River steelhead, the overall survival estimate from Lower Granite to Bonneville Dam was 0.553 (SE 0.038). For wild and hatchery steelhead released from the Snake River Smolt Trap, estimated survival probability to Lower Granite Dam tailrace was 0.940 (0.023). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.520 (0.038).

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for biweekly groups of hatchery vs. wild steelhead (Table 10). Sample sizes were adequate to estimate survival for biweekly groups of hatchery steelhead except for the late-season group of pooled detections from 1 June through 19 July. For wild steelhead, sample sizes were too low to estimate survival for any type of within-season cohorts; we were able to estimate survival only by pooling all wild-origin steelhead into a single group. Annual estimated survival across the season was higher for hatchery than for wild steelhead, and the difference was statistically significant ($P = 0.01$).

For daily groups of steelhead in 2022, we were unable to estimate survival probabilities. Even for pooled biweekly groups, the precision of nearly all survival estimates was extremely poor (Table 8). Consequently, it was impossible to assess any potential trends in survival within the 2022 migration season.

Table 10. Survival probability estimates from Lower Granite to McNary Dam for Snake River juvenile steelhead in 2022. For hatchery fish, daily groups were pooled for biweekly estimates; wild fish were pooled into a single group for the full season. Weighted means are of independent estimates for biweekly groups. Standard errors in parentheses.

	Estimated survival for groups in reaches from Lower Granite to McNary 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 Mar-5 Apr	2,567	0.973 (0.181)	1.148 (0.486)	0.413 (0.178)	0.461 (0.092)
6-19 Apr	10,267	1.180 (0.191)	0.748 (0.204)	0.659 (0.177)	0.582 (0.089)
20 Apr-3 May	37,304	0.916 (0.049)	1.064 (0.126)	0.706 (0.103)	0.688 (0.069)
4-17 May	31,813	0.920 (0.043)	1.108 (0.087)	0.883 (0.135)	0.900 (0.125)
18-31 May	11,675	0.817 (0.091)	0.925 (0.154)	0.819 (0.353)	0.619 (0.256)
1 Jun-19 Jul	4,102	0.842 (0.036)	0.913 (0.074)	0.684 (0.105)	0.526 (0.072)
Weighted mean		**0.892 (0.028)**	**1.008 (0.045)**	**0.738 (0.047)**	**0.658 (0.061)**
	Wild steelhead				
27 Mar-10 Jul	**14,978**	**0.745 (0.030)**	**1.068 (0.081)**	**0.551 (0.076)**	**0.438 (0.054)**

Detection Probabilities**—**For steelhead, detection probability estimates were very low in 2022 at Little Goose, Lower Monumental, McNary, and John Day Dam (Tables 11-13). Detection probability estimates for steelhead were also below average at Bonneville Dam, though not to the same degree as dams upstream. However, detection probability estimates were well above average at Lower Granite Dam, with its spillway detection system (Appendix Tables B5, B8, B10). Detection probability estimates at Snake River dams were generally higher for wild than for hatchery steelhead (Table 13).

Table 11. Detection probability estimates at Little Goose Dam, Lower Monumental Dam, and McNary Dam for combined wild and hatchery Snake River juvenile steelhead in 2022. Standard errors in parentheses.

Detection probability estimates for steelhead groups from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
23 Mar-5 Apr	2,634	0.069 (0.013)	0.025 (0.010)	0.104 (0.022)
6-19 Apr	10,656	0.037 (0.006)	0.027 (0.006)	0.058 (0.009)
20 Apr-3 May	38,514	0.085 (0.005)	0.030 (0.003)	0.017 (0.002)
4-17 May	36,519	0.085 (0.004)	0.076 (0.004)	0.012 (0.002)
18-31 May	16,089	0.060 (0.006)	0.080 (0.009)	0.005 (0.002)
1 Jun-19 Jul	7,037	0.256 (0.010)	0.252 (0.014)	0.084 (0.010)

Table 12. Detection probability estimates at John Day Dam and Bonneville Dam for combined wild and hatchery Snake River juvenile steelhead in 2022. Standard errors in parentheses.

Detection probability estimates for steelhead groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	John Day Dam	Bonneville Dam
23 Mar-5 Apr	2,634	0.029 (0.013)	0.180 (0.054)
6-19 Apr	10,656	0.023 (0.006)	0.155 (0.027)
20 Apr-3 May	38,514	0.013 (0.002)	0.163 (0.011)
4-17 May	36,519	0.012 (0.002)	0.168 (0.011)
18-31 May	16,089	0.036 (0.006)	0.113 (0.019)
1 Jun-19 Jul	7,037	0.071 (0.015)	0.130 (0.046)

Table 13. Detection probability estimates at Little Goose Dam, Lower Monumental Dam, and McNary Dam for Snake River juvenile steelhead in 2022. For hatchery fish, daily groups were pooled for biweekly estimates; wild fish were pooled into a single group for the full season. 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 Mar-5 Apr	2,567	0.068 (0.014)	0.025 (0.010)	0.101 (0.022)
6-19 Apr	10,267	0.036 (0.006)	0.025 (0.006)	0.055 (0.009)
20 Apr-3 May	37,304	0.087 (0.005)	0.030 (0.003)	0.018 (0.002)
4-17 May	31,813	0.080 (0.004)	0.074 (0.005)	0.010 (0.002)
18-31 May	11,675	0.066 (0.008)	0.089 (0.011)	0.005 (0.002)
1 Jun-19 Jul	4,102	0.246 (0.013)	0.241 (0.018)	0.080 (0.012)
		Wild steelhead		
27 Mar-10 Jul	14,978	0.142 (0.006)	0.117 (0.008)	0.028 (0.004)

Survival Between Lower Monumental and Ice Harbor Dam

At Ice Harbor Dam, a PIT-tag detection system became operational in 2005. In most years since then, detection probabilities have been low but sufficient for separate estimates of survival from Lower Monumental to Ice Harbor and from Ice Harbor to McNary Dam. In 2022, detections at Ice Harbor Dam were especially poor and lower than in most recent years (Table 14). At Lower Monumental Dam, detection probabilities were slightly higher than at Ice Harbor, but still almost as low as at McNary.

For yearling Chinook salmon in 2022, mean estimated survival was 1.027 (SE 0.137) from Lower Monumental to Ice Harbor Dam and 0.781 (0.054) from Ice Harbor to McNary Dam. In these same two reaches, mean estimated survival for steelhead was 0.972 (0.076) and 0.804 (0.096), respectively (Table 14).

Table 14. Survival and detection probability estimates from Lower Monumental to McNary Dam, including Ice Harbor Dam, for Snake River yearling Chinook salmon and juvenile steelhead in 2022. Weighted means are of independent estimates for biweekly groups of combined hatchery and wild fish. 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 at Ice Harbor Dam
		Hatchery and wild yearling Chinook salmon		
20 Apr-3 May	45,204	0.962 (0.252)	1.049 (0.278)	0.004 (0.001)
4-17 May	40,546	0.695 (0.135)	1.238 (0.281)	0.007 (0.001)
18-31 May	14,287	1.090 (0.248)	0.634 (0.175)	0.021 (0.004)
1-14 Jun	1,753	1.106 (0.326)	0.485 (0.165)	0.049 (0.014)
Weighted mean		**0.921 (0.104)**	**0.929 (0.172)**	
		Hatchery and wild steelhead		
23 Mar-5 Apr	2,634	0.387 (0.165)	0.779 (0.207)	0.073 (0.015)
6-19 Apr	10,656	1.091 (0.270)	0.674 (0.154)	0.028 (0.005)
20 Apr-3 May	38,514	1.246 (0.196)	0.570 (0.090)	0.011 (0.002)
4-17 May	36,519	0.964 (0.143)	0.830 (0.153)	0.009 (0.001)
18-31 May	16,089	0.986 (0.169)	0.742 (0.300)	0.032 (0.005)
1-14 Jun	5,877	1.114 (0.149)	0.555 (0.092)	0.059 (0.008)
15-18 Jun	1,052	0.500 (0.161)	1.031 (0.467)	0.094 (0.026)
Weighted mean		**1.036 (0.078)**	**0.672 (0.052)**	

Survival and Detection from Hatcheries and Smolt Traps

Snake River Hatchery Release Groups**—**Survival estimates varied among hatchery 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 1.012 (SE 0.030) for Clearwater Hatchery fish released to Clear Creek in the Middle Fork Clearwater Basin to 0.232 (0.014) for Sawtooth Hatchery fish released to the Yankee Fork of the Salmon River (Appendix Table B1).

For steelhead, estimated survival to Lower Granite ranged from 0.785 (0.016) for Niagara Springs Hatchery fish released to the tailrace of Hell's Canyon Dam to 0.567 (0.010) for Lyon's Ferry Hatchery fish released from Cottonwood Pond on the Grande Ronde River (Appendix Table B2).

For sockeye salmon, only one group of hatchery-origin fish was released in 2022. Estimated survival to Lower Granite Dam was 0.756 (0.010) for Springfield Hatchery fish released in early May from Redfish Lake Creek on the upper Salmon River (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 at dams other than Lower Granite were substantially below average but were similar among groups of the same species and origin released from different traps (Appendix Table B8).

We saw no consistent difference in estimated detection probabilities at Snake River dams between wild spring Chinook and their hatchery conspecifics released from the same trap location (e.g., Lower Grande Ronde and Salmon River Smolt Traps). For juvenile steelhead, it appeared that hatchery smolts potentially had a higher rate of detection at Lower Granite Dam than wild smolts.

For wild steelhead groups released from the Snake River, Lower Grande Ronde, and Salmon River Smolt Traps, a combination of low detection rates and very low sample sizes made it impossible to estimate detection probability at dams downstream of Lower Granite. Consequently, it was impossible to assess whether there were differences in detection probabilities between wild and hatchery steelhead released at those sites.

Upper Columbia River Hatchery Release Groups—We estimated survival probabilities from release at Upper Columbia River hatcheries to McNary, John Day, and Bonneville Dam for yearling Chinook, coho, 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 salmon, estimated survival from release to Bonneville Dam ranged from 0.674 (SE 0.163) for Entiat Hatchery fish released from the hatchery to 0.106 (0.056) for Methow Hatchery fish released from Goatwall Pond.

For Upper Columbia River steelhead, estimated survival from release to Bonneville Dam ranged from 0.380 (0.209) for Wells Hatchery fish released from Similkameen Pond to 0.097 (0.090) for Wells Hatchery fish released to the Twisp River.

For coho salmon, estimated survival from release to Bonneville Dam ranged from 0.512 (0.215) for Willard Hatchery fish released from Chewuch Pond to 0.134 (0.062) for Yakima Hatchery fish released to the Yakima River.

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 detected at both the upstream and downstream dam. We defined travel time as the number of days between last detection at the upstream dam and first detection at the downstream dam. Generally, the last detection at an upstream dam was on a monitor near the juvenile bypass outfall site; fish arrived in the tailrace within a few seconds or minutes after detection near the outfall site.

Our measures of travel time for individual fish included the time required to move through the tailrace of the upstream dam as well as through the reservoir, forebay, and entry to the collection channel of the downstream dam. Thus, travel time encompassed any delays associated with passage at the downstream dam, such as lingering in the forebay, gatewell, or collection channel prior to first detection in the juvenile bypass system.

Migration rate for each individual fish was calculated as length of the reach of interest (km) divided by travel time (d) and included the potential delays noted above. For both species, daily groups of combined hatchery and wild fish were formed based on detection date at Lower Granite Dam. Daily groups were used individually to calculate flow exposure but were pooled into weekly groups for reporting travel time statistics. We calculated the 20th percentile, median, and 80th percentile travel time and migration rate for each daily and weekly 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 these twice-detected fish, which represent a subsample of the complete tagged release group.

At dams other than Lower Granite and Bonneville, only the juvenile bypass system is monitored for PIT tags. To pass such dams undetected, a tagged fish must utilize a different passage route, such as a turbine, spillway, or sluiceway. Passage times through those routes are typically shorter than through the juvenile bypass system. Thus, at dams other than Lower Granite and Bonneville, passage time for non-detected fish is typically minutes to hours shorter than for detected fish, all of which pass via the juvenile bypass system.

Results

Median travel time decreased over the migration season (Tables 15-20). For both yearling Chinook and steelhead, estimated migration rates were generally highest in the lower river sections. Over the last several years we have noted a trend toward shorter smolt travel times relative to levels of flow and spill. However, the spill component of that trend was reversed in 2022, and despite very high levels of spill, we observed longer than usual travel times.

For the first half of the migration season, travel times for both Chinook and steelhead were unusually long (Figure 2). During the entirety of April and the first half of May, travel times in 2022 were substantially longer than in other recent years, regardless of flow. Travel times for Chinook were longer in early April of 2022 than in any other year besides 2001. Migration rates increased for both species through the month of May, and by late May travel times were roughly equal to those from recent high-flow years. The very long travel times observed in 2022 are particularly notable in that they occurred during a management regime of very high levels of spill, a regime expected to reduce smolt delay at dams.

For each daily group of PIT-tagged Chinook salmon and steelhead, we calculated an index of Snake River flow exposure (Appendix C1). We then related flow exposure to travel time for each daily group (Figure 3). For both species, the very long travel times observed in April occurred during a prolonged period of low flow. Moderate increases in flow exposure around 4, 15, and 25 May were all well correlated with reduced travel time for both Chinook and steelhead (Figure 3). For both species, general decreases in travel time as the season progressed were also presumably related to increased levels of smolt readiness.

Table 15. Travel time from Lower Granite to Bonneville Dam for Snake River yearling Chinook salmon in 2022. Daily groups of combined hatchery and wild fish were determined by day of detection at Lower Granite Dam and pooled for weekly statistics.

Travel time of yearling Chinook salmon tagged or detected at 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	49	2.9	3.9	6.4	7	2.1	2.9	3.0	4	4.6	4.6	5.1
30 Mar-5 Apr	58	10.7	18.4	25.9	2	3.9	4.4	5.0	3	8.9	12.1	15.9
6-12 Apr	88	10.9	16.0	19.8	3	3.7	4.2	4.4	0	-	-	-
13-19 Apr	177	8.3	11.3	13.8	0	-	-	-	0	-	-	-
20-26 Apr	337	4.3	5.4	7.4	3	1.7	2.5	2.8	0	-	-	-
27 Apr-3 May	579	3.9	4.4	5.9	14	1.6	1.9	2.5	4	2.6	2.8	3.2
4-10 May	1,995	2.6	3.8	5.4	98	1.9	2.2	2.8	10	3.4	4.0	4.7
11-17 May	639	4.1	4.8	6.2	25	1.5	2.1	2.4	3	3.5	4.0	4.3
18-24 May	208	3.2	3.9	4.8	8	1.5	1.7	2.8	2	3.3	3.6	3.8
25-31 May	551	2.1	2.9	3.5	19	1.2	1.4	1.7	7	2.5	2.7	2.9
1-7 Jun	219	2.1	2.9	3.1	29	1.1	1.2	1.4	15	2.5	2.8	3.8
8-14 Jun	101	1.9	2.3	2.9	21	0.7	0.9	1.1	7	2.4	2.6	2.8

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23-29 Mar	17	11.6	13.9	25.4	9	23.8	32.4	35.9
30 Mar-5 Apr	41	19.5	22.9	28.7	33	31.6	36.4	39.4
6-12 Apr	35	16.2	21.6	26.9	66	28.9	31.8	35.9
13-19 Apr	63	14.4	19.1	22.5	121	22.1	26.3	29.8
20-26 Apr	116	11.1	12.2	14.7	507	15.9	17.8	20.9
27 Apr-3 May	288	8.5	9.6	12.2	2,039	12.6	14.2	16.5
4-10 May	245	7.5	10.8	13.5	1,709	11.2	13.1	15.5
11-17 May	145	8.4	9.7	11.6	527	11.8	13.4	15.3
18-24 May	66	7.0	8.4	9.7	364	10.1	11.2	12.5
25-31 May	56	6.3	7.2	8.2	196	8.8	9.8	10.7
1-7 Jun	72	5.9	7.0	7.9	24	8.2	9.5	10.3
8-14 Jun	37	5.8	6.3	7.2	14	7.9	9.7	10.9

Table 16. Migration rate from Lower Granite to Bonneville Dam for Snake River yearling Chinook salmon in 2022. Daily groups of combined hatchery and wild fish were determined by day of detection at Lower Granite Dam and pooled for weekly statistics.

Migration rate of yearling Chinook salmon tagged or detected at 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	49	9.4	15.3	20.7	7	15.2	15.8	21.5	4	23.2	25.7	25.8
30 Mar-5 Apr	58	2.3	3.3	5.6	2	9.3	10.4	11.9	3	7.5	9.9	13.3
6-12 Apr	88	3.0	3.8	5.5	3	10.4	10.9	12.3	0	-	-	-
13-19 Apr	177	4.4	5.3	7.2	0	-	-	-	0	-	-	-
20-26 Apr	337	8.1	11.1	14.1	3	16.1	18.3	27.7	0	-	-	-
27 Apr-3 May	579	10.2	13.6	15.5	14	18.6	24.3	29.7	4	37.4	43.0	44.9
4-10 May	1,995	11.2	15.9	23.4	98	16.6	20.9	24.6	10	25.3	29.4	34.9
11-17 May	639	9.6	12.4	14.5	25	19.3	22.3	31.3	3	27.8	29.6	33.5
18-24 May	208	12.6	15.2	18.9	8	16.7	27.2	30.9	2	31.3	33.3	35.6
25-31 May	551	17.4	20.8	28.2	19	26.6	32.4	37.7	7	40.9	44.6	47.4
1-7 Jun	219	19.2	20.9	27.9	29	33.6	39.3	43.8	15	31.7	41.9	47.2
8-14 Jun	101	20.9	25.8	31.7	21	40.0	49.5	62.2	7	43.3	45.1	49.8

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23-29 Mar	17	8.8	16.2	19.4	9	12.9	14.2	19.4
30 Mar-5 Apr	41	7.8	9.8	11.6	33	11.7	12.7	14.6
6-12 Apr	35	8.4	10.4	13.9	66	12.8	14.5	15.9
13-19 Apr	63	10.0	11.8	15.6	121	15.5	17.5	20.9
20-26 Apr	116	15.3	18.4	20.3	507	22.1	26.0	29.0
27 Apr-3 May	288	18.4	23.4	26.5	2,039	27.9	32.5	36.5
4-10 May	245	16.7	20.9	30.0	1,709	29.7	35.1	41.1
11-17 May	145	19.4	23.1	26.7	527	30.2	34.4	39.0
18-24 May	66	23.1	26.6	32.3	364	36.9	41.3	45.8
25-31 May	56	27.5	31.2	35.7	196	43.1	47.2	52.1
1-7 Jun	72	28.6	32.2	38.4	24	44.8	48.6	55.9
8-14 Jun	37	31.4	35.4	38.9	14	42.3	47.3	58.7

Table 17. Travel time and migration rate from McNary to Bonneville Dam for Snake River yearling Chinook salmon in 2022. Daily groups of combined hatchery and wild fish were determined by day of detection at Lower Granite Dam and pooled for weekly statistics.

	Hatchery and wild yearling Chinook salmon tagged or detected at Lower Granite Dam											
Date at Lower	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
Granite Dam	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
30 Mar-5 Apr	1	4.0	4.0	4.0	1	2.8	2.8	2.8	2	6.3	7.1	7.8
6-12 Apr	0	-	-	-	1	2.4	2.4	2.4	2	6.4	7.3	8.2
13-19 Apr	1	5.0	5.0	5.0	4	1.6	1.8	2.5	5	4.8	6.2	8.1
20-26 Apr	1	3.5	3.5	3.5	2	2.0	2.1	2.1	7	4.4	4.7	5.4
27 Apr-3 May	2	3.4	3.6	3.8	16	1.6	1.8	2.1	15	4.3	4.8	5.2
4-10 May	5	3.3	3.8	4.8	57	1.6	1.7	2.1	14	3.7	4.2	4.8
11-17 May	3	2.3	2.6	2.6	20	1.5	1.7	1.9	9	4.0	4.2	4.4
18-24 May	4	2.3	2.8	3.4	18	1.5	1.7	2.1	8	3.5	3.9	4.2
25-31 May	3	2.5	2.7	2.7	14	1.4	1.4	1.6	4	2.9	3.1	3.5
1-7 Jun	6	2.3	2.5	3.3	4	1.1	1.2	1.2	2	2.8	3.1	3.4
	Migration rate (km/d)											
30 Mar-5 Apr	1	31.1	31.1	31.1	1	39.9	39.9	39.9	2	30.1	33.3	37.3
6-12 Apr	0	-	-	-	1	48.1	48.1	48.1	2	28.7	32.3	37.1
13-19 Apr	1	24.7	24.7	24.7	4	45.6	61.1	72.0	5	29.1	38.4	48.7
20-26 Apr	1	35.5	35.5	35.5	2	53.6	54.3	55.4	7	43.5	50.4	53.2
27 Apr-3 May	2	31.9	33.7	35.8	16	54.1	64.6	72.0	15	45.0	49.2	54.9
4-10 May	5	25.5	32.7	37.3	57	54.3	65.3	72.0	14	49.6	56.9	63.3
11-17 May	3	46.8	47.3	53.0	20	60.1	66.9	75.3	9	53.3	55.7	58.7
18-24 May	4	36.2	43.2	53.0	18	52.8	65.7	73.9	8	55.5	60.7	67.2
25-31 May	3	44.9	45.7	50.2	14	71.1	79.6	83.7	4	68.0	75.2	81.7
1-7 Jun	6	36.8	48.8	54.4	4	90.4	96.6	104.6	2	68.8	75.2	83.1

Table 18. Travel times from Lower Granite to Bonneville Dam for Snake River juvenile steelhead in 2022. Daily groups of combined hatchery and wild fish were determined by day of detection at Lower Granite Dam and pooled for weekly statistics.

Travel time of juvenile steelhead tagged or detected at 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	20	3.1	4.0	4.9	2	1.9	2.0	2.0	0	-	-	-
30 Mar-5 Apr	155	3.1	3.9	11.7	7	2.0	2.1	4.7	5	5.8	6.3	11.9
6-12 Apr	220	5.0	6.2	9.3	4	4.9	7.0	9.9	5	5.0	5.4	7.1
13-19 Apr	237	5.0	6.2	9.1	4	3.4	3.5	5.2	3	4.2	4.2	5.4
20-26 Apr	1,797	4.0	4.9	6.2	20	3.0	4.7	6.9	2	3.4	3.6	3.9
27 Apr-3 May	1,221	3.2	4.2	4.9	28	1.2	2.4	3.6	5	2.9	3.4	4.1
4-10 May	2,010	2.0	3.2	3.6	126	1.6	2.1	3.0	2	2.8	3.1	3.4
11-17 May	852	2.4	3.3	3.5	71	1.7	2.0	2.3	15	2.5	2.8	3.0
18-24 May	256	1.9	2.2	2.4	5	1.6	1.8	2.4	0	-	-	-
25-31 May	593	1.9	2.0	2.4	37	0.9	1.1	1.5	3	2.0	2.1	2.8
1-7 Jun	822	1.7	1.9	2.0	142	0.9	1.0	1.1	23	1.7	1.9	2.3
8-14 Jun	385	1.4	1.6	1.8	125	0.7	0.8	1.0	46	1.4	1.7	2.2
15-21 Jun	255	1.5	1.7	1.9	41	0.8	1.0	1.2	2	2.1	2.2	2.4

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23-29 Mar	1	14.5	14.5	14.5	1	21.8	21.8	21.8
30 Mar-5 Apr	120	13.0	15.9	21.4	130	18.4	20.8	23.9
6-12 Apr	157	14.1	16.6	21.6	140	20.2	22.8	29.5
13-19 Apr	185	12.6	15.0	17.9	333	19.5	21.8	24.9
20-26 Apr	277	10.4	12.4	14.5	1,413	15.2	16.8	19.3
27 Apr-3 May	156	8.0	9.4	10.6	2,023	12.3	13.7	15.2
4-10 May	125	6.0	7.3	9.5	2,157	9.8	10.9	12.4
11-17 May	192	6.0	7.2	8.4	1,229	9.9	11.0	12.3
18-24 May	19	6.0	6.4	7.4	542	8.8	9.4	9.9
25-31 May	25	5.0	5.2	6.0	310	7.6	8.2	8.6
1-7 Jun	92	4.3	5.0	5.8	143	6.8	7.3	8.1
8-14 Jun	147	3.7	4.2	4.8	55	6.4	6.7	7.5
15-21 Jun	18	4.1	4.6	5.8	38	6.6	7.3	7.7

Table 19. Migration rate from Lower Granite to Bonneville Dam for Snake River juvenile steelhead in 2022. Daily groups of combined hatchery and wild fish were determined by day of detection at Lower Granite Dam and pooled for weekly statistics.

Migration rate of juvenile steelhead tagged or detected at 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	20	12.2	15.2	19.2	2	22.8	23.6	24.3	0	-	-	-
30 Mar-5 Apr	155	5.1	15.3	19.4	7	9.9	21.7	23.6	5	10.0	18.8	20.7
6-12 Apr	220	6.5	9.7	12.0	4	4.7	6.6	9.4	5	16.8	22.0	23.9
13-19 Apr	237	6.6	9.7	11.9	4	8.9	13.0	13.4	3	22.1	28.3	28.5
20-26 Apr	1,797	9.7	12.3	15.1	20	6.7	9.8	15.1	2	30.4	32.6	35.2
27 Apr-3 May	1,221	12.2	14.5	18.7	28	12.9	19.5	37.4	5	29.0	35.1	41.6
4-10 May	2,010	16.4	19.0	29.4	126	15.5	21.9	29.1	2	34.9	38.0	41.8
11-17 May	852	17.0	18.4	25.0	71	19.7	22.8	26.6	15	39.5	43.0	47.2
18-24 May	256	24.6	27.6	30.9	5	19.2	26.0	28.9	0	-	-	-
25-31 May	593	25.3	29.7	31.7	37	31.5	41.4	50.0	3	42.3	55.6	58.0
1-7 Jun	822	29.3	32.3	35.7	142	40.0	46.0	52.9	23	52.7	63.3	68.8
8-14 Jun	385	32.6	37.5	43.2	125	45.1	56.8	67.6	46	53.8	71.3	83.2
15-21 Jun	255	31.6	36.1	39.5	41	38.7	46.9	56.1	2	49.6	53.4	57.5

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
23-29 Mar	1	15.5	15.5	15.5	1	21.2	21.2	21.2
30 Mar-5 Apr	120	10.5	14.1	17.3	130	19.3	22.1	25.0
6-12 Apr	157	10.4	13.6	15.9	140	15.6	20.2	22.8
13-19 Apr	185	12.6	15.0	17.9	333	18.5	21.1	23.6
20-26 Apr	277	15.5	18.2	21.6	1,413	23.9	27.4	30.2
27 Apr-3 May	156	21.3	24.0	28.3	2,023	30.3	33.6	37.4
4-10 May	125	23.7	30.9	37.6	2,157	37.1	42.2	46.8
11-17 May	192	26.9	31.3	37.6	1,229	37.4	42.0	46.8
18-24 May	19	30.4	35.0	37.8	542	46.6	48.8	52.6
25-31 May	25	37.8	42.9	44.6	310	53.7	56.3	60.9
1-7 Jun	92	38.7	45.5	51.7	143	57.1	62.8	68.2
8-14 Jun	147	46.5	53.6	60.2	55	61.3	69.1	72.3
15-21 Jun	18	39.1	49.3	54.9	38	59.6	63.4	70.0

Table 20. Travel time and migration rates from McNary to Bonneville Dam for Snake River juvenile steelhead in 2022. Daily groups of combined hatchery and wild fish were determined by day of detection at Lower Granite Dam and pooled for weekly statistics.

	Hatchery and wild juvenile steelhead tagged or detected at Lower Granite Dam											
Date at Lower Granite 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)											
30 Mar-5 Apr	3	6.8	10.8	11.7	2	2.1	2.4	2.5	12	5.6	7.4	8.1
6-12 Apr	1	26.6	26.6	26.6	4	2.2	2.3	2.9	12	4.8	5.6	7.3
13-19 Apr	3	3.8	4.9	5.4	6	1.8	2.0	2.3	8	4.1	5.4	6.1
20-26 Apr	6	3.4	3.8	4.1	15	1.7	1.8	2.0	40	4.1	4.6	5.1
27 Apr-3 May	4	3.4	3.8	4.0	25	1.6	1.7	1.8	15	4.1	4.5	4.8
4-10 May	2	3.4	3.9	4.3	21	1.6	1.7	1.8	13	3.9	4.1	4.3
11-17 May	3	2.4	3.0	3.5	16	1.5	1.6	1.8	25	3.5	3.9	4.2
18-24 May	0	-	-	-	18	1.2	1.3	1.5	1	3.2	3.2	3.2
25-31 May	1	3.0	3.0	3.0	12	1.0	1.1	1.2	3	2.9	3.1	3.1
1-7 Jun	17	1.8	2.2	3.0	6	1.0	1.0	1.1	7	2.5	2.8	3.3
8-14 Jun	24	1.8	2.0	2.2	7	1.0	1.0	1.0	13	2.6	2.7	2.9
	Migration rate (km/d)											
30 Mar-5 Apr	3	10.5	11.4	18.1	2	44.3	48.1	52.8	12	29.1	31.8	42.2
6-12 Apr	1	4.6	4.6	4.6	4	39.2	49.3	50.4	12	32.4	41.9	49.4
13-19 Apr	3	22.6	25.3	32.5	6	48.7	55.7	61.7	8	38.6	43.5	57.7
20-26 Apr	6	30.2	32.7	36.5	15	55.4	62.8	68.1	40	45.9	51.2	57.6
27 Apr-3 May	4	30.4	32.1	36.5	25	61.1	66.1	72.4	15	48.9	52.7	58.1
4-10 May	2	28.3	31.9	36.5	21	62.8	66.5	72.9	13	54.9	57.4	60.2
11-17 May	3	34.6	41.1	50.8	16	61.1	68.9	74.8	25	56.2	60.4	67.2
18-24 May	0	-	-	-	18	74.3	86.3	91.9	1	74.7	74.7	74.7
25-31 May	1	41.0	41.0	41.0	12	95.0	101.8	108.7	3	76.1	76.1	80.8
1-7 Jun	17	41.3	56.2	66.8	6	107.6	114.1	118.9	7	71.5	82.8	96.3
8-14 Jun	24	56.7	60.3	69.9	7	108.7	115.3	118.9	13	81.4	88.1	91.5

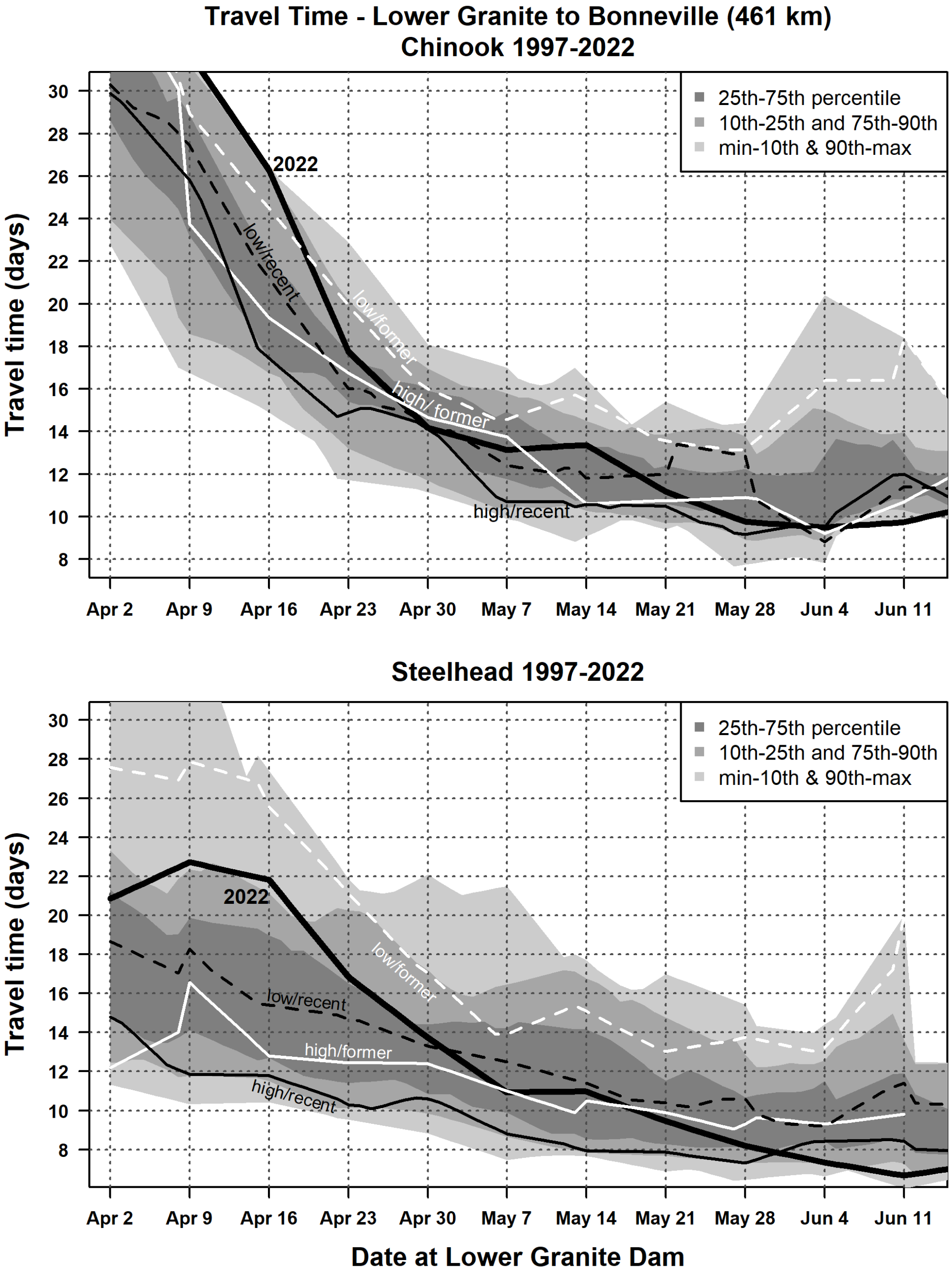


Figure 2. Median travel time (d) from Lower Granite to Bonneville Dam (461 km) vs. date passing Lower Granite Dam for yearling Chinook salmon and juvenile steelhead. Shaded regions show daily quantiles during 1997-2022 (excluding 2001). Lines show daily medians for subsets of years classified by flow level and spill regime: broken lines show low-flow years during the former (white: 2004, 2005) and present spill regimes (black: 2007, 2010, 2013, 2015, 2021); solid lines show high-flow years during the former (white: 1997, 2006) and present spill regimes (black: 2011, 2012, 2017, 2018, 2019).

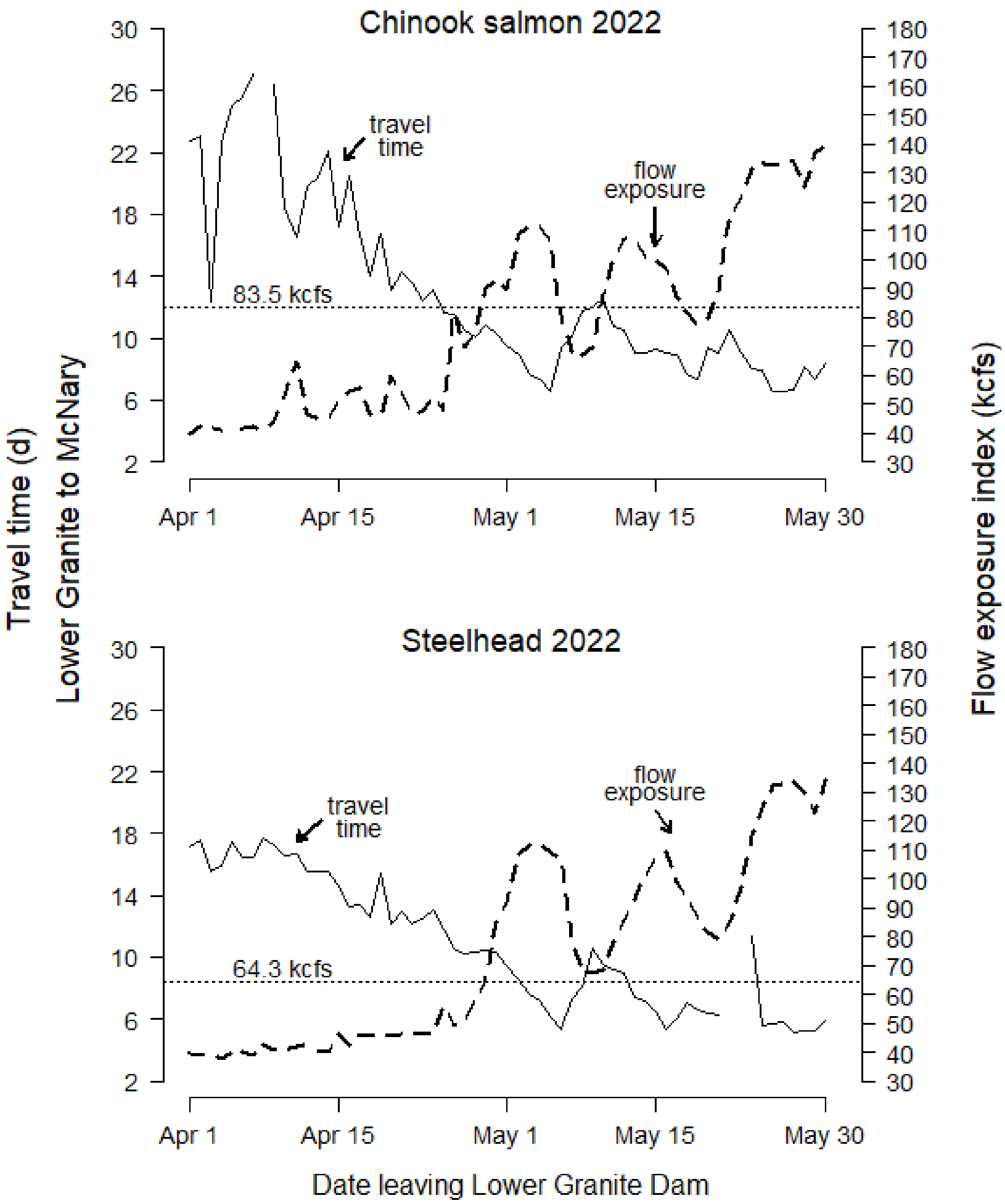


Figure 3. Median travel time (d) from Lower Granite to McNary Dam and index of flow exposure at Little Goose Dam (kcfs) for daily groups of PIT-tagged yearling Chinook salmon and juvenile steelhead during 2022. Dashed horizontal lines represent the mean flow exposure index for the year weighted by the number of PIT-tagged fish in each daily group.

Proportion Transported of Spring Migrants

Methods

To estimate the proportion of fish in the run-at-large that were transported, we required estimates of the following quantities:

1. Total number of fish passing Lower Granite Dam each day
2. Probabilities of entering the juvenile bypass systems at Little Goose and Lower Monumental Dam for daily groups of fish from Lower Granite Dam
3. Proportions of fish collected each day at each dam that were transported

These estimates were then combined to derive the overall estimated proportion of fish transported across the season.

We made estimates of the proportion transported separately by species and origin, and the process we used for each stock is detailed step-by-step below. For each of the three types of quantities, steps include data sources, calculations, key assumptions, and other underlying concepts.

Total number of fish passing Lower Granite Dam each day

1a. Acquire the Lower Granite Dam smolt report from the Smolt Monitoring Program (FPC 2021a) and extract daily "collection counts," which are counts of sampled fish expanded by sampling fraction. Collection counts estimate the total number of fish, tagged and non-tagged, that entered the juvenile bypass system each day.

1b. Use PIT-tag detection data to derive daily estimates of the probability of entering the juvenile bypass system at Lower Granite Dam, following the methods of Sandford and Smith (2002).

1c. For each day, divide the collection count by the estimated probability of entering the juvenile bypass system to get an estimate of the total number of fish (tagged and non-tagged) that passed Lower Granite Dam on that day. Subtract the collection count from the estimated total number passing for an estimate of the number of fish that were not subject to transportation because they passed via routes other than the juvenile bypass system.

A spillway detection system was installed at Lower Granite Dam in 2020. The system continued to operate in 2022, and estimated detection probabilities reported here (Appendix Tables B4, B8, B10) were derived from combined detections in spillway and bypass systems. However, the efficiency of the spillway system is not known precisely, nor is the degree of variation throughout the season. Thus, detections by the spillway system cannot be interpreted as counts of the number of PIT-tagged fish that passed via that route. Moreover, it is impossible to sample fish passing via spillway, and therefore no analog of the bypass collection count is available.

In contrast, detection efficiency in the juvenile bypass system is known to be nearly 100%; i.e., almost every tagged fish that enters is detected at least once in the system. Thus, to estimate proportion transported, we used detection data only from the bypass system, and we assumed that estimated daily detection probability estimates were equivalent to the probability of entering the bypass system.

Probabilities of entering the juvenile bypass systems at Little Goose and Lower Monumental Dam for daily groups of fish from Lower Granite Dam

2. For each daily group arriving at Lower Granite Dam (all passage routes), estimate the proportion that first entered a juvenile bypass system at (i) Lower Granite, (ii) Little Goose, or (iii) Lower Monumental Dam or that (iv) did not enter a juvenile bypass system at any of the three collector dams.

    2a. For each daily group of PIT-tagged fish detected in the bypass system at Lower Granite Dam and returned to the river, tabulate the number that were next detected at Little Goose Dam and the number that passed Little Goose undetected but entered the juvenile bypass at Lower Monumental Dam.

    2b. Translate these counts into Lower Granite *equivalents*. An equivalent is the result of an adjustment of a count at a downstream dam. For a group of fish that have a given trait—in this case a particular history of detection—that can be counted at a downstream dam, the Lower Granite equivalent is an estimate of the number of fish with that trait that passed Lower Granite Dam in order to realize the downstream count.

    2c. Assume that for non-tagged fish arriving at Lower Granite Dam on a given day, the proportion that first enters a bypass system at each dam is the same as that for PIT-tagged fish arriving at Lower Granite on that same day. These proportions are estimated from tagged fish that were detected at Lower Granite Dam, and therefore have a known passage date there. The estimated proportions are assumed to apply to all fish in the run-at-large, including the estimated numbers that passed Lower Granite Dam by routes other than bypass system.

Proportions of fish collected each day at each dam that were transported

3a. Acquire smolt transportation reports for Lower Granite, Little Goose, and Lower Monumental Dams from the Smolt Monitoring Program (FPC 2021b). For each day at each dam, calculate the proportion of collected smolts that were transported.

3b. For each daily group of fish arriving at Lower Granite Dam, estimate the proportion that entered the juvenile bypass system at each collector dam *and* were transported from that dam.

For groups arriving at Lower Granite Dam after the respective starting dates of the general transportation program at each collector dam, the proportion transported from those that entered the bypass system at each dam is almost always nearly 100%. There can be short, intermittent disruptions, usually resulting from unforeseen circumstances.

For daily groups arriving at Lower Granite Dam before the general transportation starting date, the estimated proportion that is eventually transported depends on travel-time distributions to downstream collector dams. These distributions determine the proportions from each group that arrive at each downstream dam after transportation has started. Travel-time distributions change throughout the season. For example, fish that arrive earlier at Lower Granite Dam tend to take more time to arrive at downstream dams.

To estimate downstream arrival distributions for a daily group of run-at-large fish, we assumed they had the same travel-time distributions as those observed for PIT-tagged fish detected at Lower Granite Dam on the same day.

Combine estimates to derive the proportion of smolts transported over the entire season

4. For each daily group of the run-at-large, calculate the product of the estimated quantities from steps 1-3:
   - Number of fish in the group passing Lower Granite Dam that day (step 1)
   - Proportion of fish first entering the bypass system at each dam (step 2)
   - Proportion of fish entering the bypass system that were transported (step 3).

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

5. Sum all daily estimated numbers transported and divide by the total population estimate (sum of estimated daily number passing Lower Granite Dam) to derive the overall estimated proportion transported for the season.

Results

In 2022, collection for transportation began at 07:00 on 23 April at Lower Granite, Little Goose, and Lower Monumental Dams, and the first barge departed on 24 April. Before that time, smolts collected in the juvenile bypass systems at Snake River dams were returned to the tailrace of the dam.

Estimated percentages of non-tagged yearling Chinook transported during the entire 2022 season were 30.6% for wild and 23.9% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 38.7% for wild and 24.0% for hatchery smolts. These estimates represented the proportion of smolts arriving at Lower Granite Dam that were subsequently transported, either from Lower Granite or from one of the downstream collector dams. The proportion of smolts transported in 2022 was below average, but substantially higher than in 2020 or 2021 (Figure 4; Table 21).

Before 2006, collected fish were transported throughout the season, starting from the first day on which the collection system was supplied with water. Between 2006 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 than at Lower Granite Dam). Since 2014, transportation has begun simultaneously at all three collector dams, and this schedule was followed in 2022.

In any given year, the percentage of a stock transported is largely determined by a combination of three factors: (1) migration timing, (2) the starting date of general smolt transportation, and (3) the percentage of smolts that enter the juvenile bypass system during the transportation period. In 2022, collection for transportation began on 23 April. The transportation program has started on or about 24 April since 2018, so the start date in 2022 was typical of recent years. The overall transportation rate was somewhat below average in 2022, though higher than in 2020 or 2021. Given the typical start date, possible causes of a below-average rate in 2022 are an early run, low collection rates in the juvenile bypass, or both.

However, the run in 2022 was very late for both Chinook and steelhead. We estimated that only 14.1% of wild and 7.2% of hatchery Chinook salmon, and 2.3% of wild and 12.9% of hatchery steelhead had passed Lower Granite prior to the start of transportation. These numbers were much lower than in other recent years, particularly 2020 and 2021. A late run is expected to contribute to increased transportation rates because a greater share of the population is available to be transported.

In 2022, the proportion of passing smolts collected after the start of transportation was below average but far higher than in 2020 or 2021. We estimated that 25.4% of wild and 34.9% of hatchery Chinook and 25.9% of wild and 39.6% of hatchery steelhead that passed during transport operations were collected in the juvenile bypass and transported. These collection rates are about 10-15% less than the 2007-2022 average. The difference in proportion of transported fish between origin resulted from a difference in the probability of entering the juvenile bypass system.

While a late run means that more fish arrive at dams after general transportation has begun, low collection rates result in a lower transportation rate. The combination of both of these factors in 2022 offset each other, and the end result was an overall transportation rate that was slightly below the 2007-2022 average.

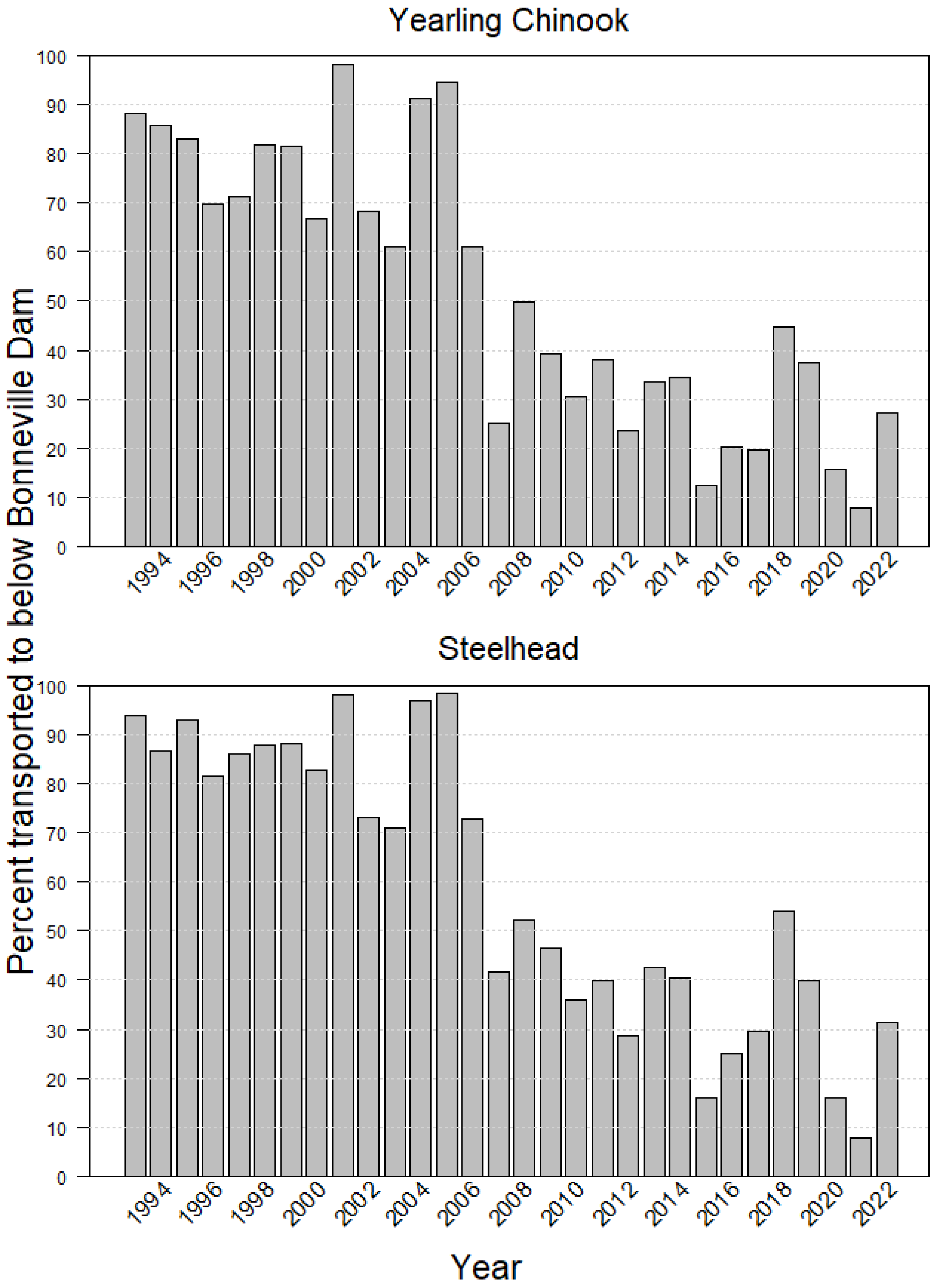


Figure 4. Annual estimated percentages of Snake River yearling Chinook salmon and juvenile steelhead arriving at Lower Granite Dam that were subsequently collected for transportation and released downstream of Bonneville Dam (mean of estimates for hatchery and wild fish), 1993-2022.

Table 21. Annual estimated percentages of Snake River yearling Chinook and juvenile steelhead arriving at Lower Granite Dam that were transported from a collector dam and released downstream of Bonneville Dam. Estimates are for hatchery and wild groups and the mean of the two, 1993-2022. Simple arithmetic means are given across all years and for periods with similar transportation schedules (1993-2006 and 2007-2022).

	Estimated percentages of fish transported, 1993-2022 (%)					
	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
2020	12.5	18.8	15.7	11.7	20.5	16.1
2021	5.9	9.8	7.9	4.3	11.1	7.7
2022	23.9	30.6	27.3	24.0	38.7	31.4
Mean						
1993-2022	**50.6**	**53.6**	**52.1**	**55.8**	**61.2**	**58.5**
1993-2006	**76.7**	**80.9**	**78.8**	**86.0**	**86.7**	**86.4**
2007-2022	**27.7**	**29.8**	**28.7**	**29.4**	**38.9**	**34.2**

Comparisons Among Annual Estimates

Comparison Among Years

We made two types of comparisons between annual survival estimates from 2022 and those from the previous 29 study years. First, we compared estimated survival to Lower Granite Dam with distance of the respective hatcheries from the dam for Snake River hatchery yearling Chinook.

Second, for Snake and Columbia River yearling Chinook, steelhead, and sockeye, we compared estimates of mean annual survival through specific reaches in 2022 to those in all previous study years for which these data were available.

We also compared detection probability estimates in 2022 to those from previous study years. For all yearling Chinook salmon released upstream from Lower Granite Dam in 2022, we calculated annual mean detection probability at three major Snake River dams and three major lower Columbia River dams. We compared these estimates to annual mean detection probability estimates for the same stocks at the same dams in the years 1998-2022.

Snake River Stocks

Yearling Chinook Salmon**—**For yearling Chinook salmon, estimated survival to Lower Granite Dam was above average for fish from a majority of hatcheries in 2022, with below-average survival estimated only for fish from Lookingglass and Pahsimeroi Hatchery (Table 22). Dworshak and Sawtooth Hatchery fish had the highest survival on record for those hatcheries. In 2021, an outbreak of bacterial kidney disease at Pahsimeroi Hatchery resulted in low survival, but in 2022, survival of Pahsimeroi fish was only moderately below average.

Over the years of the study, we have consistently observed an inverse relationship between estimated survival and distance from the release site to Lower Granite Dam. This relationship is illustrated in Figure 5 for hatchery yearling Chinook salmon, using mean estimated survival across years ($R^2 = 0.815$, $P = 0.005$).

Table 22. Survival probability estimates from release to Lower Granite Dam for groups of yearling Chinook salmon released from selected Snake River Basin hatcheries, 1993-2022. 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)

Table 22. Continued.

	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
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)	0.545 (0.050)
2020	0.811 (0.011)	0.747 (0.029)	0.629 (0.017)	0.567 (0.010)	0.733 (0.011)	0.559 (0.018)	0.681 (0.020)	0.675 (0.036)
2021	0.784 (0.012)	0.808 (0.041)	0.757 (0.026)	0.631 (0.011)	0.783 (0.012)	0.287 (0.012)	0.637 (0.016)	0.670 (0.069)
2022	0.911 (0.015)	0.748 (0.034)	0.639 (0.024)	0.737 (0.010)	0.732 (0.012)	0.468 (0.012)	0.706 (0.018)	0.706 (0.050)
Mean	**0.775 (0.013)**	**0.670 (0.016)**	**0.658 (0.009)**	**0.692 (0.018)**	**0.617 (0.015)**	**0.522 (0.031)**	**0.494 (0.030)**	**0.633 (0.011)**

* Released at Imnaha River Weir.

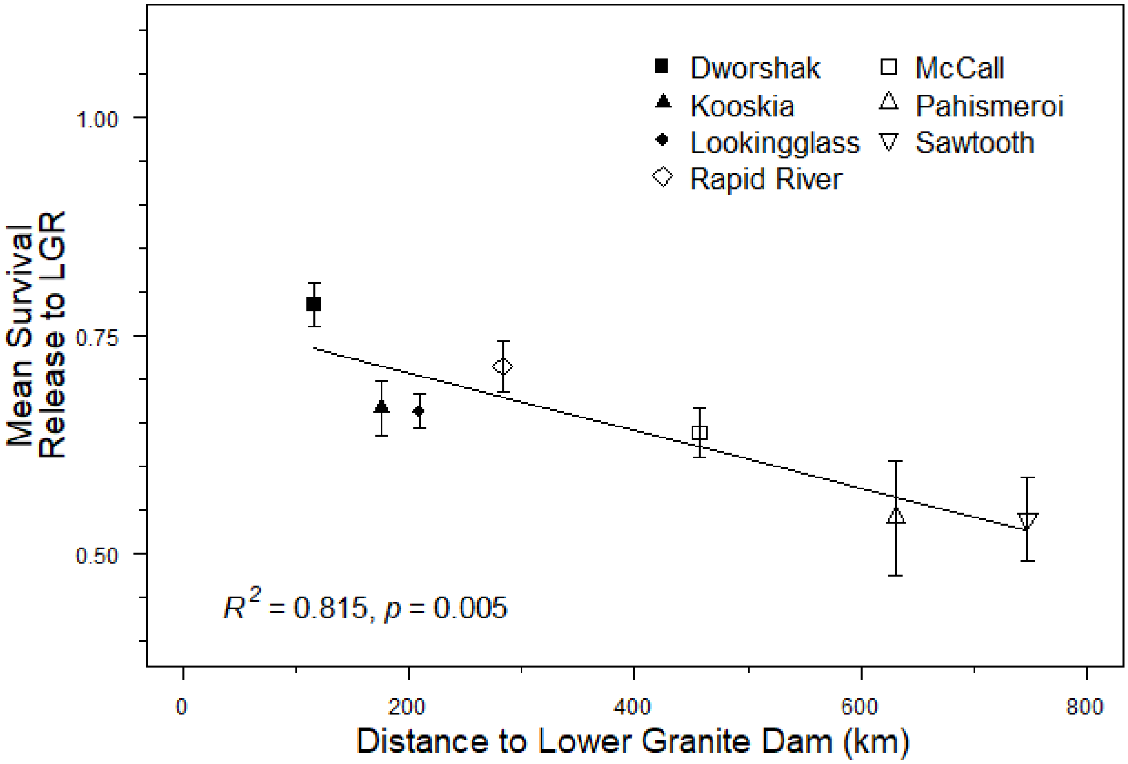


Figure 5. Mean estimated survival probability of yearling Chinook from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2022, vs. distance (km) from release to Lower Granite Dam. The coefficient of determination between survival and migration distance is also shown, along with the *P*-value for a test of the null hypothesis of zero correlation. Whiskers are 95% confidence intervals.

For combined wild and hatchery yearling Chinook salmon in 2022, mean estimated survival was 0.709 (95% CI 0.558-0.860) from Lower Granite to McNary Dam and 0.689 (0.560-0.818) from McNary to Bonneville Dam (Tables 23-24; Figures 6-7). The estimate from Lower Granite to McNary Dam was moderately below the long-term mean of 0.734, but the difference was not statistically significant (*P* = 0.75). The estimate from McNary to Bonneville was slightly below the long-term mean of 0.704, but again, the difference was not significant (*P* = 0.82). The overall estimate from Lower Granite to Bonneville Dam was 0.528, which was nearly equal to the long-term mean of 0.524 and not significantly different from it (*P* = 0.89).

For combined wild and hatchery yearling Chinook salmon in 2022, mean estimated survival from the Snake River Smolt Trap to the tailrace of Bonneville Dam was 0.508 (95% CI 0.423-0.594; Table 24). This estimate was above the long-term mean of 0.485 as well as the estimate from 2021 of 0.471, although it was not significantly different from either (*P* = 0.60, 0.71 respectively).

For wild Chinook smolts, we did not have sufficient data to estimate survival for biweekly groups. Instead, we used a single pooled group of all wild fish released upstream from Lower Granite Dam and detected passing the dam plus those tagged at the dam. Using this method for wild yearling Chinook salmon in 2022, estimated survival from Lower Granite to McNary Dam was 0.631 (95% CI 0.502-0.760). This estimate was below but not significantly different from the long-term average of 0.715 (Table 25; *P* = 0.19).

For these wild Chinook salmon, estimated survival from McNary to Bonneville Dam was 0.824 (95% CI 0.538-1.110), which was substantially higher than the long-term average of 0.656 (Table 25). However, due to the uncertainty in this estimate, the difference was not significant (*P* = 0.24).

For this same pooled group of wild Chinook, estimated survival from Lower Granite to Bonneville Dam was 0.520 (95% CI 0.373-0.667; Table 25), which was above the long-term average of 0.475 but not significantly different from it, again due to the poor precision of the estimate (*P* = 0.55).

Though only 121 wild Chinook were tagged at the Snake River Smolt Trap in 2022, we were able to use these fish to estimate survival between the trap and Lower Granite Dam. For these fish, mean estimated survival from the trap to Bonneville Dam was 0.611 (0.270-0.955), which was well above the long-term mean of 0.447 but not significantly different from it due to the extremely poor precision of the estimate (*P* = 0.33).

Table 23. Annual survival probability estimates from the Snake River Smolt Trap to Bonneville Dam for Snake River yearling Chinook salmon (combined hatchery and wild fish), 1993-2022. Shaded columns are reaches that comprise two dams and reservoirs; the following column gives the square root of the two-project estimate to facilitate comparison with one-project estimates. Standard errors in parentheses. Simple arithmetic means across all available years 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
1993	0.828 (0.013)	0.854 (0.012)	NA	NA	NA	NA	NA	NA
1994	0.935 (0.023)	0.830 (0.009)	0.847 (0.010)	NA	NA	NA	NA	NA
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

Table 23. Continued.

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
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
2020	0.848 (0.058)	0.811 (0.039)	1.171 (0.128)	0.847 (0.095)	0.920	0.862 (0.039)*	0.865 (0.060)*	0.930*
2021	0.867 (0.108)	0.806 (0.067)	1.136 (0.127)	0.854 (0.146)	0.924	0.960 (0.077)*	0.796 (0.096)*	0.892*
2022	0.963 (0.072)	0.823 (0.035)	1.014 (0.059)	0.869 (0.138)	0.932	0.806 (0.087)*	0.892 (0.077)*	0.944*
Mean	**0.920 (0.009)**	**0.915 (0.009)**	**0.942 (0.014)**	**0.860 (0.010)**	**0.927 (0.006)**	**0.868 (0.017)**	**0.811 (0.020)**	**0.899 (0.011)**

* Estimates for 2020-2022 in the reaches between McNary Dam and Bonneville Dam used a different method than in previous years.

Table 24. Annual survival probability estimates through the entire hydropower system, and through component river reaches for Snake River yearling Chinook salmon (combined hatchery and wild fish), 1993–2022. Standard errors in parentheses. Simple arithmetic means across all available years are given.

	Annual survival estimates for hatchery and wild yearling Chinook (SE)				
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1993	0.828 (0.013)	NA	NA	NA	NA
1994	0.935 (0.023)	NA	NA	NA	NA
1995	0.905 (0.010)	0.715 (0.031)	NA	NA	NA
1996	0.977 (0.025)	0.648 (0.026)	NA	NA	NA
1997	NA	0.653 (0.072)	NA	NA	NA
1998	0.924 (0.011)	0.770 (0.009)	NA	NA	NA
1999	0.940 (0.009)	0.792 (0.006)	0.704 (0.058)	0.557 (0.046)	0.524 (0.043)
2000	0.929 (0.014)	0.760 (0.012)	0.640 (0.122)	0.486 (0.093)	0.452 (0.087)
2001	0.954 (0.015)	0.556 (0.009)	0.501 (0.027)	0.279 (0.016)	0.266 (0.016)
2002	0.953 (0.022)	0.757 (0.009)	0.763 (0.079)	0.578 (0.060)	0.551 (0.059)
2003	0.993 (0.023)	0.731 (0.010)	0.728 (0.030)	0.532 (0.023)	0.528 (0.026)
2004	0.893 (0.009)	0.666 (0.011)	0.594 (0.074)	0.395 (0.050)	0.353 (0.045)
2005	0.919 (0.015)	0.732 (0.009)	0.788 (0.093)	0.577 (0.068)	0.530 (0.063)
2006	0.952 (0.011)	0.764 (0.007)	0.842 (0.021)	0.643 (0.017)	0.612 (0.018)
2007	0.943 (0.028)	0.783 (0.006)	0.763 (0.044)	0.597 (0.035)	0.563 (0.037)
2008	0.992 (0.018)	0.782 (0.011)	0.594 (0.066)	0.465 (0.052)	0.460 (0.052)
2009	0.958 (0.010)	0.787 (0.007)	0.705 (0.031)	0.555 (0.025)	0.531 (0.025)
2010	0.968 (0.040)	0.772 (0.012)	0.738 (0.039)	0.569 (0.032)	0.551 (0.038)
2011	0.943 (0.009)	0.746 (0.010)	0.687 (0.065)	0.513 (0.049)	0.483 (0.046)
2012	0.928 (0.012)	0.790 (0.016)	0.802 (0.051)	0.634 (0.042)	0.588 (0.040)

Table 24. Continued.

	Annual survival estimates for hatchery and wild yearling Chinook (SE)				
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
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)
2020	0.848 (0.058)	0.766 (0.018)	0.733 (0.045)*	0.563 (0.039)	0.477 (0.046)
2021	0.867 (0.108)	0.730 (0.026)	0.746 (0.112)*	0.543 (0.085)	0.471 (0.094)
2022	0.963 (0.072)	0.709 (0.077)	0.689 (0.066)*	0.528 (0.022)	0.508 (0.044)
Mean	**0.920 (0.009)**	**0.734 (0.011)**	**0.704 (0.017)**	**0.524 (0.017)**	**0.485 (0.017)**

* The estimates for 2020-2022 for the reach between McNary Dam and Bonneville Dam used a different method than in previous years.

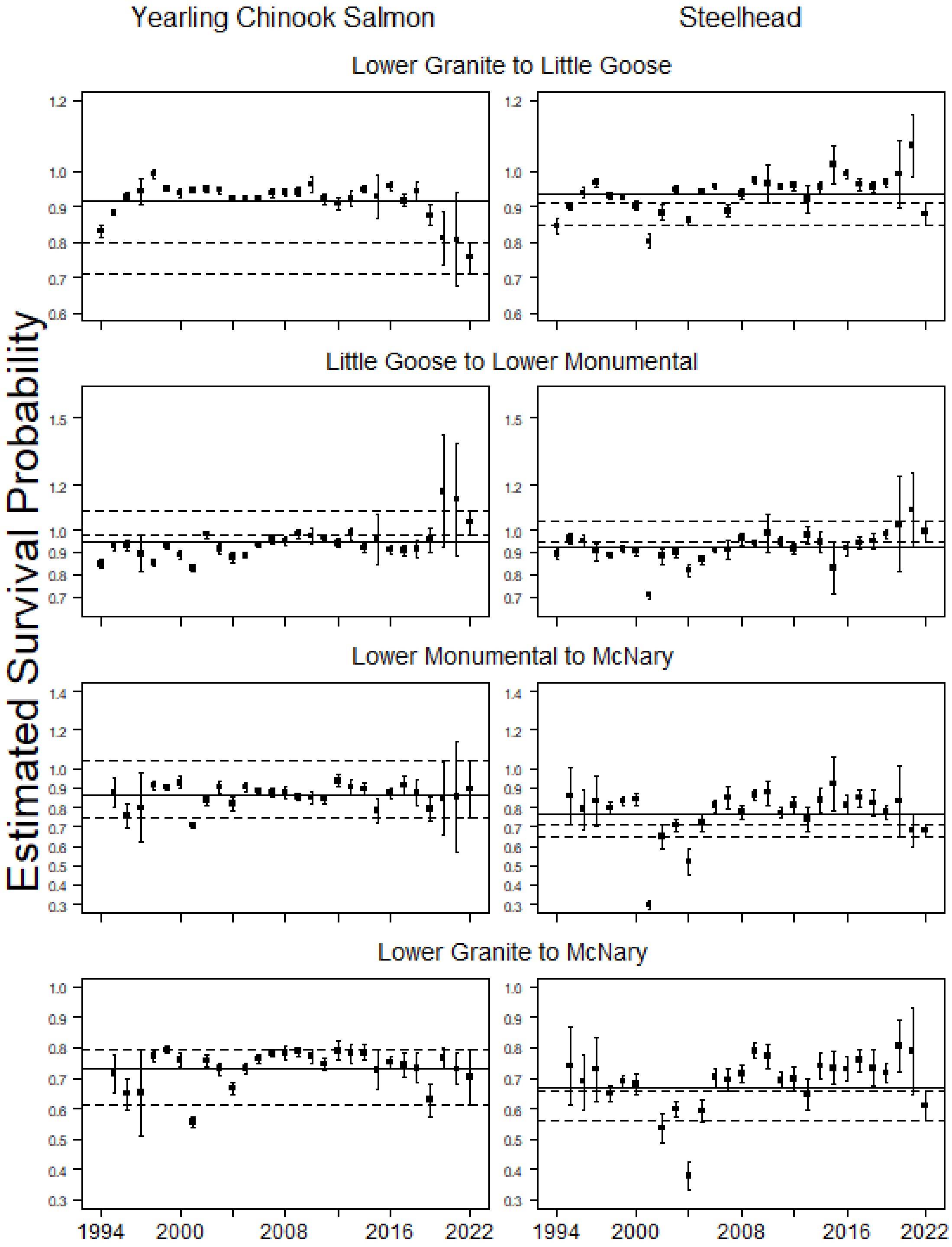


Figure 6. Annual survival probability estimates through Snake River reaches for Snake River yearling Chinook salmon and juvenile steelhead (combined hatchery and wild fish), 1993-2022. Whiskers represent 95% CIs. Dashed lines indicate 95% CI endpoints for 2022 estimates; solid lines indicate long-term means (1993-2022).

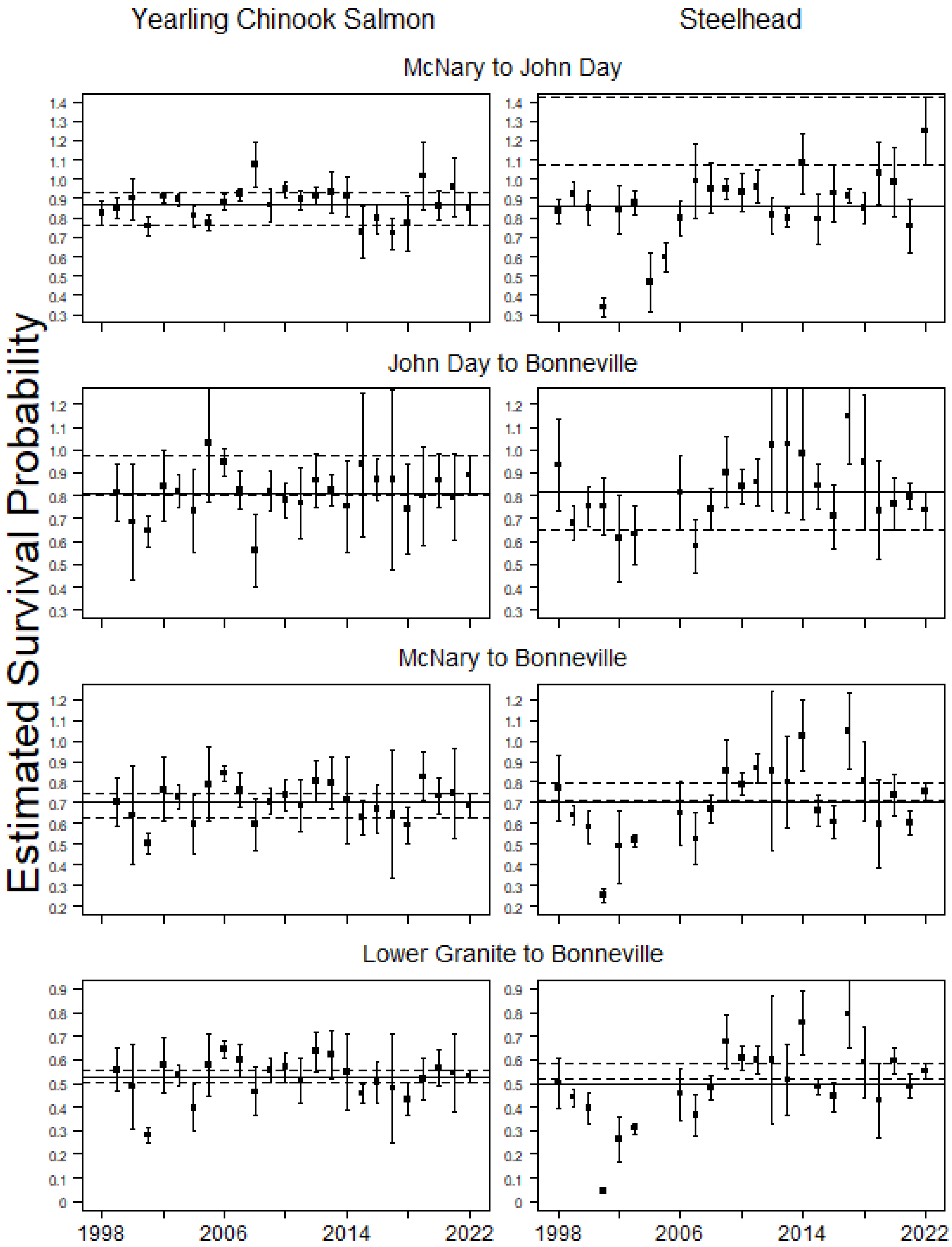


Figure 7. Annual survival probability estimates through Columbia River reaches and from Lower Granite to Bonneville Dam for Snake River yearling Chinook and juvenile steelhead (combined hatchery and wild fish), 1993-2022. Whiskers represent 95% CIs. Dashed lines indicate 95% CI endpoints for 2022 estimates; solid lines indicate long-term means (1993-2022).

Table 25. Annual survival probability estimates through the entire hydropower system, and through component river reaches for Snake River yearling Chinook salmon (wild fish only), 1993–2022. Standard errors in parentheses. Simple arithmetic means across all available years are given.

Annual survival estimates for wild yearling Chinook

Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1993	0.847 (0.024)	NA	NA	NA	NA
1994	0.913 (0.036)	NA	NA	NA	NA
1995	0.944 (0.015)	0.697 (0.097)	NA	NA	NA
1996	0.984 (0.039)	0.574 (0.059)	NA	NA	NA
1997	NA	NA	NA	NA	NA
1998	0.915 (0.019)	0.771 (0.015)	NA	NA	NA
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)

Table 25. Continued.

	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
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)
2020	0.703 (0.111)[a]	0.674 (0.073)	0.463 (0.145)	0.312 (0.103)	0.219 (0.081)
2021	NA	0.673 (0.053)	0.533 (0.117)	0.359 (0.074)	NA
2022	1.175 (0.292)[b]	0.631 (0.066)	0.824 (0.146)	0.520 (0.075)	0.611 (0.176)
Mean	**0.917 (0.016)**	**0.715 (0.013)**	**0.656 (0.031)**	**0.475 (0.025)**	**0.447 (0.026)**

a. Based on a sample size of just 69 tagged fish.
b. Based on a sample size of just 121 tagged fish.

Steelhead—For combined wild and hatchery steelhead, mean estimated survival from Lower Granite to McNary Dam was 0.610 (95% CI 0.502-0.718) in 2022, which was significantly lower than the 2021 estimate of 0.788 ($P = 0.05$; Tables 26-27; Figures 6-7). This estimate was also lower than the long-term average of 0.670, but not significantly different from it ($P = 0.30$).

Mean estimated survival from McNary to Bonneville Dam for wild and hatchery Snake River steelhead was 0.757 (0.665-0.849) in 2022, which was much higher than the estimate of 0.602 in 2021, and the difference was significant ($P < 0.01$). The 2022 estimate was also higher than the long-term average of 0.697, but the difference was not statistically significant ($P = 0.30$).

Estimated survival from the Snake River Smolt Trap to Bonneville Dam for combined wild and hatchery steelhead was 0.520 (0.446-0.594; Table 27), which was higher than both the estimate of 0.456 from 2021 and the long-term average of 0.463. The difference between estimates for 2021 vs. 2022 was not significant ($P = 0.17$), and the difference between the estimates for 2022 vs. the long-term average was also not significant ($P = 0.24$).

For wild steelhead smolts, we did not have sufficient data to estimate survival for biweekly groups. Instead, we used a single pooled group of all wild fish released upstream from Lower Granite Dam and detected passing the dam plus those tagged at the dam. Using this method, estimated survival for wild steelhead in 2022 was 0.438 (95% CI 0.332-0.544; Table 28) from Lower Granite to McNary Dam. This estimate was significantly below the long-term average of 0.646 ($P < 0.01$). Estimated survival for wild steelhead from McNary to Bonneville Dam was 1.190 (0.776-1.604), which was far above the long-term average of 0.651 and significantly different from it ($P < 0.01$).

Estimated survival for wild steelhead from the Snake River Smolt Trap to Bonneville Dam in 2022 was 0.500 (95% CI 0.344-0.657; Table 28), which was higher than the long-term average of 0.424. However, the difference was not significant ($P = 0.36$).

Table 26. Annual survival probability estimates from Snake River Smolt Trap to Bonneville Dam for Snake River juvenile steelhead (combined hatchery and wild fish), 1993–2022. Shaded columns are reaches that comprise two dams and reservoirs; the following column gives the square root of the two-project estimate to facilitate comparison with one-project estimates. Standard errors in parentheses. Simple arithmetic means across all available years 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
1993	0.905 (0.006)	NA	NA	NA	NA	NA	NA	NA
1994	0.794 (0.009)	0.844 (0.011)	0.892 (0.011)	NA	NA	NA	NA	NA
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

Table 26. Continued.

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
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)	1.145 (0.104)	1.070
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
2020	0.914 (0.041)	0.991 (0.049)	1.025 (0.109)	0.834 (0.092)	0.913	0.985 (0.090)*	0.762 (0.057)*	0.873*
2021	0.936 (0.029)	1.070 (0.045)	1.089 (0.083)	0.681 (0.043)	0.825	0.757 (0.071)*	0.795 (0.029)*	0.892*
2022	0.940 (0.023)	0.881 (0.027)	0.992 (0.043)	0.681 (0.034)	0.825	1.265 (0.198)*	0.737 (0.091)*	0.858*
Mean	**0.950 (0.009)**	**0.937 (0.010)**	**0.925 (0.013)**	**0.770 (0.024)**	**0.874 (0.015)**	**0.860 (0.037)**	**0.817 (0.030)**	**0.901 (0.016)**

* Estimates for 2020-2022 in the reaches between McNary Dam and Bonneville Dam used a different method than in previous years.

Table 27. Annual survival probability estimates through the entire hydropower system, and through component river reaches for Snake River juvenile steelhead (combined hatchery and wild fish), 1993-2022. Standard errors in parentheses. Simple arithmetic means across all available years are given.

Annual survival estimates for hatchery and wild steelhead

Year	Snake River Smolt Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1993	0.905 (0.006)	NA	NA	NA	NA
1994	0.794 (0.009)	NA	NA	NA	NA
1995	0.945 (0.008)	0.739 (0.066)	NA	NA	NA
1996	0.951 (0.015)	0.688 (0.046)	NA	NA	NA
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)

Table 27. Continued.

	Annual survival estimates for hatchery and wild steelhead				
Year	Snake River Smolt Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
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)	1.045 (0.095)	0.793 (0.075)	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 (0.027)	0.717 (0.017)	0.595 (0.109)	0.427 (0.079)	0.412 (0.077)
2020	0.914 (0.041)	0.807 (0.043)	0.738 (0.052)*	0.595 (0.027)	0.544 (0.035)
2021	0.936 (0.029)	0.788 (0.073)	0.602 (0.029)*	0.487 (0.026)	0.456 (0.028)
2022	0.940 (0.023)	0.610 (0.055)	0.757 (0.047)*	0.553 (0.038)	0.520 (0.038)
Mean	**0.950 (0.009)**	**0.670 (0.025)**	**0.697 (0.036)**	**0.493 (0.032)**	**0.463 (0.032)**

* The 2020-2022 estimates for the reach between McNary and Bonneville Dam used a different method than in previous years.

Table 28. Annual survival probability estimates through the entire hydropower system, and through component river reaches for Snake River juvenile steelhead (wild fish only), 1993–2022. Standard errors in parentheses. Simple arithmetic means across all available years are given.

	Annual survival estimates for wild steelhead				
Year	Snake River Smolt Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1993	0.898 (0.009)	NA	NA	NA	NA
1994	0.844 (0.011)	NA	NA	NA	NA
1995	0.955 (0.013)	NA	NA	NA	NA
1996	0.973 (0.022)	NA	NA	NA	NA
1997	0.968 (0.051)	NA	NA	NA	NA
1998	0.919 (0.017)	0.698 (0.030)	NA	NA	NA
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

Table 28. Continued.

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
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)
2020	0.802 (0.109)[a]	NA	NA	NA	NA
2021	1.079 (0.141)[b]	0.624 (0.074)	0.605 (0.073)[c]	0.389 (0.037)	0.450 (0.079)
2022	0.958 (0.091)	0.438 (0.054)	1.190 (0.211)	0.522 (0.067)	0.500 (0.080)
Mean	**0.950 (0.012)**	**0.646 (0.029)**	**0.651 (0.049)**	**0.434 (0.032)**	**0.424 (0.032)**

a. Based on a sample size of just 124 tagged fish.

b. Based on a sample size of just 290 tagged fish.

c. The 2021 estimate for the reach between McNary and Bonneville Dam used a different method than in previous years.

Sockeye Salmon—For pooled groups of wild and hatchery Snake River sockeye salmon, estimated survival from Lower Granite to McNary Dam was 1.059 in 2022 (95% CI 0.748-1.498; Table 29). This estimate was well above both the 2021 estimate of 0.817 and the long-term average of 0.667 (1996-2022). However, the survival estimate from McNary to Bonneville Dam was 0.412 (0.274-0.620), which was well below the long-term average of 0.551. For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.436 (0.348-0.545) in 2022. This estimate was slightly above the long-term average of 0.408.

Table 29. Annual survival probability estimates for Snake River juvenile sockeye salmon (combined hatchery and wild fish) in reaches from Lower Granite to Bonneville Dam, 1996-2022. Standard errors in parentheses. Simple arithmetic means across all available years are given.

	Annual survival estimates for Snake River sockeye		
Year	Lower Granite to McNary Dam	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)
2020	0.803 (0.111)	0.546 (0.149)	0.439 (0.104)
2021	0.817 (0.094)	0.452 (0.067)	0.369 (0.034)
2022	1.059 (0.189)	0.412 (0.087)	0.436 (0.050)
Mean	**0.667 (0.035)**	**0.551 (0.058)**	**0.408 (0.042)**

Upper Columbia River Stocks

Sockeye Salmon—In past years, we have reported survival from Rock Island to Bonneville Dam for sockeye from the upper Columbia River. However, tagging operations at Rock Island Dam were discontinued after 2021. Thus, we are no longer able to estimate survival for that reach.

The longest continuing time series of PIT-tagged sockeye releases in the upper Columbia is that of fish released from the lower Wenatchee River screw trap. We have survival estimates (previously unpublished) from this release site starting in 2014. We have selected this series as the one to carry forward for upper Columbia River sockeye, and we will publish estimates for this stock henceforth (Table 30).

For Upper Columbia River sockeye salmon captured, tagged, and released from the lower Wenatchee River smolt trap in 2022, estimated survival to McNary Dam was 0.434 (95% CI 0.293-0.643; Table 30). This estimate was well below the estimate from 2021 of 0.642; however, it was only slightly lower than the long-term average of 0.488.

Estimated survival between McNary and Bonneville Dam for upper Columbia River sockeye was 1.006 (0.478-2.117), which was substantially above the long-term average of 0.700, but extremely imprecise. Estimated survival of sockeye from the lower Wenatchee River smolt trap to Bonneville Dam in 2022 was 0.458 (0.188-1.115). This estimate was higher than the 2021 estimate of 0.361 and the long-term average of 0.257. However, this estimate was also very imprecise.

Yearling Chinook Salmon—For pooled groups of hatchery yearling Chinook from the Upper Columbia Basin, estimated survival in 2022 from McNary to Bonneville Dam was 0.772 (95% CI 0.630-0.945), which was below the 1999-2022 average of 0.801 but not significantly different from it (P = 0.72; Table 31).

Steelhead—For pooled groups of hatchery steelhead from the Upper Columbia Basin, estimated survival from McNary to Bonneville Dam in 2022 was 0.897 (95% CI 0.695-1.157). This estimate was well above the long-term average of 0.760 but not significantly different from it due to the poor precision of the estimate (P = 0.25; Table 31).

Table 30. Annual survival probability estimates for Columbia River juvenile sockeye salmon (combined hatchery and wild fish) in reaches from Lower Wenatchee to Bonneville Dam, 1998-2022. Standard errors in parentheses. Simple arithmetic means across all available years are given.

	Annual survival estimates for upper Columbia River sockeye		
	Lower Wenatchee to McNary Dam[a]	McNary to Bonneville Dam[b]	Lower Wenatchee to Bonneville Dam[a]
1998	NA	1.655 (1.617)	NA
1999	NA	0.683 (0.177)	NA
2000	NA	0.894 (0.867)	NA
2001	NA	NA	NA
2002	NA	0.286 (0.110)	NA
2003	NA	NA	NA
2004	NA	1.246 (1.218)	NA
2005	NA	0.226 (0.209)	NA
2006	NA	0.767 (0.243)	NA
2007	NA	0.642 (0.296)	NA
2008	NA	0.679 (0.363)	NA
2009	NA	0.958 (0.405)	NA
2010	NA	0.627 (0.152)	NA
2011	NA	0.691 (0.676)	NA
2012	NA	0.840 (0.405)	NA
2013	NA	0.658 (0.217)	NA
2014	0.332 (0.079)	0.565 (0.269)	0.053 (0.044)
2015	0.430 (0.062)	0.446 (0.200)	0.195 (0.064)
2016	0.270 (0.055)	0.545 (0.126)	NA
2017	0.551 (0.141)	0.611 (0.181)	NA
2018	0.655 (0.064)	0.560 (0.112)	0.364 (0.154)
2019	0.640 (0.135)	0.701 (0.120)	0.264 (0.126)
2020	0.436 (0.095)	0.288 (0.154)	0.106 (0.062)
2021	0.642 (0.238)	0.533 (0.180)	0.361 (0.332)
2022	0.434 (0.088)	1.006 (0.396)	0.458 (0.219)
Mean	**0.488 (0.047)**	**0.700 (0.066)**	**0.257 (0.056)**

[a] Estimates in these columns use all fish tagged at the Lower Wenatchee smolt trap.

[b] Estimates in this column use all fish tagged upstream from the Yakima River.

Table 31. Annual survival probability estimates from release to Bonneville Dam for upper Columbia River yearling Chinook salmon and juvenile steelhead (hatchery-origin only), 1999-2022. Multiple release sites were used in each year, and sites were not the same in all years. Standard errors in parentheses. Simple arithmetic means across all available years are given.

	Annual survival estimates for upper Columbia River stocks			
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)
2020	0.629 (0.025)	0.867 (0.045)	0.922 (0.094)	0.800 (0.083)
2021	0.529 (0.028)	0.807 (0.066)	0.773 (0.071)	0.624 (0.053)
2022	0.480 (0.035)	0.810 (0.079)	0.952 (0.092)	0.772 (0.080)
Mean	**0.555 (0.011)**	**0.889 (0.019)**	**0.898 (0.034)**	**0.801 (0.026)**

Table 31. Continued.

Annual survival estimates for upper Columbia River stocks

Year	Release site to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
		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)
2020	0.420 (0.035)	0.879 (0.082)	0.859 (0.084)	0.756 (0.092)
2021	0.324 (0.025)	0.854 (0.100)	0.661 (0.066)	0.564 (0.050)
2022	0.222 (0.023)	1.581 (0.241)	0.567 (0.077)	0.897 (0.117)
Mean	**0.400 (0.016)**	**0.925 (0.043)**	**0.837 (0.049)**	**0.760 (0.042)**

Detection Probabilities

Based on our estimates, the probability of detection for PIT-tagged juvenile Chinook salmon was extremely low at most dams on the Snake and Columbia Rivers during 2022 (Figure 8). Detection probabilities at Little Goose and Lower Monumental Dam were slightly higher in 2022 than in 2020 or 2021, but still well below those seen in most years prior to 2020.

Detection probabilities were the lowest ever at McNary and extremely low at John Day Dam in 2022, continuing a precipitous trend of declining detection over the past few years at those dams (Figure 8). Detection probability at Bonneville Dam has not trended in any consistent direction in recent years, but was below average in 2022. The absence of a consistent decline in detection probability at Bonneville Dam is likely due to the fact that the dam has detection capability in both the juvenile bypass system and corner collector at Powerhouse Two.

In contrast to other dams, detection probability at Lower Granite Dam was high in 2022 as a result of the spillway detection system (Figure 8). Detection in the bypass system at Lower Granite Dam was just under 10% in 2022. Had the bypass system been the only detection site at Lower Granite, as it is at all other dams besides Bonneville, detection probability would have been far below average in 2022.

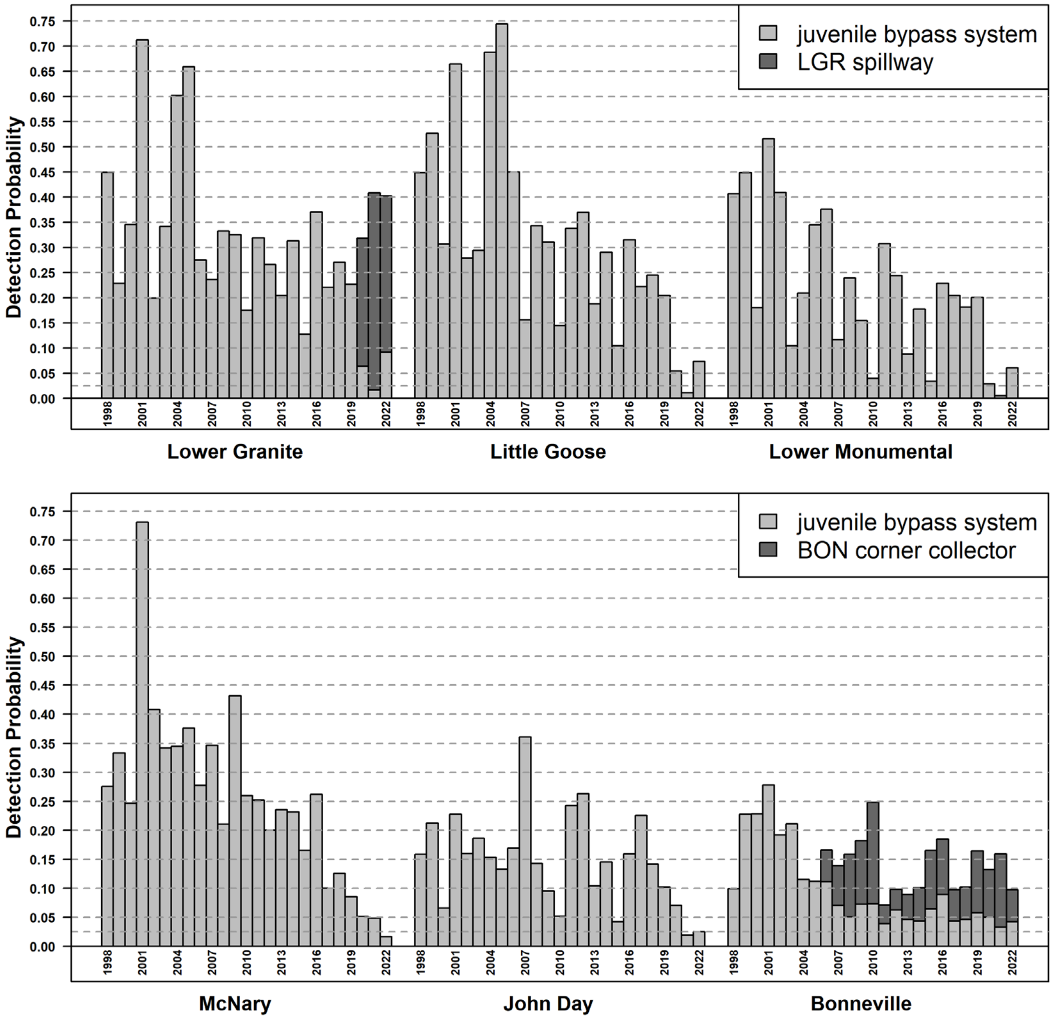


Figure 8. Annual mean detection probability for Snake River yearling Chinook salmon at six major dams on the Snake and Columbia Rivers, 1998-2022. Ice Harbor Dam was excluded because of persistent very low juvenile detection probabilities.

Comparison Between Snake and Columbia River Stocks

In 2022, estimated survival from McNary to Bonneville Dam was lower for hatchery and wild yearling Chinook originating in the Snake River (0.688; 95% CI 0.570-0.806; Table 32) than for those originating in the Upper Columbia River Basin (0.834; 0.681-0.987), but the difference was not statistically significant due to the poor precision of both estimates (*P* = 0.14).

For combined hatchery and wild steelhead migrating from McNary to Bonneville during 2022, estimated survival for Snake River fish was 0.754 (0.668-0.840; Table 32). This was lower than the survival estimate for Upper Columbia River fish (0.980; 0.759-1.201), but the difference was not quite statistically significant due to the poor precision of the estimates (*P* = 0.06).

For hatchery and wild sockeye, estimated survival from McNary to Bonneville was far lower for stocks originating in the Snake (0.412; 0.274-0.620; Table 32) than in the Upper Columbia River Basin (1.006; 0.478-2.117). Despite extremely poor precision of the estimate for Upper Columbia River stocks, the difference was statistically significant (*P* = 0.04).

Table 32. Annual survival probability estimates from McNary to Bonneville Dam for various spring-migrating salmonid stocks (hatchery and wild combined) in 2022. In shaded rows, the annual estimates are weighted means of estimates for biweekly 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 of McNary Dam. All Chinook salmon are spring/summer run. Standard errors in parentheses.

			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	Lower Granite Dam tailrace	108,660	0.806 (0.087)	0.892 (0.077)	0.689 (0.066)
Upper Columbia Chinook	Upper Columbia sites[a]	216,434	0.919 (0.077)	0.908 (0.083)	0.834 (0.078)
Upper Columbia Chinook	Yakima River sites[b]	77,677	0.891 (0.142)	0.759 (0.202)	0.676 (0.168)
Upper Columbia Coho	Upper Columbia sites[a]	56,023	1.231 (0.198)	0.841 (0.138)	1.035 (0.161)
Upper Columbia Coho	Yakima River sites[b]	61,779	1.027 (0.231)	0.524 (0.139)	0.538 (0.120)
Snake River Sockeye	Snake River sites[c]	49,988	0.700 (0.235)	0.588 (0.181)	0.412 (0.087)
Upper Columbia Sockeye	Upper Columbia sites[a]	14,314	0.900 (0.206)	1.096 (0.434)	0.986 (0.388)
Snake River Steelhead	Lower Granite Dam tailrace	111,449	1.265 (0.198)	0.737 (0.091)	0.757 (0.047)
Upper Columbia Steelhead	Upper Columbia sites[a]	101,903	1.766 (0.242)	0.555 (0.069)	0.980 (0.113)

[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

After two years of field work restrictions imposed in response to the COVID-19 pandemic, a combination of relaxed restrictions and adapted protocols allowed NOAA to resume operations in 2022. Both the tagging program at Lower Granite Dam and the pair-trawl detection system in the estuary were operated at nearly normal capacity. The number of wild fish tagged at Lower Granite Dam was still somewhat below average, but the primary cause was the low number of smolts entering the bypass system at the dam during tagging operations (Table 33). The estuary trawl operated at normal capacity, with sampling conducted during both day and night hours in 2022, compared to no sampling in 2020 and only daytime sampling in 2021.

Extremely high spill levels combined with below-average flows resulted in very low proportions of fish passing via juvenile bypass systems, with consequent very low detection rates in bypass systems. However, the number of fish detected in the bypass system at Lower Granite Dam was not as low in 2022 as in 2020 or 2021 (Table 33). The late run in 2022 likely contributed to this slightly higher rate of bypass, as a greater proportion of fish passed during late May and June when the proportion of flow spilled was not as high.

Large numbers of fish were detected by the spillway detection system at Lower Granite Dam, which compensated for what would otherwise have been a season of below-average sample sizes for survival estimation. The spillway system was installed during winter 2019-2020, and 2022 was its third year of operation. A total of 91,008 yearling Chinook and 72,522 steelhead were detected by the spillway system during the 2022 migration season (Table 33). Of the more than 200,000 smolts used for survival estimation from Lower Granite Dam, 67% were detected in the spillway system, 15% were tagged after collection in the bypass system, and 18% were detected in the bypass system.

A formal study of detection efficiency for the spillway system was conducted in spring 2022. That study determined that the detection efficiency of the spillway detection system was 65.5% for fish tagged with 12-mm PIT tags passing via the center of the spillbay (Axel et al. 2023). However, fish that passed near the spillbay edges had a lower chance of being detected, from 26.9-27.4%. The study also found that in 2021 and 2022, the majority of run-of-river smolts passed near the center of the spillbay rather than at the edges, and thus would be expected to be detected at the higher rate.

Table 33. Total number of PIT-tagged hatchery and wild yearling Chinook salmon and juvenile steelhead used for survival probability estimates from Lower Granite Dam, 2010-2022. Fish are categorized by location of detection or tagging. Only smolts returned to the river after detection or tagging are included.

	Smolt numbers at Lower Granite Dam (n)							
	Detected in spillway system		Detected in juvenile bypass system		Tagged in juvenile bypass system		Total	
Year	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
Yearling Chinook salmon								
2010	-	-	35,402	12,411	47,902	17,008	83,304	29,419
2011	-	-	70,206	17,495	47	16,029	70,253	33,524
2012	-	-	51,282	12,831	46	16,749	51,328	29,580
2013	-	-	43,617	8,550	13	11,773	43,630	20,323
2014	-	-	69,152	15,502	76	17,917	69,228	33,419
2015	-	-	26,210	3,465	33	8,300	26,243	11,765
2016	-	-	87,431	11,964	85	22,145	87,516	34,109
2017	-	-	45,355	8,158	10	14,241	45,365	22,399
2018	-	-	54,989	9,409	0	11,823	54,989	21,232
2019	-	-	38,961	6,376	14	6,349	38,975	12,725
2020	60,290	5,344	14,106	2,295	0	0	74,396	7,639
2021	94,298	6,850	3,768	600	57	1,770	98,123	9,220
2022	81,920	9,088	23,047	3,995	57	6,285	105,024	19,368
Steelhead								
2010	-	-	33,171	5,035	16,173	11,991	49,344	17,026
2011	-	-	60,961	5,350	22,011	18,001	82,972	23,351
2012	-	-	45,350	7,438	20,121	20,122	65,471	27,560
2013	-	-	29,420	5,400	17,380	7,457	46,800	12,857
2014	-	-	42,082	6,823	20,593	14,493	62,675	21,316
2015	-	-	14,626	1,578	25,278	17,065	39,904	18,643
2016	-	-	55,467	5,625	17,972	14,774	73,439	20,399
2017	-	-	42,253	3,619	22,049	18,422	64,302	22,041
2018	-	-	47,465	5,699	20,249	15,396	67,714	21,095
2019	-	-	47,919	4,249	20,888	14,758	68,807	19,007
2020	60,090	3,442	9,899	1,161	0	0	69,989	4,603
2021	83,846	7,173	4,756	476	18,120	4,854	106,722	12,503
2022	68,917	3,605	16,294	1,650	21,758	9,350	106,969	14,605

Unfortunately, even with additional data from the spillway detection system, sample sizes for both wild Chinook and wild steelhead were below average in 2022 (Table 33). The shortage of data for wild smolts impacted the quality of survival estimates for both stocks.

Using the single-release-model, detection information is required from points downstream of Bonneville Dam in order to estimate survival to Bonneville. Such information is critical to the model, as it provides evidence that a PIT-tagged smolt had been alive in the tailrace of Bonneville Dam after passing the dam. Before 2020, our principal source for such information was the estuary PIT trawl program. However, trawl operations were suspended in 2020 because of COVID-19 precautions. With no data from the trawl, we used alternative sources of detection information for estimates in 2020.

Considering the positive results from these estimates, we continued to use these alternative sources of detection information in addition to data from resumed trawl operations. Thus, for 2022 we used four sources of detection data from fish that had passed Bonneville Dam:

1) Tags detected by the estuary trawl
2) Tags detected by monitoring systems installed on two pile dikes in the estuary
3) Tags deposited by avian predators on estuary island colonies, on the Astoria-Megler Bridge, on transmission towers near Troutdale, Oregon, and at other miscellaneous nesting and roosting locations in the estuary
4) Tags of juvenile fish detected in the adult fish ladder at Bonneville Dam. Some precocious juveniles pass Bonneville Dam in the downstream direction and then forego ocean rearing, instead ascending the ladder to undertake a spawning migration. This behavior is far more common in yearling Chinook than in other species, and such fish are known as “mini-jacks.”

We used all of these data sources in 2022 (Table 34), combining all available detections from sources below Bonneville Dam into a single virtual “final detection site” for survival estimation using the single-release model.

Low detection probabilities resulting from high spill also required use of an alternative method to estimate survival downstream from McNary Dam. Rather than our customary groupings of fish based on release or detection date at McNary, we followed cohorts defined at Lower Granite Dam throughout the entire hydropower system to Bonneville Dam and the estuary (see methods in *Survival from Release to Bonneville Dam*).

Table 34. Number of PIT tags detected or recovered at various locations downstream from Bonneville Dam, 2022. Only tags that contributed to one or more of the survival estimates in this report are included in this table. That is, these counts do not include tags from stocks for which we do not report survival or tags recovered from avian sites that were from smolts that migrated in previous years.

	Tags detected or recovered in 2022 (n)			
Site	Yearling Chinook	Steelhead	Coho	Sockeye
Tags detected in live fish				
Columbia River estuary trawl	3,673	3,387	345	438
Pile dike 6	1,680	579	138	34
Pile dike 7	94	59	26	3
Bonneville Dam adult ladders	1,485	15	110	1
Tags recovered on avian nesting, loafing, or roosting site				
East Sand Island	447	682	70	12
Rice Island	363	1,341	8	25
Miller Sands Island	13	14	2	1
Pier 3, Port of Astoria	65	218	3	6
Astoria-Megler Bridge	891	648	101	85
Troutdale transmission towers	511	573	75	66
Total	**9,222**	**7,516**	**878**	**671**

Overall, the use of a combination of alternative methods and data sources introduced a new variable when comparing results from 2020-2022 with those from the time series of smolt migration years prior to 2020. We are conducting a reanalysis of historical data that applies the new approaches used in 2020-2022 where possible. We are also investigating the consequences of changing our primary data source at Lower Granite Dam from fish that passed via the juvenile bypass system to fish that passed via the spillway.

Preliminary findings from these investigations have given us no reason to suspect that the alternative methods and data sources used in 2020-2022 resulted in systematic bias in estimates. We have found that for a subset of past migration years, the addition of avian-recovery data to sample data from the trawl resulted in higher estimates of survival to Bonneville Dam for yearling Chinook. However, these increases were small, and there was no such systematic effect for steelhead. These investigations are ongoing, and results will be published after completion.

In the reach from Lower Granite to McNary, we observed below-average survival for all stocks of spring Chinook and steelhead. However, estimated survival for combined hatchery and wild Chinook was only very slightly below average. Due to poor precision, only the estimate for wild steelhead was significantly different from the long-term mean in this reach. Snake River sockeye was an exception, with estimated survival well above average for this reach in 2022 (though the estimate was very imprecise).

Although survival estimates in the Snake River were mostly below average, those in the Columbia River were above average from McNary to Bonneville Dam. In particular, survival estimates were far above average in this reach for wild-only stocks of Snake River spring Chinook and steelhead, hatchery upper Columbia River steelhead, and wild and hatchery upper Columbia River sockeye. However, due to extremely poor detection at lower Columbia River dams, essentially all estimates in this reach had extremely low precision. Only the estimates for wild Snake River steelhead and upper Columbia River hatchery steelhead were significantly different from the long-term mean.

For most stocks of hatchery Chinook and steelhead, and for most Chinook and steelhead released from smolt traps, survival to Lower Granite Dam was average or above average in 2022 (Table 22). One exception was yearling Chinook salmon reared at Pahsimeroi Hatchery, which displayed moderately below-average survival in 2022.

Multiple incidents of bacterial kidney disease (BKD) have occurred at the hatchery in recent years, with outbreaks in 2019 and 2021 (Trevor Conder, National Marine Fisheries Service, personal communication). Bacterial kidney disease is highly transmissible and known to cause high mortality rates in salmonids (Fryer and Sanders 1981). These BKD outbreaks almost certainly contributed to very low survival of Pahsimeroi Hatchery fish in those years, and an ongoing struggle with BKD may have depressed the survival of Pahsimeroi Hatchery fish in 2022.

We have observed a steep decline in the number of Chinook captured and tagged at the Snake River Smolt Trap in recent years. In 2022, only 121 wild Chinook smolts were tagged there. We were able to estimate survival to Lower Granite for these wild Chinook, but the extremely small sample size resulted in a very imprecise estimate, and it also called into question the representativeness of the sample. The number of hatchery Chinook smolts tagged at the trap has rebounded somewhat, with 1,024 hatchery smolts tagged in 2022. This sample size was well below the long-term mean, but it was at least large enough to ensure a representative sample.

In 2022, environmental conditions presented a migration season with water temperatures that were substantially cooler than average and flows that were below average overall (Appendix Figure C1). The spring freshet was substantially later than average in 2022. Mean flow in the Snake River was far below average until the start of the freshet in late May, but flow was above average at the peak of the freshet in June. Daily water temperatures were cooler than average by one to two degrees for most of the season.

Spill discharge levels, in terms of absolute volume, were above average in 2022 (Appendix Figure C2). Because flow volume was low during April and most of May, spill percentages were extremely high for that period. After the start of the spring freshet in late May, spill percentages declined somewhat. Overall spill percentages in 2022 were not quite as high as those in 2020-2021, but they were still among the highest on record.

These high spill proportions were the result of a management program that began in 2020, known as *Flexible Spill Operation*. This program uses 16 h of high spill each day, which is intended to decrease travel time and increase survival of smolts during their downstream migration. These 16 h are combined with two, 4-h periods of reduced spill, which are provided to aid adult upstream passage and allow increased power generation.

To accommodate the new spill program, in 2020 the limit on total dissolved gas (TDG) was increased from 120 to 125% saturation in the tailrace (BPA 2020). This higher limit allowed a much higher proportion of flow to be spilled (typically 60-90% of total flow at the dams during peak spill hours). During hours of reduced spill, typical spill proportions were 25-50%.

In 2022, these very high spill percentages resulted in above-average levels of TDG during late-season periods of high flow. This is because TDG is most directly affected by spill volume rather than spill percent. Lower flows earlier in the season resulted in spill volumes that were at or below average, and thus levels of TDG were also average at most dams. Overall, daily average TDG values were generally below 120% at both Snake and Columbia River dams for most of the migration season (Appendix Figures C3, C10-C11).

Hourly TDG levels can vary widely within a day under the *Flexible Spill Operations* program; therefore, daily average TDG values do not reflect maximum exposures experienced by fish. During the entire juvenile salmonid migration period, hourly TDG levels were at least 115% for 55-93% of the time, at least 120% for 28-55% of the time, and at least 125% for 1-17% of the time (Table 35).

Hourly TDG also varied by dam, but exceeded 130% for 32 hourly periods during 11-14 June at Ice Harbor (2% of total migration season hours). At Little Goose, TDG exceeded 130% for 2 hourly periods on 11 June (<1% of total hours). Hourly TDG levels were not measured during periods of high June flow at Lower Granite and Bonneville Dams. These omissions most certainly resulted in underestimates of gas exposure at those dams.

Table 35. Summary of total dissolved gas (TDG) levels from monitors downstream of dams in 2022. Measurements include the period of 3 April-15 June at Snake River dams and 10 April-15 June at Columbia River dams. Numbers derived from hourly records. Gas dissipates with distance from the dam, so measurements can depend on monitor location; however, all monitors measured TDG levels lower than the maximum TDG, which is produced in the immediate tailrace. Distance (km) downstream from the respective tailrace is given for each monitor.

		Total dissolved gas (%)		Total migration season hours (%)		
Dam	Monitor distance from tailrace (km)	Mean	Max	TDG ≥ 115%	TDG ≥ 120%	TDG ≥ 125%
Snake River (3 April-15 June)						
Lower Granite*	1.3	116.7	129.0	54.5	28.3	5.8
Little Goose	1.1	118.3	130.6	61.5	36.9	17.2
Lower Monumental	1.6	119.2	128.8	71.6	45.3	13.2
Ice Harbor	5.8	117.9	135.9	55.8	30.9	14.1
Columbia River (10 April-15 June)						
McNary	2.1	119.3	128.4	87.1	41.9	6.3
John Day	1.3	119.1	128.1	80.0	41.8	15.6
The Dalles	4.0	119.3	127.7	90.5	43.1	7.7
Bonneville*	0.4	119.7	125.4	93.0	55.6	0.1

* Hourly measurements were missing at the Lower Granite Dam tailrace monitor for 68 hours during high flows from 11 to 14 June and from the Bonneville Cascade monitor for 204 hours during high flows from 7 to 15 June, so peak hours of gas production were not recorded at those locations.

Exposure to high levels of TDG can cause gas bubble trauma in fish (also known as gas bubble disease), which can result in injury and death (Bouk 1980; Weitkamp and Katz 1980). The disease manifests as bubbles in tissues and blood and affects the eyes, fins, lateral line, body surface, gills, heart, and other internal organs. It can lead to death directly, through physiological mechanisms, or indirectly, through increased susceptibility to pathogens or predation due to impaired senses and reduced swimming ability. Severity of gas bubble trauma depends on absolute TDG levels and on duration of exposure, temperature, depth, and fish size.

Levels of TDG decrease with increasing depth in the water column, so fish can reduce exposure by swimming deeper. Laboratory researchers examined the effects of TDG supersaturation on yearling Chinook and juvenile steelhead in shallow tanks (0.25 m), assessing the formation of gas bubble trauma and resulting mortality (Dawley and Ebel 1975). For both species, they found that exposure to 120% TDG resulted in over 50% mortality within 1.5 d and 100% mortality within 3 d. At 115% TDG, steelhead reached 10% mortality in 10 d and 50% mortality in 20 d, while Chinook reached 7% mortality after 33 d.

Dawley et al. (1976) performed a similar experiment with subyearling Chinook and juvenile steelhead exposed to TDG levels ranging 100-127%. In addition to shallow tanks, deeper tanks (2.5 m) were used to allow for depth compensation by fish. They found that the average depth occupied by fish within the deep tanks increased with increasing TDG. They also found that time to 25% mortality of fall Chinook in deep tanks was comparable to that in shallow tanks with approximately 10% lower TDG. However, mortality was still substantial in deep tanks at 127% TDG, with approximately 12% mortality for subyearling Chinook and 25% for steelhead at 7 d.

Beeman and Maule (2006) studied the migration depth of radio-tagged yearling Chinook and steelhead smolts between Ice Harbor and McNary Dam during 1997-1999. They found that mean depths of steelhead ranged from 2.0 m in the Snake River portion of the study area to 2.3 m in McNary Dam forebay, while mean depths of yearling Chinook ranged from 1.5 m in the Snake River to 3.2 m near McNary. Mean TDG at the monitor downstream from Ice Harbor Dam was 114-133% during the study period.

Beeman and Maule (2006) concluded that TDG was an important predictor of migration depth for both species, though the relationship differed. For steelhead, mean migration depth increased by 0.3 m with each 10% increase in TDG, while mean depth actually decreased for Chinook by 0.2 m for every 10% increase in TDG. Despite these differences, they concluded that fish migrating in the hydropower system likely use depth to compensate for increased TDG.

We do not know how TDG affected fish survival in 2022, although levels were quite high in late May and early June. It is possible that exposure to TDG affected fish, especially those migrating during the late-season spikes in daily TDG, which exceeded 125%. We saw no evidence that low survival rates in the reach from Lower Granite to McNary during 2022 were a result of direct mortality due to TDG. However, effects of sustained TDG exposure, as well as acute exposure during brief periods of very high TDG, may have left some fish more susceptible to predation.

Predation by piscivorous fish is another likely contributor to the survival patterns we found for salmonids in 2022. Several species of piscivorous fish reside in Snake and Columbia 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 inception of the program, indices of both abundance and consumption of juvenile salmon have decreased for northern pikeminnow (Porter 2012; Storch et al. 2014). We saw no evidence of this pattern changing in 2022.

No predator control program currently exists for walleye or smallmouth bass, but restrictions on recreational fishing, such as bag limits and size limits, were relaxed in 2017. Populations of smallmouth bass in Snake River reservoirs do not appear to have changed in a consistent direction (Table 36; Erhardt et al. 2018). Collection counts at Snake River dams have not been trending in any particular direction in recent years; however, the number of smallmouth bass seen in the bypass at Lower Granite Dam was very high in 2021 and in 2022.

Erhardt et al. (2018) noted that Chinook yearlings are less vulnerable to smallmouth bass predation than subyearlings because yearlings are larger and migrate when the river is 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. Storch et al. (2014) estimated that spring indices of smallmouth bass predation on salmonids 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 since 2013 (Table 36). Data for Little Goose in 2022 are not yet available, but a record number of walleye were seen in the bypass of Lower Monumental Dam in 2022. These observations suggest the possibility that juvenile salmonids faced increased predation from smallmouth bass and walleye in Snake River reservoirs in 2022.

Table 36. Collection counts of notable incidental species at the juvenile fish bypass facilities of Snake River dams. Counts shown are from the expanded sample plus the total number of individuals observed in the separator. Data from U.S. Army Corps of Engineers Juvenile Fish Collection and Bypass reports.

	Number of individuals seen in juvenile bypass systems at three Snake River dams (n)								
	Smallmouth bass			Walleye			Siberian prawn		
Year	Lower Granite	Little Goose	Lower Monumental	Lower Granite	Little Goose	Lower Monumental	Lower Granite	Little Goose	Lower Monumental
2008	-	15,503	-	-	32	-	-	5,213	-
2009	-	5,092	-	-	19	-	-	6,327	-
2010	1,024	4,150	12,171	0	20	10	11,711	38,676	8,599
2011	682	3,691	393	1	8	19	3,400	15,743	2,818
2012	620	2,442	10,984	1	7	8	3,831	23,183	2,219
2013	445	1,279	428	0	9	9	6,634	45,015	12,969
2014	2,037	3,528	1,457	0	14	92	9,839	81,310	18,388
2015	2,160	2,102	779	1	27	337	20,979	464,586	48,243
2016	4,819	2,992	848	3	65	608	25,848	51,518	10,527
2017	1,604	8,977	1,764	1	110	733	4,148	31,668	9,020
2018	3,625	2,939	1,046	5	170	352	43,434	11,159	1,557
2019	7,781	4,896	1,053	13	101	656	71,565	36,217	2,182
2020	3,037	1,922	-	5	137	-	145,030	87,409	-
2021	15,380	5,933	782	14	743	859	1,179,365	131,109	8,461
2022	20,444	-	708	31	-	1,274	668,377	-	2,867

Whether similar patterns are occurring in Columbia River reservoirs is not clear. Smallmouth bass, northern pikeminnow, and walleye are all known to be abundant in McNary and John Day reservoirs (Rieman et al. 1991; Tabor et al. 1993), but recent data on the populations of these predator fish are not available.

Little current information exists for smallmouth bass and walleye population trends in the Columbia River. However, juvenile salmonids have been observed at high rates in the stomachs of walleye captured in Bonneville Pool. In 2021 there was some evidence that predation by smallmouth bass on salmonid smolts had increased in Bonneville Pool (Winther et al. 2022). We do not yet know if this predation also increased in 2022, but such a finding would not comport with the higher-than-average survival we found for most Columbia River salmonid stocks in 2022.

Wild smolts are smaller than their hatchery counterparts, which increases their vulnerability to gape-limited predators such as piscivorous fish. Predation by piscivorous fish may have been a factor in the below-average survival we found in 2022 for multiple salmonid stocks in Snake River in 2022, particularly wild stocks. However, wild Chinook yearlings are still substantially larger than wild subyearlings, and piscivorous fish in Columbia River reservoirs have been demonstrated to prey primarily on subyearlings (Rieman et al. 1991; Tabor et al. 1993).

Overall, it is unclear how environmental conditions in the Snake and Columbia Rivers influenced the vulnerability of juvenile salmonids to predation by piscivorous fish in 2022. Cool water temperatures decrease the metabolic rate and feeding activity of piscivorous fish and therefore decrease rates of predation. Conversely, lower flows increase the vulnerability of prey fish to visual predators (Gregory and Levings 1998).

Water was cool and flows were low during the first half of the migration season, but flows increased to well above average later in the season, when the bulk of migration occurred. Accordingly, smolt travel times were unusually long in April and much of May, and longer travel times increase the exposure of smolts to predators, but again, travel times shortened later in the season. Thus, environmental factors in 2022 presented a mix of expectations, with some tending to reduce vulnerability to piscivorous predators, while others tended to increase it.

Fish are not the only taxa that prey upon migrating smolts. Avian piscivores are abundant along the Columbia River below its confluence with the Snake, and their populations and consumption rates have been intensively monitored (Collis et al. 2002; Ryan et al. 2001, 2003; Roby et al. 2008, 2021; Evans et al. 2012; Collis et al. 2020; Evans et al. 2023).

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

Starting in 2014 and continuing through 2021, passive and active dissuasion measures were employed on the Crescent Island Caspian tern colony. Those efforts eliminated tern nesting on Crescent Island; however, terns displaced from this colony appeared to relocate to other colonies within the mid-Columbia Basin. In 2021 and 2022, elevations were raised in John Day reservoir to eliminate alternative tern nesting sites. In 2022, nesting dissuasion was terminated on Crescent Island, and Caspian terns re-established the colony there with approximately 149 breeding pairs.

Thus, since the start of tern management in 2014, adaptive management efforts have succeeded in shifting the locations of ten colonies, but have not succeeded in moving substantial numbers of terns out of the Columbia Basin. The total number of breeding pairs in the Columbia Plateau has declined, but not to levels that meet goals set by regional managers. The combined population size of Caspian tern colonies in the plateau region was estimated at about 511 breeding pairs in 2022, which was the largest number seen since 2017 (Evans et al. 2023). Not surprisingly, estimated consumption rates of Caspian terns on salmonid stocks were higher in 2022 than in 2021.

In addition to Caspian terns, a number of other piscivorous bird colonies were observed in the mid-Columbia Basin in 2022. In addition to several small colonies, large colonies of gulls were seen in Potholes Reservoir, at Miller Rocks in The Dalles reservoir, on Crescent and Badger Islands in McNary Reservoir, and on Island 20 in the Hanford reach. Small colonies of double-crested cormorants were observed on Foundation Island and several other islands, and a sizeable colony of American white pelican was observed on Badger Island (Evans et al. 2023). In general, the estimated consumption rate on salmonids by cormorants and gulls was lower in 2022 than in 2021, but not unusually low compared to consumption rates seen in previous years.

Clearly, avian predation is still a significant source of mortality for Columbia Basin salmonids, particularly steelhead. The combined estimated consumption rate across all surveyed waterbird populations was 25.3% for Snake River steelhead and 29.4% for upper Columbia River steelhead in 2022. Estimated overall avian consumption rates on Snake River Chinook and sockeye were lower, but far from negligible, at 11.1 and 13.4%, respectively in 2022 (Evans et al. 2023).

Despite these estimates, we cannot say with certainty to what degree avian predation influenced the overall survival of juvenile salmonids in 2022. The majority of avian predator colonies are located on the mainstem Columbia River from Lake Wallula to the estuary, and the majority of avian predation is be expected to occur in that reach. While uncertainty in estimates of avian predation is high due to differing methodologies among years, overall estimates of avian predation were average to below average in 2022 (Evans et al. 2023). This estimate does seem to comport with the above-average survival estimates we found for many stocks in the lower Columbia River.

On the other hand, for wild Snake River Chinook and steelhead in the reach from Lower Granite to McNary, it seems unlikely that avian predation was a major cause of low estimated survival. Hatchery smolts tend to be more vulnerable to avian predators than wild smolts (Flagg et al. 2000), so if avian predation were a major cause of mortality for wild smolts in 2022, we would expect to see similar effects on hatchery stocks, but that was not the case. Avian predation may have contributed to the below-average survival of wild Snake River smolts we observed in 2022, but other factors were likely more influential.

An exploding population of invasive Siberian prawn *Palaemon modestus* also may have influenced survival of juvenile salmon in Snake River reservoirs in 2022 and other recent years. This species of prawn was first documented in the Snake River in 1998 (Haskell et al. 2006). Siberian prawns consume the same types of prey as juvenile salmon, and competition with these prawns may depress growth rates of juvenile salmon in Snake River reservoirs (Tiffan et al. 2014; Erhardt and Tiffan 2016; Tiffan and Hurst 2016).

Collection counts of Siberian prawns at Snake River dams were low in the 2000s but have increased significantly (Tiffan and Hurst 2016). Extremely high counts of prawns were observed at Lower Granite Dam in both 2021 and 2022; these counts were substantially higher than counts observed there previously (Table 36). Collection counts were also above average at Little Goose and Lower Monumental Dams in 2021 and 2022. This suggests the possibility that salmonids continue to face increased competition from Siberian prawn, at least in Lower Granite reservoir. However, it is not clear whether Siberian prawn was a factor in the low survival of wild Chinook and steelhead observed in Snake River reaches during 2022.

It seems doubtful that competition with Siberian prawns would impact wild smolts but not hatchery fish, and estimated survival was much closer to average for both hatchery Chinook and hatchery steelhead than for their wild conspecifics in 2022. Additionally, survival estimates were not below average from the Snake River Smolt Trap to Lower Granite Dam, a reach in which the observed number of prawns was very high in 2022.

Court-ordered increases in spill were implemented in 2006; in subsequent years, surface collectors were installed at Lower Granite and four additional dams. With these changes, average travel time between Lower Granite and Bonneville Dam has generally decreased, more so for steelhead than for Chinook smolts. Fish can linger in the forebay for hours or days before passing a dam. Spilling some amount of water throughout the day, especially when surface weirs are in place, greatly decreases this forebay delay.

As spill levels have repeatedly increased over the years, travel time has generally become very short throughout the season. However, in more recent years the decreases in travel time have been marginal. Beyond a certain level of spill, further increases appear to yield diminishing returns in terms of speeding migration and shortening travel time. Despite very high spill levels in 2022, travel times for both Chinook and steelhead were unusually long. Smolt travel times seemed much more influenced by flow than by spill, as travel times began to shorten only when flows started to increase in mid-May.

High spill volumes such as those in 2022 are likely to induce eddies in the tailrace at some dams. The severity of tailrace eddies depends on flow and spill conditions, as well as general configuration of the dam (Bellerud 2017; Fredricks 2017). However, in April 2022, the combination of low flows and extremely high rates of spill may have resulted in eddies that were more severe than in past years. Powerful eddies in the tailrace may increase the time it takes for smolts to exit the tailrace and continue downstream movement, both slowing travel time and potentially increasing exposure to predation (Roby et al. 2016).

In 2022, there was a rebound in estimated proportion of smolts transported, following two years of very low proportions. The primary cause of this rebound was the late run timing of Snake River stocks. Collection rates during transport operations remained well below average due to high rates of spill. Thus, as long as elevated spill rates continue, we anticipate that transportation rates in future years, with more typical earlier run timing, are likely to be substantially lower than those observed in 2022.

Increased use of spill and surface-passage structures has successfully promoted spillway passage. Nevertheless, higher proportions of spillway passage result in lower proportions of tagged fish entering bypass systems, and consequently lower rates of PIT-tag detection. There is evidence that surface spill is disproportionately attractive to fish at lower flow levels. In 2022, extremely high levels of spill combined with low flows resulted in extremely low detection rates at all dams. The only two exceptions were Lower Granite with its new spillway detection system and Bonneville with its corner collector (Figure 8).

For survival estimates based on PIT-tag data, sample size is directly proportional to the number of detected fish, which in turn depends on both detection probability and total number of tagged migrants. Reduced effective 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 in attempts to increase survival of juvenile fish passing dams within the Federal Columbia River Power System.

The present emphasis on spillway passage reduces detection rates by reducing the proportion of fish that enter juvenile bypass systems. At most dams, juvenile bypass systems remain as the only passage route for which PIT-tag monitoring technology is available. While emphasizing spillway passage might indeed increase smolt survival, the quality of information gathered to verify higher rates of survival has been degraded by reduced detection probabilities. Consequences of reduced detection probability include:

1) Reduced certainty in survival estimates: standard errors become larger and confidence intervals wider. Estimates are also more likely to be further from the true survival value and are frequently greater than 100%.
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 inversely correlated: 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 two lowermost reaches within the migration corridor: those 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. Higher uncertainty in turn reduces the quality of predictive models based on these estimates. Ultimately, this uncertainty may weaken the efficacy of management decisions informed by estimates and model predictions, hinder the development of appropriate restoration plans, and impair the ability to monitor and assess restoration plans after they are implemented.

If detection rates remain low, precision in survival estimates can be increased only by releasing larger numbers of tagged fish. 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.

At Lower Granite Dam, the spillway detection system in the ogee compensates for decreased detection rates in the juvenile bypass system. These two detection systems combined to result in overall detection probabilities that were not depressed during the 2022 migration season.

Large variations in flow and spill impact detection probabilities within the migration season and can impact the accuracy of survival and detection probability estimates from mark-recapture models. Such variations can also introduce bias to estimates of travel time. An additional benefit of having detection capability in more than one passage route is that overall detection probability is far less dependent on fluctuations in spill and flow.

Furthermore, detection capability in multiple passage routes will advance our understanding of passage-route distributions throughout the migration season, producing valuable insight into fish passage behavior. The spillway detection system allows us to track fish that passed Lower Granite Dam via different routes on the same day. In the future, once sufficient data have been collected, we will be able to directly compare both subsequent downstream survival and smolt-to-adult return rate between passage routes.

The success of the spillway detection system at Lower Granite Dam has been encouraging. Because the present management goal is to maximize spillway passage, the spillway is the ideal location for expanded detection capability. Increased detection rates will pay dividends, not only for survival estimates, but for all other investments in PIT-tag research within the region.

We believe that the region should prioritize installation of spillway systems at additional dams on the Snake and Columbia Rivers, particularly McNary and Bonneville Dam. These two dams are of critical importance to survival estimation for listed salmonid stocks. Continued development of new and alternative technologies to boost our abilities to detect PIT-tagged fish should remain a high priority as well.

Further development of PIT-tag detection methods could lead to other improvements; for example, autonomous detection barges that allow detection in forebays or tailraces of dams. Stationary, removable, or semi-permanent arrays placed downstream of Bonneville Dam could enhance or even supplant data from the estuary pair trawl detection system. These and other alternative methods for increasing detections should be actively pursued.

This study provides information that is essential for monitoring the status and trends of imperiled salmonid stocks as they migrate to the ocean. Without sufficient detections of PIT-tagged fish, our ability to monitor these stocks—and the effects of management actions on their survival—has been severely diminished. Improved detection rates are critical to protect these valuable natural resources and avoid exposing threatened stocks to further harm, which without such improvement we will no longer be able to measure.

Conclusions and Recommendations

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

1) Develop PIT-tag detection capability in spillways or surface passage structures at Bonneville and McNary Dam. Such capability would immediately improve detection rates and increase certainty in annual estimates of survival for juvenile salmonids passing Snake and Columbia River dams.

2) Pursue development of PIT-detection technologies that could improve detection rates below Bonneville and potentially at other dams.

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

4) Continue development and maintenance of instream PIT-detection systems for use in tributaries. Such systems can 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.

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. B. Sandford provided assessments of detection probability from the new spillway detector at Lower Granite Dam and assisted in collating data for PIT-tags recovered from avian colonies. G. Axel provided estimates of detection probability for the spillway detection system at Lower Granite Dam.

We thank K. Tiffan for providing published and unpublished data about smallmouth bass and Siberian prawn abundance and ecology. Thanks also to K. Anderson for assistance in acquiring unpublished dam bypass reports. We thank A. Evans, L. Sullivan, and other researchers at Real Time Research, the Bonneville Power Administration, and the U. S. Army Corps of Engineers for collecting and reporting PIT-tag recovery data from avian colonies and for providing preliminary estimates of predation rates by avian predators.

Thanks also to J. Butzerin for editorial advice and assistance to improve the quality of this report. We are grateful to 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

Axel, G. A., D. Widener, S. G. Smith, M. G. Nesbit, and B. P. Sandford. 2023. Post-construction assessment of passive integrated transponder detection efficiencies in spillbay 1 at Lower Granite Dam. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, OR.

Beeman, J. W., and A. G. Maule. 2006. Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River reservoir. Transactions of the American Fisheries Society 135:584-594.

Bellerud, B. 2017. John Day Dam model trip report 4/24/2017-4/29/2017 ERDC (U.S. Army Engineer Research and Development Center), Vicksburg, MS. Trip report to the U.S. Army Corps of Engineers. Available from National Marine Fisheries Service Northwest Regional Office, 1201 Northeast Lloyd Boulevard, Suite 1100, Portland, Oregon.

Bouk, G. R. 1980. Etiology of gas bubble disease. Transactions of the American Fisheries Society 109:703-707.

BPA (Bonneville Power Administration). 2020. Federal agencies spill record amount of water at dams. BPA News & Us web page. Newsroom article 9 June 2020. Available at https://electricenergyonline.com/article/energy/category/hydro/86/839802/federal-agencies-spill-record-amount-of-water-at-dams-.html (May 2023).

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 2021).

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. Available from the National Marine Service, Northwest Region.

Dawley, E. M., and W. J. Ebel. 1975. Effects of various concentrations of dissolved gas on juvenile chinook salmon and steelhead trout. Fishery Bulletin 73(4):787-796.

Dawley, E. M., M. Schiewe, and B. Monk. 1976. Effects of long-term exposure to supersaturation of dissolved atmospheric gases on juvenile chinook salmon and steelhead trout in deep and shallow test tanks. *In* D. H. Fickeisen and M. J. Schneider, eds., Gas bubble disease: proceedings of a workshop held in Richland, WA. Energy Research and Development Administration.

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.

Evans, A. F., K. Collis, N. V. Banet, A. Turecek, J. Marchiani, E. Casey, Q. Payton, B. Cramer, D. D. Roby, and T. J. Lawes. 2023. Avian predation in the Columbia River Basin: 2022 final annual report. Report of Real Time Research, Inc. to the Bonneville Power Administration, Portland, OR.

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, OR.

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, OR.

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, OR.

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, OR

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, OR.

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, OR.

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, OR.

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, OR.

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, OR.

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, OR.

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, OR.

Faulkner, J. R., B. L. Bellerud, D. L. Widener, 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.

Flagg, T. A., B. A. Berejikian, J. Colt, W. W. Dickhoff, L. W. Harrell, D. J. Maynard, C. E. Nash, M. S. Strom, R. N. Iwamoto, C. V. Mahnken. 2000. Ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations. NOAA Technical Memorandum NMFS-NWFSC-41.

FPC (Fish Passage Center). 2021a. Smolt passage index: daily passage index by project. Online interactive database. Available at fpc.org/smolt/smolt_queries/Q_smoltpassageindexquery.php. (January 2022).

FPC (Fish Passage Center). 2021b. Smolt data: historic and real-time smolt transportation data. Online interactive database. Available at fpc.org/smolt/transportation/smolt_transportation_query.html (January 2022).

Fredricks, G. 2017. Gas cap spill ERDC trip report, September 2017. Trip report to the U.S. Army Corps of Engineers. Available from National Marine Fisheries Service Northwest Regional Office, 1201 Northeast Lloyd Boulevard, Suite 1100, Portland, Oregon.

Fryer, J. L. and J. E. Sanders. 1981. Bacterial kidney disease of salmonid fish. Annual Review of Microbiology 35:273-298.

Gregory, R. S. and C. D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127:275-285.

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, OR.

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, OR.

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, G. Scheer, S. Haeseker, R. Lessard, T. Copeland, J. Ebel, A. Storch, and D. Rawding. 2022. Comparative survival study of PIT-tagged spring/summer/fall Chinook, summer steelhead, and sockeye: 2021 annual report. Report of the Comparative Survival Study Oversight Committee and Fish Passage Center to the Bonneville Power Administration, Portland, OR. Available: https://www.fpc.org/documents/CSS/2021_CSS_Annual_Report.pdf

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, OR.

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, OR.

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, OR.

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 2021).

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by Northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448–458.

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 of Real Time Research 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.

Roby D. D, A. F. Evans, and K. Collis (editors). 2021. Avian predation synthesis report—avian predation on salmonids in the Columbia River Basin: a synopsis of ecology and management. Report of Real Time Research, Inc. and Oregon State University to the U.S Army Corps of Engineers, Bonneville Power Administration, Grant County Public Utility District, and Oregon Department of Fish and Wildlife. Available from birdresearchnw.org (April 2022).

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, OR.

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, OR.

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, OR.

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, OR.

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, OR.

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, OR.

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. Report to the Bonneville Power Administration, Portland, OR.

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:831–838.

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.

Weitkamp, D. E., and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

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, OR.

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, OR.

Widener, D. L., J. R. Faulkner, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2020. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2019. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, OR.

Widener, D. L., J. R. Faulkner, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2021. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2020. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, OR.

Widener, D. L., J. R. Faulkner, S. G. Smith, and T. M. Marsh. 2023. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2021. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, OR.

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. Fishery Bulletin, 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.

Winther, E., G. Waltz, A. Martin. 2022. Report on the predation index, predator control fisheries, and program evaluation for the Columbia River basin northern pikeminnow sport reward program, 2021 annual report. Report of the Pacific States Marine Fisheries Commission to the Bonneville Power Administration, Portland, OR.

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, OR.

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, OR.

Appendix A: Evaluation of Model Assumptions

Background

Using the Cormack-Jolly-Seber (CJS), or single-release 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 Lower Granite to Little Goose Dam. Each event has an associated probability of occurrence, and probabilities are 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. It is necessarily an imperfect record, as survival without detection cannot always be distinguished from mortality. For a given group of tagged fish, the single-release 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 single-release model:

A1) All fish in a single group of tagged fish have common event probabilities (that is, 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 further implies the assumption that detected and nondetected fish at a given dam have the same probability of survival in downstream reaches and have the same conditional probability of detection at downstream dams.

Methods

We used the methods presented by Burnham et al. (1987; pp 71-77) to assess goodness-of-fit of the single-release 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 biweekly groups of yearling Chinook salmon and steelhead (hatchery and wild combined) leaving Lower Granite Dam during the migration year (Snake River-origin fish only, i.e., the groups used for survival estimates reported in Tables 1-2 and 7-8).

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 a passage route that is monitored for PIT tags (e.g., juvenile collection system) and those that are not (e.g., 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 hydropower system experience, while behavioral responses occur as a result of particular hydropower system 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 conducted, we followed the nomenclature of Burnham et al. (1987). For release groups from Lower Granite Dam, we analyzed 6-digit detection histories indicating detection status at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams, and the final digit for detection anywhere below Bonneville Dam (estuary trawl, Bonneville adult ladder, or piscivorous bird recovery).

A first series of tests is called Test 2 (Burnham et al. 1987). The first component test in the series for Lower Granite Dam groups is called Test 2.C2, based on the following contingency table:

Test 2.C2	First site detected below Little Goose				
df = 4	Lower Monumental	McNary	John Day	Bonneville	Below Bonneville
Not detected at Little Goose	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}
Detected at Little Goose	n_{21}	n_{22}	n_{23}	n_{24}	n_{25}

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 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}, n_{13}/n_{23}, n_{14}/n_{24}, and n_{15}/n_{25} are equal in expectation). 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-site downstream detections at Lower Monumental. Conversely, if fish detected at Little Goose become less likely to be detected downstream, they will have fewer first-site downstream detections at Lower Monumental. Inherent differences among fish could also result in violations of Test 2.C2 and would be difficult to distinguish from behavioral responses.

There are three additional component tests of Test 2 (Tests 2.C3, 2.C4, and 2.C5), with each conditioned on respective detection status at McNary, John Day, and Bonneville Dams and which take forms analogous to that of Test 2.C2.

The next series of tests is called Test 3, which has two subseries called Test 3.SR and Test 3.Sm. The first test in the 3.SR subseries 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. However, differences in mortality expressed below McNary could cause violations, as could behavioral responses (which could also be 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 first test in the 3.Sm series is Test 3.Sm3, based on the contingency table:

Test 3.Sm3	First site detected below Lower Monumental			
df = 3	McNary	John Day	Bonneville	Below Bonneville
Detected at Lower Monumental, not detected at Little Goose	n_{11}	n_{12}	n_{13}	n_{14}
Detected at Lower Monumental, detected at Little Goose	n_{21}	n_{22}	n_{23}	n_{24}

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.

There are three additional component 3.SR tests (SR4, SR5, SR6), respectively conditioned on detection at McNary, John Day, and Bonneville and analogous to Lower Monumental in Test 3.SR3. Similarly, there are two additional component 3.Sm tests (Sm4 and Sm5), respectively conditioned on detection at McNary and John Day and analogous to Lower Monumental in Test 3.Sm3.

Contingency table tests are not possible when any of the row or column totals are zero. Furthermore, when any of the expected cell counts of a table are less than 5.0, the χ^2 distribution does not sufficiently approximate the sampling distribution of the test statistic. For tables with more than two columns, if any column that was two or more columns from the left had a zero column total, we combined the two rightmost columns to create tables with successively fewer columns until the column totals were no longer zero or until there were only two columns remaining.

No test was possible if a 2 × 2 table had a zero column total. When a test was still possible for a table (regardless of table size) but one or more of the expected cell counts in the table was less than 5, we conducted a Fisher's exact test and reported the *p*-value from that test. We assumed that the assumptions of the χ^2 test were met for all overall tests.

Results

For release groups in 2022, there were more significant overall tests (sum of Tests 2 and 3) than expected by chance alone for both yearling Chinook and steelhead (5% are expected by chance alone with $\alpha = 0.05$; Appendix Table A1). There were six biweekly groups of yearling Chinook salmon, and the overall sum of χ^2 test statistics was significant for 2 of them (33%). The overall test was significant for 2 of the 6 steelhead groups (33%). For both yearling Chinook and steelhead, sums of Test 2 were the reason for significant overall tests, with none of the sums of Test 3 being significant for either species.

Among all individual component tests (i.e., 2.C2, 3.SR3, etc.), 3 tests out of 59 (5%) were significant for yearling Chinook salmon and 7 out of 62 (11%) were significant for steelhead (Appendix Tables A2-A5). There was a 57% chance of 3 or more tests out of 59 being significant if the true test-wise probability of a "false positive" result was $\alpha = 0.05$. For steelhead, there was a 3% chance of having 7 or more significant tests out of 62.

Thus, the number of observed positive tests for Chinook could have been due to chance, provided there were no true assumption violations, but the number of significant tests for steelhead was not likely due to chance. Due to the very low detection probabilities at most dams, many of the tests were likely under-powered. Therefore, the tests would not likely detect an assumption violation if one were actually present.

We diagnosed patterns in the contingency tables that led to significant tests, and results were similar to those we reported in past years. For biweekly groups of yearling Chinook, there was one significant component tests for Test 2 (Test 2.C5) and two significant component tests for Test 3 (Tests 3.Sm3 and 3.SR6). For Test 2.C5, fish detected at John Day Dam had relatively more first detections or recoveries downstream of Bonneville Dam than fish not detected at John Day Dam. For Test 3.Sm3, of fish detected at Lower Monumental Dam, those that were also detected at Little Goose Dam had relatively more detections at McNary Dam than those not detected at Little Goose Dam. For Test 3.SR6, of fish detected at Bonneville Dam, those that were also detected at John Day Dam were more likely to be detected or recovered in the estuary than those not detected at John Day Dam.

For steelhead, there were five significant component tests for Test 2 (Tests 2.C2, 2.C3, and 2.C4) and two significant component tests for Test 3 (Tests 3.SR3 and 3.SR4). For all but one of the significant component tests for Test 2, fish detected at the reference dam of the test had relatively more detections at a downstream dam than fish not detected at the reference dam. The exception was for one instance of instance of Test 2.C3, for which relatively fewer detected fish were detected downstream. For both of the component tests for Test 3, fish detected at both the reference dam and the adjacent upstream dam had relatively fewer detections downstream than fish detected at the reference dam but not the adjacent dam upstream.

Discussion

In 2022, as in previous years, we concluded that inherent differences in detectability (guideability) of fish within a release group was the most likely cause of patterns we observed in contingency table tests. Zabel et al. (2002, 2005) and Faulkner et al. (2019) provided evidence of inherent differences in guidance/detection related to length of fish at tagging, and similar observations were made in evaluating the 2022 data.

Fish size probably does not explain all inherent differences, but it appeared to explain some. Faulkner et al. (2019) found larger fish were less likely to be detected in juvenile bypass systems than smaller fish at most dams, and that relationship held for both yearling Chinook and steelhead. This relationship means that fish detected at one dam will tend to be smaller, and therefore inherently more likely to be detected at a subsequent dam downstream. This pattern held for the majority of significant component tests for both Chinook and steelhead in 2022. However, the pattern did not hold for all tests, which offers evidence that size selection is not 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. The flexible spill operation resulted in wide variations of spill percentage within a given day. These variations in turn may have resulted in wide variation in the proportion of fish entering bypass systems and being detected.

This scenario creates heterogeneity of detection probabilities at each dam and could result in patterns of detection for subsets of fish in a cohort—patterns that could lead to fish detected at one dam being more or less likely to be detected at the next dam. This process is complicated, and further research is needed to determine whether such a scenario could have led to some of the assumption violations observed in 2022.

Although the contingency table tests did well at detecting some violations of CJS model assumptions, there were instances where assumptions could have been violated without resulting in significant tests. A specific example would be in the case 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 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 is conditioned on fish with at least one detection, either at the site at which subgroups are defined or at sites downstream. To discern differential post-detection mortality requires knowledge of the fate of individual non-detected fish at the site of interest and downstream. However, 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 assumption tests described here can discern differential post-detection mortality between two consecutive detection sites.

Results in previous years (e.g., Zabel et al. 2002) led us to conclude that some 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 a small amount of heterogeneity). However, under current conditions with far lower detection probabilities, further investigation is needed to evaluate the effects of assumption violations.

Appendix Table A1. Number of tests of goodness-of-fit to the single-release model conducted, and number of significant ($\alpha = 0.05$) results for groups of Snake River Chinook salmon and juvenile steelhead in 2022. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for biweekly groups for tests.

		Species		
Test		Chinook	Steelhead	Total
Test 2.C2	Tests (n)	6	6	12
	Significant tests (n)	0	1	1
Test 2.C3	Tests (n)	6	6	12
	Significant tests (n)	0	2	2
Test 2.C4	Tests (n)	6	6	12
	Significant tests (n)	0	1	1
Test 2.C5	Tests (n)	6	6	12
	Significant tests (n)	1	1	2
Test 3.SR3	Tests (n)	6	6	12
	Significant tests (n)	0	1	1
Test 3.Sm3	Tests (n)	4	4	8
	Significant tests (n)	1	0	1
Test 3.SR4	Tests (n)	6	6	12
	Significant tests (n)	0	1	1
Test 3.Sm4	Tests (n)	3	5	8
	Significant tests (n)	0	0	0
Test 3.SR5	Tests (n)	6	6	12
	Significant tests (n)	0	0	0
Test 3.Sm5	Tests (n)	4	5	9
	Significant tests (n)	0	0	0
Test 3.SR6	Tests (n)	6	6	12
	Significant tests (n)	1	0	1
Test 2 sum	Tests (n)	6	6	12
	Significant tests (n)	2	2	4
Test 3 sum	Tests (n)	6	6	12
	Significant tests (n)	0	0	0
Test 2 + 3	Tests (n)	6	6	12
	Significant tests (n)	2	2	4

Appendix Table A2. Results of Test 2 and overall tests of goodness-of-fit to the single-release model for groups of Snake River yearling Chinook salmon 2022. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for biweekly groups for tests.

	Overall (2+3)		Test 2 (sum)		Test 2.C2	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	17.66	0.344	12.87	0.231	5.44	0.314
6–19 Apr	12.13	0.596	10.05	0.436	3.25	0.516
20 Apr–3 May	34.41	**0.003**	24.01	**0.008**	9.11	0.062
4–17 May	35.06	**0.020**	18.98	**0.041**	4.38	0.357
18–31 May	21.29	0.380	9.03	0.529	2.09	0.725
1 Jun–26 Jul	13.79	0.796	7.24	0.703	1.96	0.685
Total (df)	134.34 (104)	**0.024**	82.18 (60)	**0.030**	26.23 (24)	0.342

	Test 2.C3		Test 2.C4		Test 2.C5	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	6.30	0.056	1.08	0.709	0.05	1.000
6–19 Apr	4.98	0.128	0.87	0.812	0.95	0.428
20 Apr–3 May	2.33	0.470	3.73	0.180	8.84	**0.003**
4–17 May	6.92	0.074	5.14	0.077	2.54	0.111
18–31 May	4.57	0.206	0.00	1.000	2.37	0.124
1 Jun–26 Jul	2.16	0.644	2.82	0.225	0.30	0.584
Total (df)	27.26 (18)	0.074	13.64 (12)	0.324	15.05 (6)	**0.020**

Appendix Table A3. Results of Test 3 tests of goodness-of-fit to the single-release model for groups of Snake River yearling Chinook salmon in 2022. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for biweekly groups for tests.

Release	Test 3 (sum)		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
period	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	4.79	0.571	1.17	0.400	0.77	1.000	1.46	0.573
6–19 Apr	2.08	0.721	0.19	1.000	-	-	0.24	1.000
20 Apr–3 May	10.40	0.065	2.12	0.235	-	-	0.97	1.000
4–17 May	16.08	0.097	0.08	0.777	14.59	**0.003**	0.01	1.000
18–31 May	12.26	0.268	1.05	0.354	2.06	0.724	0.75	0.476
1 Jun–26 Jul	6.55	0.684	0.45	0.502	1.99	0.518	0.42	0.516
Total (df)	52.16 (44)	0.186	5.06 (6)	0.536	19.41 (10)	**0.035**	3.85 (6)	0.697

	Test 3.Sm4		Test 3.SR5		Test 3.Sm5		Test 3.SR6	
	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	-	-	0.74	1.000	-	-	0.65	1.000
6–19 Apr	-	-	0.98	1.000	-	-	0.67	0.336
20 Apr–3 May	-	-	2.23	0.147	3.10	0.229	1.98	0.159
4–17 May	0.18	1.000	0.00	0.954	0.14	1.000	1.08	0.300
18–31 May	1.12	1.000	1.79	0.238	0.90	1.000	4.59	**0.049**
1 Jun–26 Jul	1.69	0.542	0.16	0.765	0.55	1.000	1.29	0.442
Total (df)	2.99 (6)	0.810	5.90 (6)	0.434	4.69 (4)	0.321	10.26 (6)	0.114

Appendix Table A4. Results of Test 2 and overall tests of goodness-of-fit to the single-release model for groups of Snake River juvenile steelhead in 2022. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for biweekly groups for tests.

	Overall (2+3)		Test 2 (sum)		Test 2.C2	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	18.02	0.388	15.71	0.108	6.64	0.217
6–19 Apr	24.69	0.102	17.35	0.067	5.38	0.243
20 Apr–3 May	30.14	0.068	14.17	0.165	8.57	0.073
4–17 May	53.35	**<0.001**	40.21	**<0.001**	28.49	**<0.001**
18–31 May	14.82	0.464	7.49	0.679	3.43	0.367
1 Jun–19 Jul	32.34	**0.040**	22.67	**0.012**	0.80	0.939
Total (df)	173.36 (109)	**<0.001**	117.60 (60)	**<0.001**	53.21 (24)	**0.001**

	Test 2.C3		Test 2.C4		Test 2.C5	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	4.86	0.296	0.50	0.738	3.71	0.089
6–19 Apr	3.77	0.215	8.02	**0.018**	0.18	0.751
20 Apr–3 May	0.80	0.849	1.66	0.436	3.14	0.076
4–17 May	10.17	**0.017**	0.41	0.725	1.14	0.287
18–31 May	4.02	0.198	0.02	1.000	0.02	0.901
1 Jun–19 Jul	14.23	**0.003**	2.28	0.371	5.36	**0.030**
Total (df)	37.85 (18)	**0.004**	12.89 (12)	0.377	13.55 (6)	**0.035**

Appendix Table A5. Results of Test 3 tests of goodness-of-fit to the single-release model for groups of Snake River juvenile steelhead in 2022. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for biweekly groups for tests.

Release	Test 3 (sum)		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
period	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	2.31	0.941	0.01	1.000	0.24	1.000	0.55	0.687
6–19 Apr	7.34	0.394	0.79	1.000	-	-	1.00	0.401
20 Apr–3 May	15.97	0.100	0.92	0.336	2.36	0.479	4.96	**0.026**
4–17 May	13.14	0.216	0.13	0.719	4.09	0.278	0.92	0.339
18–31 May	7.33	0.197	4.99	**0.016**	-	-	0.92	1.000
1 Jun–19 Jul	9.67	0.470	1.40	0.237	3.37	0.392	2.81	0.093
Total (df)	55.76 (49)	0.236	8.24 (6)	0.221	10.06 (10)	0.435	11.16 (6)	0.084

	Test 3.Sm4		Test 3.SR5		Test 3.Sm5		Test 3.SR6	
	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–5 Apr	0.70	1.000	0.61	1.000	-	-	0.20	0.646
6–19 Apr	3.09	0.202	0.02	1.000	0.93	1.000	1.51	0.211
20 Apr–3 May	4.11	0.321	2.54	0.111	0.98	1.000	0.10	0.749
4–17 May	4.60	0.054	1.12	0.290	0.11	0.706	2.17	0.140
18–31 May	-	-	0.68	0.412	0.16	1.000	0.58	0.764
1 Jun–19 Jul	0.91	1.000	0.53	0.465	0.65	0.648	0.00	1.000
Total (df)	13.41 (10)	0.202	5.50 (6)	0.481	2.83 (5)	0.726	4.56 (6)	0.601

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

Appendix Table B1. Survival probability estimates for yearling Chinook salmon released from Snake River Basin hatcheries in 2022. 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
			Yearling Chinook salmon			
Clearwater Hatchery						
Clear Creek	9,742	1.012 (0.030)	0.680 (0.097)	1.258 (0.322)	1.378 (0.664)	1.194 (0.512)
Powell Pond	25,463	0.715 (0.014)	0.735 (0.108)	1.136 (0.328)	0.832 (0.266)	0.496 (0.099)
Red River Pond	17,083	0.881 (0.022)	0.763 (0.124)	1.056 (0.277)	1.096 (0.416)	0.778 (0.246)
Selway River	17,006	0.764 (0.016)	0.491 (0.064)	1.772 (0.662)	0.702 (0.287)	0.467 (0.096)
N Fork Clearwater R	17,076	0.971 (0.020)	1.106 (0.267)	0.521 (0.178)	1.334 (0.459)	0.747 (0.181)
Dworshak Hatchery						
N Fork Clearwater R	41,846	0.911 (0.015)	0.719 (0.084)	0.978 (0.186)	0.839 (0.184)	0.538 (0.084)
Kooskia Hatchery						
Kooskia	6,000	0.748 (0.034)	0.758 (0.278)	1.415 (0.931)	1.553 (1.377)	1.247 (0.862)
Lookingglass Hatchery						
Catherine Creek Pond	20,929	0.530 (0.016)	0.756 (0.096)	1.070 (0.215)	0.646 (0.157)	0.277 (0.050)
Grande Ronde Pond	1,993	0.491 (0.046)	0.727 (0.158)	1.832 (0.932)	1.243 (1.339)	0.812 (0.787)
Imnaha River	8,988	0.260 (0.016)	0.531 (0.090)	1.385 (0.507)	0.924 (0.590)	0.176 (0.095)
Imnaha Weir	11,968	0.639 (0.024)	0.839 (0.129)	1.219 (0.386)	0.661 (0.337)	0.432 (0.182)
Lookingglass Hatchery	4,970	0.622 (0.029)	0.800 (0.123)	1.077 (0.269)	1.878 (1.344)	1.006 (0.690)
Lostine Pond	1,363	0.460 (0.042)	1.021 (0.308)	1.602 (0.986)	NA	NA
McCall Hatchery						
Knox Bridge	51,745	0.732 (0.012)	0.812 (0.071)	0.972 (0.134)	0.775 (0.132)	0.448 (0.059)
Johnson Creek	2,029	0.611 (0.062)	0.673 (0.222)	0.736 (0.354)	NA	NA
Nez Perce Tribal Hatchery						
Nez Perce Hatchery	5,200	0.755 (0.040)	0.571 (0.098)	0.902 (0.263)	NA	NA
Sweetwater Creek	600	0.593 (0.149)	0.823 (0.799)	NA	NA	NA
Pahsimeroi Hatchery						
Pahsimeroi Pond	21,356	0.468 (0.012)	0.712 (0.084)	1.443 (0.300)	0.741 (0.236)	0.357 (0.095)

Appendix Table B1. 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
			Yearling Chinook salmon			
Rapid River Hatchery						
Rapid River Hatchery	51,869	0.737 (0.010)	0.674 (0.059)	1.011 (0.151)	1.103 (0.234)	0.553 (0.096)
Sawtooth Hatchery						
Alturas Lake Creek	1,000	0.638 (0.055)	0.696 (0.194)	1.200 (0.627)	0.506 (0.382)	0.270 (0.163)
Hells Canyon Dam	1,992	0.666 (0.039)	0.563 (0.153)	1.364 (0.618)	1.531 (1.171)	0.784 (0.526)
Sawtooth Hatchery	18,868	0.706 (0.018)	0.605 (0.065)	1.450 (0.311)	0.574 (0.173)	0.355 (0.083)
Yankee Fork	8,484	0.232 (0.014)	1.552 (0.642)	1.629 (1.708)	0.617 (0.848)	0.363 (0.351)

Appendix Table B2. Survival probability estimates for juvenile steelhead released from Snake River Basin hatcheries in 2022. 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	10,608	0.734 (0.013)	0.939 (0.139)	0.826 (0.203)	0.775 (0.201)	0.441 (0.072)
Newsome Creek	15,689	0.725 (0.011)	0.801 (0.088)	1.433 (0.303)	0.929 (0.288)	0.773 (0.194)
S Fork Clearwater R	4,647	0.721 (0.017)	0.786 (0.138)	1.190 (0.578)	0.790 (0.424)	0.532 (0.146)
Dworshak Hatchery						
Clear Creek	6,888	0.721 (0.014)	0.736 (0.094)	1.412 (0.524)	0.471 (0.202)	0.353 (0.086)
S Fork Clearwater R	5,973	0.688 (0.015)	0.790 (0.120)	1.403 (0.502)	0.592 (0.282)	0.452 (0.155)
Mainstem Clearwater R	19,940	0.757 (0.008)	0.882 (0.078)	1.108 (0.267)	0.734 (0.210)	0.542 (0.096)
Hagerman Hatchery						
East Fork Salmon R	8,576	0.603 (0.019)	0.961 (0.156)	0.717 (0.167)	0.549 (0.147)	0.228 (0.047)
Sawtooth Hatchery	22,906	0.668 (0.010)	0.996 (0.142)	1.442 (0.381)	0.560 (0.174)	0.537 (0.116)
Irrigon Hatchery						
Big Canyon Facility	6,793	0.746 (0.017)	0.913 (0.149)	0.745 (0.213)	0.973 (0.372)	0.494 (0.148)
Little Sheep Facility	14,915	0.730 (0.011)	1.098 (0.115)	0.751 (0.117)	0.773 (0.173)	0.465 (0.089)
Wallowa Hatchery	10,739	0.710 (0.013)	0.816 (0.102)	1.102 (0.261)	0.589 (0.176)	0.376 (0.082)
Lyons Ferry Hatchery						
Cottonwood Pond	5,989	0.567 (0.010)	0.881 (0.134)	1.461 (0.593)	0.794 (0.443)	0.580 (0.238)

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 (continued)			
Magic Valley Hatchery						
Little Salmon R	4,393	0.896 (0.022)	0.920 (0.176)	0.745 (0.216)	1.060 (0.450)	0.650 (0.237)
Pahsimeroi R Trap	11,358	0.727 (0.015)	1.355 (0.246)	0.679 (0.174)	1.188 (0.443)	0.795 (0.259)
Sawtooth Hatchery	5,690	0.773 (0.018)	0.852 (0.189)	1.070 (0.332)	0.701 (0.312)	0.494 (0.192)
Yankee Fork	13,210	0.692 (0.013)	0.932 (0.102)	1.010 (0.172)	0.990 (0.269)	0.644 (0.152)
Niagara Springs Hatchery						
Hells Canyon Dam	8,578	0.785 (0.016)	0.859 (0.110)	0.697 (0.144)	1.246 (0.355)	0.585 (0.134)
Little Salmon R	5,080	0.863 (0.021)	0.940 (0.201)	0.917 (0.324)	0.524 (0.224)	0.390 (0.123)
Pahsimeroi R Trap	8,882	0.707 (0.016)	0.830 (0.139)	2.644 (1.222)	0.469 (0.299)	0.727 (0.341)

Appendix Table B3. Survival probability estimates for juvenile Sockeye and Coho salmon released from Snake River Basin hatcheries for migration year 2022. 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								
Springfield Hatchery								
Redfish Lake Creek	3-4 May 2022	49,830	0.602 (0.011)	1.087 (0.282)	1.296 (0.458)	0.747 (0.224)	1.052 (0.188)	0.633 (0.112)
Coho salmon								
Cascade Hatchery								
Lostine River	30 March 2022	1,000	0.390 (0.044)	0.498 (0.358)	NA	NA	NA	NA
Eagle Creek Hatchery								
Kooskia Hatchery	27-28 Mar 2022	4,998	0.614 (0.026)	0.812 (0.414)	1.449 (1.224)	0.475 (0.382)	0.559 (0.250)	0.343 (0.153)
N Lapwai Valley P	29 March 2022	4,997	0.842 (0.027)	0.702 (0.194)	2.528 (2.519)	0.371 (0.405)	0.657 (0.342)	0.554 (0.287)
Kooskia Hatchery								
Kooskia Hatchery	28 March 2022	4,000	0.428 (0.027)	0.698 (0.357)	0.979 (0.803)	NA	NA	NA

Appendix Table B4. Detection probability estimates for yearling Chinook salmon released from Snake River Basin hatcheries in 2022. 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	9,742	0.365 (0.012)	0.082 (0.012)	0.069 (0.015)	0.007 (0.003)
Powell Pond	25,463	0.475 (0.010)	0.047 (0.007)	0.026 (0.006)	0.016 (0.003)
Red River Pond	17,083	0.383 (0.010)	0.053 (0.009)	0.047 (0.010)	0.008 (0.003)
Selway River	17,006	0.538 (0.012)	0.070 (0.010)	0.021 (0.008)	0.018 (0.004)
N F Clearwater R	17,076	0.482 (0.011)	0.027 (0.006)	0.031 (0.008)	0.012 (0.003)
Dworshak Hatchery					
N F Clearwater R	41,846	0.407 (0.007)	0.042 (0.005)	0.040 (0.006)	0.013 (0.002)
Kooskia Hatchery					
Kooskia	6,000	0.434 (0.021)	0.045 (0.017)	0.035 (0.019)	0.008 (0.006)
Lookingglass Hatchery					
Catherine Cr Pond	20,929	0.323 (0.010)	0.077 (0.010)	0.087 (0.014)	0.033 (0.006)
Grande Ronde P	1,993	0.297 (0.031)	0.124 (0.027)	0.042 (0.020)	0.012 (0.012)
Imnaha Weir	8,988	0.338 (0.022)	0.187 (0.031)	0.115 (0.038)	0.023 (0.013)
Imnaha River	11,968	0.317 (0.013)	0.095 (0.015)	0.067 (0.019)	0.012 (0.005)
Lookingglass H	4,970	0.383 (0.020)	0.077 (0.012)	0.073 (0.016)	0.008 (0.006)
Lostine Pond	1,363	0.390 (0.039)	0.080 (0.026)	0.040 (0.023)	0.000 (0.000)
McCall Hatchery					
Knox Bridge	51,745	0.346 (0.006)	0.066 (0.006)	0.070 (0.007)	0.020 (0.003)
Johnson Creek	2,029	0.330 (0.036)	0.068 (0.023)	0.069 (0.027)	NA
Nez Perce Tribal Hatchery					
Nez Perce H	5,200	0.390 (0.022)	0.085 (0.015)	0.066 (0.017)	NA
Sweetwater Creek	600	0.298 (0.078)	0.042 (0.041)	NA	NA
Pahsimeroi Hatchery					
Pahsimeroi Pond	21,356	0.396 (0.011)	0.097 (0.012)	0.072 (0.012)	0.015 (0.004)
Rapid River Hatchery					
Rapid River H	51,869	0.452 (0.007)	0.071 (0.006)	0.060 (0.007)	0.013 (0.002)
Sawtooth Hatchery					
Alturas Lake Cr	1,000	0.458 (0.043)	0.104 (0.031)	0.055 (0.027)	0.030 (0.021)
Hells Canyon D	1,992	0.540 (0.034)	0.054 (0.016)	0.040 (0.016)	0.015 (0.010)
Sawtooth H	18,868	0.392 (0.010)	0.098 (0.011)	0.062 (0.012)	0.016 (0.004)
Yankee Fork	8,484	0.384 (0.025)	0.045 (0.019)	0.022 (0.022)	0.006 (0.006)

Appendix Table B5. Detection probability estimates for juvenile steelhead released from Snake River Basin hatcheries in 2022. 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	10,608	0.629 (0.012)	0.068 (0.010)	0.066 (0.013)	0.043 (0.008)
Newsome Creek	15,689	0.602 (0.010)	0.085 (0.010)	0.049 (0.009)	0.012 (0.003)
S Fork Clearwater R	4,647	0.697 (0.017)	0.093 (0.017)	0.035 (0.016)	0.035 (0.010)
Dworshak Hatchery					
Clear Creek	6,888	0.658 (0.014)	0.150 (0.020)	0.043 (0.015)	0.032 (0.009)
S Fork Clearwater R	5,973	0.645 (0.015)	0.120 (0.019)	0.055 (0.018)	0.019 (0.007)
Mainstem Clearwater	19,940	0.689 (0.008)	0.128 (0.012)	0.034 (0.008)	0.021 (0.004)
Hagerman Hatchery					
East Fork Salmon R	8,576	0.410 (0.014)	0.088 (0.015)	0.126 (0.021)	0.034 (0.008)
Sawtooth Hatchery	22,906	0.586 (0.009)	0.050 (0.007)	0.027 (0.006)	0.011 (0.003)
Irrigon Hatchery					
Big Canyon Facility	6,793	0.616 (0.015)	0.076 (0.013)	0.053 (0.013)	0.018 (0.006)
Little Sheep Facility	14,915	0.596 (0.010)	0.068 (0.007)	0.090 (0.011)	0.020 (0.004)
Wallowa Hatchery	10,739	0.604 (0.012)	0.084 (0.011)	0.052 (0.011)	0.021 (0.005)
Lyons Ferry Hatchery					
Cottonwood Pond	5,989	0.832 (0.012)	0.112 (0.018)	0.029 (0.011)	0.011 (0.005)
Magic Valley Hatchery					
Little Salmon R	4,393	0.578 (0.016)	0.084 (0.017)	0.078 (0.017)	0.013 (0.005)
Pahsimeroi R Trap	11,358	0.499 (0.011)	0.045 (0.008)	0.055 (0.010)	0.007 (0.002)
Sawtooth Hatchery	5,690	0.584 (0.015)	0.057 (0.013)	0.070 (0.015)	0.009 (0.004)
Yankee Fork	13,210	0.471 (0.010)	0.087 (0.010)	0.102 (0.013)	0.015 (0.004)
Niagara Springs Hatchery					
Hells Canyon Dam	8,578	0.559 (0.013)	0.094 (0.012)	0.108 (0.018)	0.028 (0.007)
Little Salmon R	5,080	0.596 (0.016)	0.067 (0.015)	0.061 (0.017)	0.016 (0.006)
Pahsimeroi Trap	8,882	0.570 (0.014)	0.084 (0.014)	0.020 (0.009)	0.006 (0.003)

Appendix Table B6. Detection probability estimates for juvenile Sockeye and Coho salmon released from Snake River Basin hatcheries for migration year 2022. Standard errors in parentheses.

Hatchery/ Release site	Release date	Number released	Detection probability: Lower Granite	Little Goose	Lower Monumental	McNary
			Sockeye salmon			
Springfield Hatchery						
Redfish Lake Creek	3-4 May	51,310	0.431 (0.008)	0.015 (0.004)	0.019 (0.005)	0.013 (0.002)
			Coho salmon			
Cascade Hatchery						
Lostine River	30 March	1,000	0.483 (0.058)	0.143 (0.104)	NA	0.071 (0.049)
Eagle Creek Hatchery						
Kooskia Hatchery	27-28 Mar	4,988	0.517 (0.023)	0.039 (0.020)	0.017 (0.011)	0.013 (0.006)
N Lapwai Valley P	29 March	4,999	0.565 (0.019)	0.041 (0.012)	0.008 (0.008)	0.006 (0.004)
Kooskia Hatchery						
Kooskia Hatchery	28 March	3,943	0.501 (0.033)	0.040 (0.021)	0.031 (0.020)	NA

Appendix Table B7. Survival probability estimates for juvenile salmonids released from traps in Snake River Basin in 2022. 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	28 Mar-24 May	52	121	1.175 (0.292)	NA	NA	NA	NA
Grande Ronde	09 Mar-26 May	100	494	0.856 (0.095)	0.842 (0.509)	0.998 (1.080)	0.566 (0.731)	0.407 (0.366)
Imnaha	01 Feb-27 May	142	4,772	0.734 (0.030)	0.758 (0.130)	1.361 (0.478)	0.845 (0.478)	0.640 (0.302)
Lolo Creek	12 Mar-27 May	159	424	0.790 (0.136)	0.803 (0.453)	0.513 (0.365)	NA	NA
Salmon	11 Mar-18 May	233	1,601	0.985 (0.072)	0.578 (0.214)	2.104 (1.612)	0.306 (0.285)	0.367 (0.234)
Lookingglass Cr	02 Feb-04 May	235	526	0.488 (0.066)	0.852 (0.508)	0.952 (0.993)	NA	NA
Minam	02 Apr-26 May	246	789	0.589 (0.050)	1.056 (0.358)	0.539 (0.251)	2.200 (2.193)	0.738 (0.696)
Lostine	06 Feb-26 May	274	1,019	0.661 (0.062)	0.954 (0.297)	2.499 (2.504)	0.106 (0.115)	0.168 (0.079)
Catherine Creek	08 Mar-26 May	362	701	0.314 (0.034)	0.557 (0.152)	1.590 (1.010)	0.875 (0.956)	0.243 (0.220)
U. Grande Ronde	24 Mar-25 May	397	697	0.558 (0.055)	0.905 (0.290)	0.717 (0.345)	0.677 (0.413)	0.246 (0.120)
S. Fork Salmon	14 Mar-10 Apr	408	1,211	0.615 (0.044)	0.712 (0.254)	1.371 (0.854)	0.705 (0.748)	0.423 (0.389)
Secesh River	18 Mar-17 May	411	502	0.748 (0.084)	0.945 (0.299)	0.991 (0.530)	NA	NA
Johnson Creek	04 Mar-23 May	436	785	0.537 (0.051)	0.659 (0.118)	1.432 (0.513)	0.727 (0.525)	0.368 (0.237)
Panther Creek	19 Mar-27 May	468	1,242	0.795 (0.058)	0.922 (0.178)	0.594 (0.159)	NA	NA
Big Creek	19 Mar-25 Apr	489	747	0.666 (0.075)	0.727 (0.336)	0.578 (0.416)	0.556 (0.560)	0.155 (0.126)
Lower Lemhi R.	29 Mar-27 May	553	1,043	0.765 (0.074)	1.159 (0.736)	0.901 (0.830)	0.388 (0.431)	0.310 (0.276)
Upper Lemhi R.	22 Mar-30 May	595	1,070	0.628 (0.064)	0.499 (0.175)	1.193 (0.836)	NA	NA
Pahsimeroi	17 Mar-31 May	621	229	0.537 (0.136)	NA	NA	NA	NA
Marsh Creek	20 Mar-03 May	630	345	0.506 (0.068)	NA	NA	NA	NA
Sawtooth	17 Mar-27 May	747	718	0.417 (0.048)	2.794 (2.602)	0.120 (0.124)	NA	NA

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	10 Mar-25 May	52	360	0.958 (0.091)	NA	NA	NA	NA
Asotin Creek	05 Feb-31 May	64	3,121	0.468 (0.027)	0.976 (0.286)	1.000 (0.540)	0.265 (0.165)	0.121 (0.050)
Big Bear Creek	31 Mar-31 May	99	438	0.675 (0.100)	0.892 (0.755)	0.298 (0.276)	NA	NA
Grande Ronde	13 Mar-26 May	100	69	0.826 (0.316)	NA	NA	NA	NA
Imnaha	06 Feb-27 May	142	3,350	0.854 (0.028)	1.308 (0.292)	1.406 (0.593)	0.611 (0.622)	0.959 (0.913)
Lolo Creek	12 Mar-27 May	159	378	1.104 (0.171)	0.372 (0.147)	NA	NA	NA
Lochsa River	18 Mar-16 May	208	360	0.884 (0.130)	0.500 (0.250)	0.577 (0.347)	NA	NA
Salmon	10 Mar-18 May	233	60	1.017 (0.461)	NA	NA	NA	NA
Lostine	06 Feb-29 May	274	286	0.066 (0.025)	NA	NA	NA	NA
Catherine Creek	14 Mar-29 May	362	451	0.113 (0.027)	NA	NA	NA	NA
U. Grande Ronde	24 Mar-28 May	397	563	0.570 (0.062)	1.219 (0.610)	0.433 (0.306)	0.793 (0.795)	0.238 (0.209)
Lower Lemhi R.	31 Mar-28 May	553	350	0.731 (0.091)	0.872 (0.733)	1.084 (1.359)	NA	NA
Hayden Creek	29 Mar-27 May	596	380	0.258 (0.056)	1.161 (1.018)	0.479 (0.564)	NA	NA
Sawtooth	17 Mar-27 May	747	955	0.196 (0.037)	0.354 (0.161)	NA	NA	NA
Hatchery Chinook Salmon								
Snake	28 Mar-25 May	52	1,024	0.935 (0.073)	1.814 (0.866)	0.621 (0.390)	0.722 (0.741)	0.761 (0.713)
Grande Ronde	03 Apr-26 May	100	1,094	0.676 (0.063)	0.967 (0.312)	0.653 (0.275)	0.501 (0.273)	0.214 (0.100)
Salmon	16 Mar-06 May	233	4,001	0.903 (0.039)	0.781 (0.124)	0.846 (0.197)	1.714 (1.206)	1.022 (0.697)
Hatchery steelhead								
Snake	01 Apr-25 May	52	3,475	0.939 (0.024)	0.952 (0.155)	1.172 (0.354)	1.850 (1.351)	1.938 (1.325)
Grande Ronde	05 Apr-26 May	100	1,241	0.822 (0.039)	0.547 (0.114)	1.475 (0.666)	0.725 (0.545)	0.480 (0.305)
Salmon	11 Apr-18 May	233	1,295	0.853 (0.041)	0.863 (0.194)	1.260 (0.490)	NA	NA

Appendix Table B8. Detection probability estimates for juvenile salmonids released from fish traps in Snake River Basin in 2022. 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	28 Mar-24 May	52	121	0.317 (0.089)	NA	0.226 (0.149)	NA
Grande Ronde	09 Mar-26 May	100	494	0.440 (0.054)	0.090 (0.056)	0.080 (0.072)	0.036 (0.035)
Imnaha	01 Feb-27 May	142	4,772	0.433 (0.019)	0.101 (0.018)	0.055 (0.017)	0.016 (0.008)
Lolo Creek	12 Mar-27 May	159	424	0.290 (0.055)	0.155 (0.085)	0.268 (0.110)	NA
Salmon	11 Mar-18 May	233	1,601	0.394 (0.031)	0.099 (0.037)	0.049 (0.033)	0.024 (0.017)
Lookingglass Cr	02 Feb-04 May	235	526	0.445 (0.065)	0.096 (0.059)	0.106 (0.092)	NA
Minam	02 Apr-26 May	246	789	0.445 (0.042)	0.129 (0.045)	0.196 (0.065)	0.025 (0.025)
Lostine	06 Feb-26 May	274	1,019	0.379 (0.039)	0.115 (0.036)	0.037 (0.036)	0.068 (0.038)
Catherine Creek	08 Mar-26 May	362	701	0.532 (0.060)	0.242 (0.072)	0.148 (0.090)	0.056 (0.054)
U. Grande Ronde	24 Mar-25 May	397	697	0.391 (0.044)	0.170 (0.056)	0.196 (0.072)	0.100 (0.055)
S. Fork Salmon	14 Mar-10 Apr	408	1,211	0.493 (0.038)	0.104 (0.039)	0.103 (0.053)	0.017 (0.017)
Secesh River	18 Mar-17 May	411	502	0.373 (0.048)	0.115 (0.038)	0.108 (0.051)	NA
Johnson Creek	04 Mar-23 May	436	785	0.378 (0.041)	0.232 (0.043)	0.143 (0.050)	0.057 (0.039)
Panther Creek	19 Mar-27 May	468	1,242	0.345 (0.029)	0.127 (0.025)	0.173 (0.038)	0.013 (0.012)
Big Creek	19 Mar-25 Apr	489	747	0.408 (0.050)	0.155 (0.072)	0.214 (0.115)	0.040 (0.039)
Lower Lemhi R.	29 Mar-27 May	553	1,043	0.381 (0.040)	0.063 (0.040)	0.060 (0.040)	0.018 (0.018)
Upper Lemhi R.	22 Mar-30 May	595	1,070	0.417 (0.046)	0.148 (0.053)	0.079 (0.050)	NA
Pahsimeroi	17 Mar-31 May	621	229	0.374 (0.102)	NA	NA	NA
Marsh Creek	20 Mar-03 May	630	345	0.447 (0.067)	NA	0.117 (0.103)	0.118 (0.078)
Sawtooth	17 Mar-27 May	747	718	0.431 (0.054)	0.052 (0.049)	0.219 (0.090)	NA

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	10 Mar-25 May	52	360	0.638 (0.066)	NA	NA	NA
Asotin Creek	05 Feb-31 May	64	3,121	0.472 (0.029)	0.083 (0.025)	0.076 (0.035)	0.040 (0.020)
Big Bear Creek	31 Mar-31 May	99	438	0.402 (0.065)	0.083 (0.071)	0.344 (0.105)	NA
Grande Ronde	13 Mar-26 May	100	69	0.509 (0.204)	NA	NA	NA
Imnaha	06 Feb-27 May	142	3,350	0.510 (0.019)	0.065 (0.015)	0.045 (0.016)	0.004 (0.004)
Lolo Creek	12 Mar-27 May	159	378	0.371 (0.062)	0.217 (0.084)	NA	NA
Lochsa River	18 Mar-16 May	208	360	0.437 (0.070)	0.070 (0.039)	0.121 (0.055)	NA
Salmon	10 Mar-18 May	233	60	0.443 (0.210)	NA	0.333 (0.272)	NA
Lostine	06 Feb-29 May	274	286	0.474 (0.187)	NA	NA	NA
Catherine Creek	14 Mar-29 May	362	451	0.647 (0.146)	NA	NA	NA
U. Grande Ronde	24 Mar-28 May	397	563	0.455 (0.054)	0.126 (0.064)	0.140 (0.073)	0.046 (0.044)
Lower Lemhi R.	31 Mar-28 May	553	350	0.497 (0.068)	0.084 (0.072)	0.068 (0.063)	NA
Hayden Creek	29 Mar-27 May	596	380	0.438 (0.100)	0.100 (0.090)	0.217 (0.178)	NA
Sawtooth	17 Mar-27 May	747	955	0.477 (0.093)	0.237 (0.109)	NA	NA
Hatchery Chinook salmon							
Snake	28 Mar-25 May	52	1,024	0.412 (0.036)	0.028 (0.014)	0.054 (0.024)	0.012 (0.012)
Grande Ronde	03 Apr-26 May	100	4,001	0.417 (0.020)	0.070 (0.012)	0.093 (0.017)	0.008 (0.006)
Salmon	16 Mar-06 May	233	1,094	0.365 (0.037)	0.067 (0.023)	0.112 (0.035)	0.039 (0.022)
Hatchery steelhead							
Snake	01 Apr-25 May	52	3,475	0.654 (0.018)	0.057 (0.010)	0.033 (0.009)	0.005 (0.004)
Grande Ronde	05 Apr-26 May	100	1,295	0.577 (0.031)	0.074 (0.018)	0.056 (0.019)	NA
Salmon	11 Apr-18 May	233	1,241	0.667 (0.034)	0.114 (0.026)	0.044 (0.019)	0.019 (0.013)

Appendix Table B9. Survival probability estimates for yearling Chinook, steelhead, and Coho salmon released from upper-Columbia River hatcheries in 2022. 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			
Cle Elum Hatchery						
Clark Flat Pond	16,001	0.484 (0.140)	0.438 (0.170)	1.015 (0.446)	0.445 (0.204)	0.215 (0.077)
Easton Pond	12,009	0.303 (0.096)	1.027 (0.591)	0.618 (0.452)	0.634 (0.403)	0.192 (0.106)
Jack Creek Pond	11,997	0.596 (0.258)	0.358 (0.196)	0.918 (0.532)	0.329 (0.212)	0.196 (0.093)
East Bank Hatchery						
Carlton Pond	5,216	0.302 (0.097)	1.773 (1.023)	0.871 (0.728)	1.544 (1.167)	0.466 (0.319)
Chelan River	10,369	0.395 (0.081)	2.316 (0.882)	0.472 (0.188)	1.094 (0.341)	0.432 (0.101)
Chiwawa Pond	10,451	1.134 (0.548)	0.510 (0.276)	0.831 (0.290)	0.424 (0.231)	0.481 (0.121)
Dryden Pond	20,937	0.611 (0.098)	0.770 (0.161)	1.063 (0.205)	0.818 (0.174)	0.500 (0.070)
Nason Acclimation F.	10,040	0.286 (0.085)	1.318 (0.491)	1.105 (0.495)	1.457 (0.711)	0.417 (0.162)
Entiat Hatchery						
Entiat Hatchery	19,969	0.480 (0.078)	0.950 (0.222)	1.479 (0.434)	1.405 (0.409)	0.674 (0.163)
Leavenworth Hatchery						
Leavenworth NFH	21,928	0.525 (0.124)	0.647 (0.184)	0.973 (0.270)	0.63 (0.206)	0.330 (0.075)
Methow Hatchery						
Chewuch Pond	4,992	0.379 (0.204)	0.513 (0.311)	1.278 (0.688)	0.656 (0.465)	0.249 (0.115)
Goatwall Pond	4,979	0.233 (0.219)	1.112 (1.209)	0.408 (0.310)	0.453 (0.489)	0.106 (0.056)
Methow Hatchery	4,968	0.244 (0.096)	NA	NA	NA	NA
Twisp Pond	4,988	0.354 (0.234)	0.694 (0.517)	NA	NA	NA
Wells Hatchery						
Wells Hatchery	10,980	0.487 (0.076)	1.232 (0.359)	0.974 (0.484)	1.200 (0.551)	0.584 (0.252)
Winthrop Hatchery						
Winthrop NFH	19,929	0.948 (0.460)	0.509 (0.283)	0.645 (0.206)	0.328 (0.169)	0.311 (0.052)

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			
Chiwawa Hatchery						
Chiwawa River	20,006	0.189 (0.038)	1.175 (0.311)	0.663 (0.174)	0.780 (0.216)	0.148 (0.029)
Wells Hatchery						
Antoine Creek	4,995	0.171 (0.074)	2.886 (2.308)	0.319 (0.233)	0.921 (0.47)	0.158 (0.044)
Methow Hatchery	4,998	NA	NA	NA	NA	NA
Salmon Creek	4,999	0.323 (0.174)	1.490 (1.288)	0.616 (0.509)	0.917 (0.656)	0.297 (0.140)
Similkameen Pond	4,996	0.378 (0.251)	1.124 (0.967)	0.894 (0.694)	1.005 (0.866)	0.380 (0.209)
St. Marys Pond	4,993	0.238 (0.104)	NA	NA	NA	NA
Twisp River	2,496	0.138 (0.089)	1.116 (1.275)	0.630 (0.835)	0.703 (0.798)	0.097 (0.090)
Wells Hatchery	4,997	0.267 (0.063)	1.580 (0.590)	0.370 (0.131)	0.584 (0.182)	0.156 (0.032)
Winthrop NFH	2,497	0.161 (0.061)	1.950 (1.481)	0.626 (0.530)	1.222 (0.791)	0.196 (0.104)
Winthrop Hatchery						
Twisp Pond	4,464	0.049 (0.018)	NA	NA	NA	NA
Winthrop NFH	31,217	0.216 (0.052)	1.505 (0.472)	0.597 (0.144)	0.898 (0.244)	0.194 (0.025)

Appendix Table B9. Continued.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
Coho salmon						
Cascade Hatchery						
Eightmile Pond	2,474	0.208 (0.088)	1.915 (1.493)	NA	NA	NA
Leavenworth NFH	5,000	0.194 (0.050)	2.116 (0.965)	1.635 (1.096)	NA	NA
Rolfing Pond	9,999	0.284 (0.068)	0.854 (0.269)	0.983 (0.348)	0.840 (0.315)	0.238 (0.069)
Twisp Pond	2,498	0.224 (0.094)	1.491 (0.914)	1.111 (0.715)	1.656 (1.029)	0.371 (0.172)
Wells Hatchery						
Twisp Pond	2,488	0.266 (0.120)	1.057 (0.736)	1.723 (1.897)	1.820 (1.937)	0.485 (0.468)
Willard Hatchery						
Beaver Creek Pond	4,999	0.212 (0.096)	2.080 (1.697)	0.348 (0.325)	0.723 (0.568)	0.154 (0.099)
Chewuch Pond	5,001	0.420 (0.156)	2.692 (2.097)	0.452 (0.363)	1.217 (0.681)	0.512 (0.215)
Eightmile Pond	4,985	0.275 (0.100)	1.030 (0.532)	1.719 (1.135)	1.770 (1.164)	0.486 (0.267)
Leavenworth NFH	5,000	0.176 (0.062)	1.403 (0.760)	0.725 (0.418)	1.017 (0.547)	0.179 (0.072)
Winthrop Hatchery						
Early Winters Pond	4,995	0.297 (0.105)	1.051 (0.529)	0.663 (0.271)	0.697 (0.281)	0.207 (0.040)
Midvalley Pond	4,981	NA	NA	NA	NA	NA
Winthrop NFH	4,973	0.237 (0.083)	2.341 (1.759)	0.590 (0.436)	1.380 (0.652)	0.328 (0.105)
Yakima Hatchery						
Prosser Hatchery	2,039	0.022 (0.011)	2.954 (3.017)	0.254 (0.307)	0.750 (0.688)	0.016 (0.013)
Yakima River	9,672	0.217 (0.101)	0.814 (0.509)	0.758 (0.471)	0.617 (0.405)	0.134 (0.062)

Appendix Table B10. Detection probability estimates for yearling Chinook salmon, steelhead, and Coho salmon released from upper-Columbia River hatcheries in 2022. Standard errors in parentheses.

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Yearling Chinook salmon		
Cle Elum Hatchery				
Clark Flat Pond	16,001	0.024 (0.007)	0.034 (0.009)	0.088 (0.032)
Easton Pond	12,009	0.034 (0.011)	0.020 (0.010)	0.070 (0.039)
Jack Creek Pond	11,997	0.016 (0.007)	0.036 (0.012)	0.074 (0.036)
East Bank Hatchery				
Carlton Pond	5,216	0.036 (0.012)	0.026 (0.013)	0.047 (0.032)
Chelan River	10,369	0.027 (0.006)	0.016 (0.005)	0.090 (0.021)
Chiwawa Pond	10,451	0.005 (0.003)	0.025 (0.006)	0.093 (0.024)
Dryden Pond	20,937	0.020 (0.003)	0.033 (0.005)	0.089 (0.013)
Nason Acclimation F.	10,040	0.016 (0.005)	0.042 (0.010)	0.082 (0.032)
Entiat Hatchery				
Entiat Hatchery	19,969	0.027 (0.005)	0.034 (0.006)	0.043 (0.011)
Leavenworth Hatchery				
Leavenworth NFH	21,928	0.014 (0.004)	0.040 (0.007)	0.096 (0.022)
Methow Hatchery				
Chewuch Pond	4,992	0.013 (0.008)	0.056 (0.017)	0.125 (0.058)
Goatwall Pond	4,979	0.008 (0.008)	0.036 (0.020)	0.122 (0.066)
Methow Hatchery	4,968	0.019 (0.008)	0.019 (0.009)	0.039 (0.027)
Twisp Pond	4,988	0.010 (0.007)	0.043 (0.016)	0.021 (0.021)
Wells Hatchery				
Wells Hatchery	10,980	0.054 (0.009)	0.035 (0.009)	0.052 (0.022)
Winthrop Hatchery				
Winthrop NFH	19,929	0.004 (0.002)	0.013 (0.004)	0.113 (0.019)
		Steelhead		
Chiwawa Hatchery				
Chiwawa River	20,006	0.028 (0.006)	0.052 (0.010)	0.123 (0.025)
Wells Hatchery				
Antoine Creek	4,995	0.019 (0.009)	0.010 (0.007)	0.185 (0.053)
Methow Hatchery	4,998	NA	0.007 (0.004)	0.128 (0.033)
Salmon Creek	4,999	0.016 (0.009)	0.012 (0.009)	0.082 (0.039)
Similkameen Pond	4,996	0.010 (0.007)	0.017 (0.010)	0.073 (0.041)
St. Marys Pond	4,993	0.014 (0.007)	0.004 (0.004)	0.132 (0.039)
Twisp River	2,496	0.046 (0.032)	0.031 (0.031)	0.091 (0.087)
Wells Hatchery	4,997	0.039 (0.011)	0.038 (0.012)	0.287 (0.060)
Winthrop NFH	2,497	0.052 (0.023)	0.026 (0.018)	0.125 (0.068)
Winthrop Hatchery				
Twisp Pond	4,464	0.041 (0.020)	NA	0.143 (0.059)
Winthrop NFH	31,217	0.011 (0.003)	0.018 (0.004)	0.141 (0.019)

Appendix Table B10. Continued.

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Coho salmon		
Cascade Hatchery				
Eightmile Pond	2,474	0.029 (0.014)	0.016 (0.011)	NA
Leavenworth NFH	5,000	0.035 (0.011)	0.023 (0.009)	0.065 (0.036)
Rolfing Pond	9,999	0.029 (0.008)	0.048 (0.011)	0.143 (0.042)
Twisp Pond	2,498	0.025 (0.012)	0.030 (0.015)	0.118 (0.055)
Wells Hatchery				
Twisp Pond	2,488	0.038 (0.018)	0.036 (0.020)	0.056 (0.054)
Willard Hatchery				
Beaver Creek Pond	4,999	0.024 (0.012)	0.015 (0.011)	0.167 (0.108)
Chewuch Pond	5,001	0.018 (0.007)	0.006 (0.005)	0.102 (0.043)
Eightmile Pond	4,985	0.023 (0.009)	0.026 (0.010)	0.083 (0.046)
Leavenworth NFH	5,000	0.031 (0.012)	0.031 (0.014)	0.149 (0.061)
Winthrop Hatchery				
Early Winters Pond	4,995	0.017 (0.007)	0.018 (0.007)	0.278 (0.056)
Midvalley Pond	4,981	NA	0.009 (0.005)	0.105 (0.038)
Winthrop NFH	4,973	0.020 (0.008)	0.007 (0.005)	0.151 (0.049)
Yakima Hatchery				
Prosser Hatchery	2,039	0.091 (0.061)	0.077 (0.074)	0.333 (0.272)
Yakima River	9,672	0.017 (0.008)	0.026 (0.011)	0.129 (0.060)

Appendix C: Environmental Conditions and Salmonid Passage Timing

Methods

In August 2022 we obtained data on daily flow, temperature, spill, and dissolved gas saturation (TDG) at Snake River dams from Columbia River DART (1996-present). We also obtained collection counts of yearling Chinook salmon and steelhead (hatchery and wild combined) compiled by the Smolt Monitoring Program (FPC 2021a).

Using these data, we created plots to compare daily measures of flow, temperature, spill, and TDG in 2022 vs. in selected recent years. We plotted conditions in 2022 against long-term daily quantiles using values from 1989-2022 for flow and temperature and from 2006-2022 for spill and TDG. Periods selected for flow and temperature quantiles were based on available data. For spill and TDG we used only the period since the first year of court-ordered spill.

We combined collection count data with daily estimates of the proportion of fish that used the juvenile bypass system (equivalent to daily estimates of PIT-tag detection probability) to calculate daily estimates of the number of smolts passing Lower Granite Dam. For visual comparison, we normalized daily estimates by dividing by the annual total and created plots of daily passage proportions to compare with those during selected recent years 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 percentiles of PIT-tag detection at Lower Monumental Dam for the daily group. We then investigated the relationship between this index and estimates of travel time from Lower Granite Dam to McNary Dam tailrace (results shown in Figure 3).

Results

Environmental conditions in 2022 resulted in a very late spring freshet and cooler-than-average water temperatures, and management actions produced extremely high spill percentages for the whole migration season. During the main migration period of 1 April-15 June, mean flow at Little Goose Dam was 79.5 kcfs, which was moderately below the long-term mean of 91.5 kcfs (1993-2022). Daily flow values were far below long-term daily medians for the entirety of April and for much of May, with the exception of two brief pulses of flow around 7 and 18 May. The spring freshet was delayed, and did not noticeably start until mid-May. The spring freshet did not reach full force until the beginning of June, but once it did, daily flow values were far above the long-term daily median through the first half of June (Appendix Figure C1).

At Little Goose Dam, mean water temperature during the 2022 migration period was 10.0°C, which was below the long-term mean of 11.2°C (1993-2022). Spring 2022 was the third coldest spring in the past 30 years. Daily water temperatures were one to two degrees cooler than average except during the very beginning of April and during brief spikes in temperature around 7 and 21 May and 1 June. All three of these spikes in water temperature appeared to be roughly coincident with increases in flow (Appendix Figure C1).

At Snake River dams, mean spill discharge during the 2022 migration was 46.6 kcfs, which was well above the 2006-2022 mean of 36.3 kcfs and was the fourth highest rate of spill discharge in the past 30 years. Daily spill discharge was essentially average for the month of April, but far above average during May and especially far above average in early June (Appendix Figure C2).

Spill as a percentage of flow at Snake River dams averaged 59.5% in 2022, considerably greater than the long-term mean of 39.3% (2006-2022). Spill proportions in 2022 were only slightly below those in 2020 and 2021, and 2022 had the third highest mean spill percent on record. Daily mean spill percentages in 2022 were very consistent and extremely high for all of April and May. While not quite as high, daily mean spill percentages were still above average in early June (Appendix Figure C2).

Daily mean percent dissolved gas saturation was substantially above the long-term median in 2022, but not as high as in 2020, likely due to the lower absolute levels of spill discharge in 2022 (Appendix Figure C3). Daily mean percent dissolved gas saturation was actually slightly below the long-term median for most of April, but rose considerably in May and again in early June. Daily dissolved gas values ranged between 118 and 122% for the majority of May and June, but peaks in daily dissolved gas briefly exceeded 125% around 11 June.

Peaks in both Chinook and steelhead passage at Lower Granite Dam were later than normal in 2022, with few fish of either species passing prior to 20 April. The first noticeable increase in flow, from 7-10 May, appeared to be associated with an enormous spike in passage of both species at about the same time (Appendix Figure C4). Earlier small increases in passage around 30 April and 4 May occurred during a period when flow was quite low, though water temperatures were rising.

Daily water temperature and flow values are typically highly correlated across all four federal dams in the lower Columbia River, and we illustrated these patterns using data from The Dalles Dam (Appendix Figure C5). Daily flow values at these dams in 2022 were well below the long-term median for April and most of May, but rose to well above the long-term median by early June. In mid-to-late April, daily flows were among the lowest recorded in the past three decades. In contrast, early June flows were among the highest seen in the past three decades.

Daily water temperature values in 2022 were consistently about one degree cooler than average in the lower Columbia River for nearly the entire migration period (Appendix Figure C5). The exceptions were during the first week of April, when water temperatures were about equal to average, and during early June, when water temperatures were one to two degrees below average.

Daily and seasonal spill patterns varied widely among the four lower Columbia River dams in 2022. At McNary Dam, daily spill volumes steadily increased from slightly below average during April, to slightly above average during May, and finally to far above average during early June (Appendix Figure C6). However, spill as a percentage of flow at McNary Dam was far above average for the entire migration period, and during the month of May it was the highest yet seen at McNary.

At John Day Dam, spill volume was slightly above average overall. Similar to spill volumes at McNary, daily spill volumes at John Day started slightly below average during April but rose steadily over the season and by early June were far above average (Appendix Figure C7). In contrast, spill as a percentage of flow was extremely high for the entire migration season in 2022, even more so at John Day than at McNary. During April, daily spill percentages were close to the highest ever recorded at John Day, and during much of May daily spill percentages were the highest ever recorded.

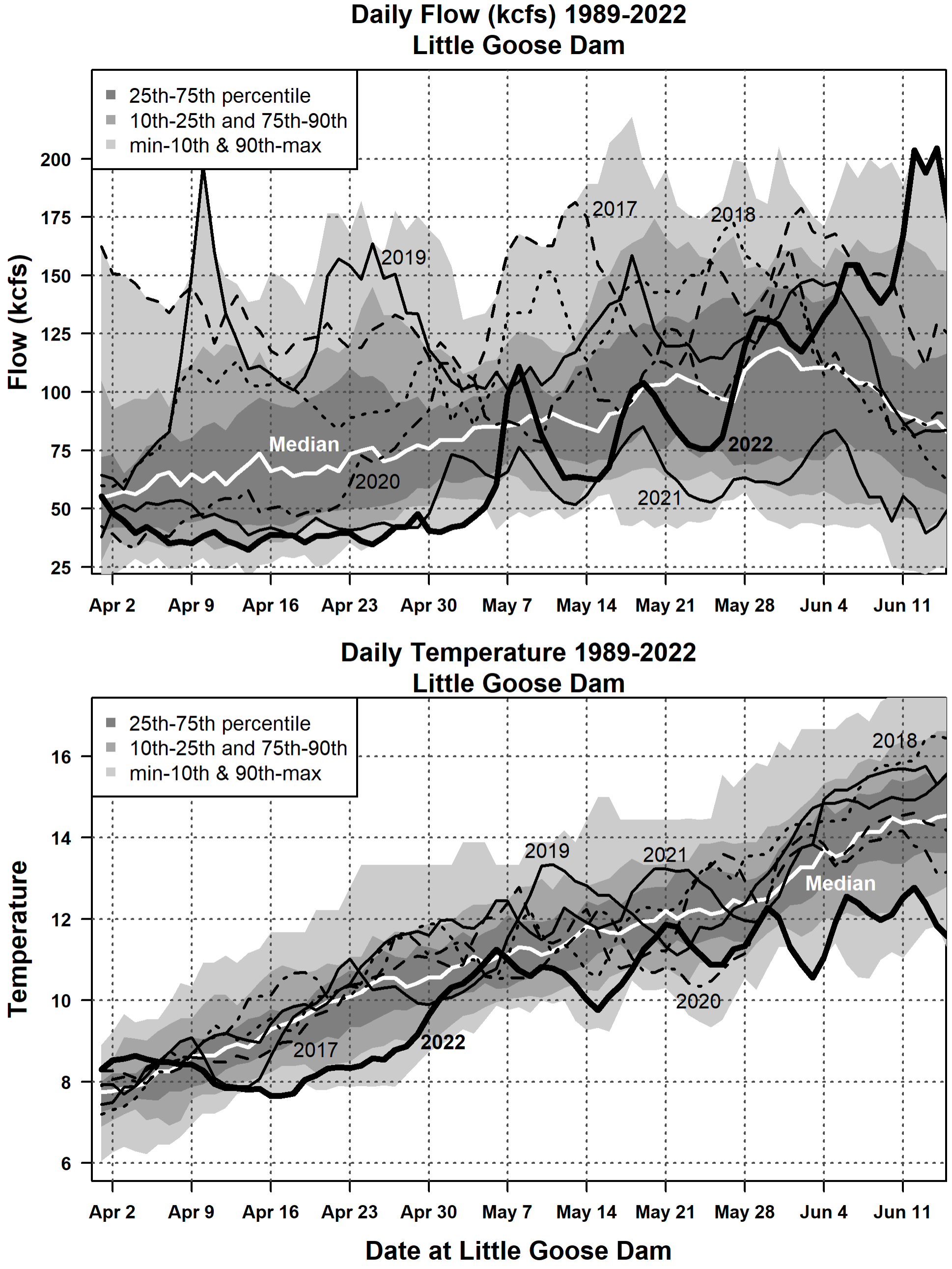
Spill operations at The Dalles Dam are less variable from year to year than at other dams, primarily because of operations designed to match a constant target of 40% spill. This spill percentage was matched almost exactly during April and May 2022 (Appendix Figure C8). However, because flow was well below average, spill volumes at

The Dalles were also below average in April and May. In early June, increases in flow resulted in forced spill above the 40% target, and as a result, both spill percent and spill volume rose sharply to levels among the highest on record for The Dalles.

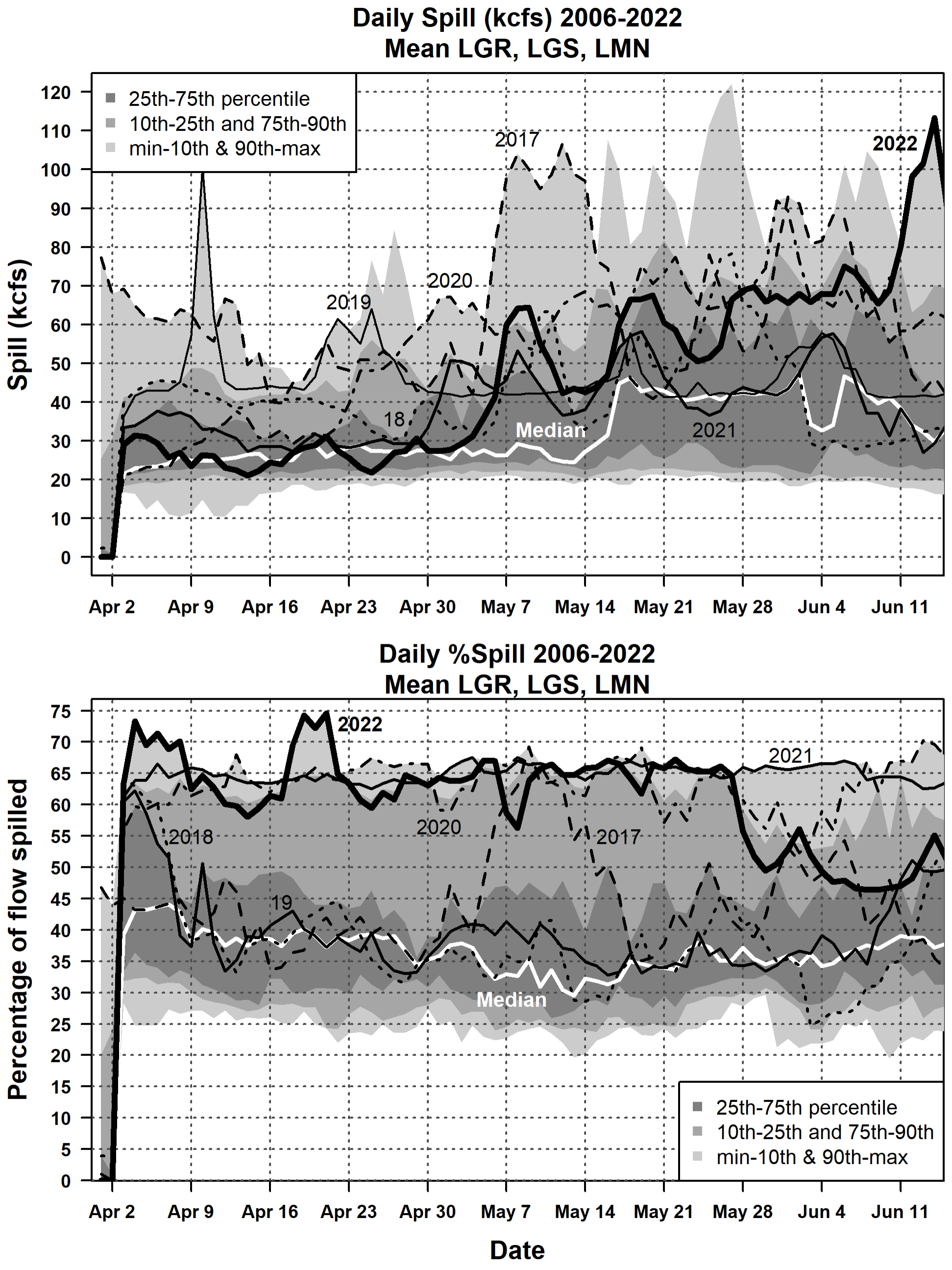
At Bonneville Dam in 2022, daily spill volumes were average in early April and slightly above average in late April and May, but spill volumes rose to well above average in early June (Appendix Figure C9). However, spill as a percentage of flow was extremely high at Bonneville Dam during April and well above average for most of May. By early June, daily spill percentage declined at Bonneville to only slightly above average.

Daily mean percent dissolved gas saturation stayed close to the long-term median in April and May 2022 at McNary and John Day Dam (Appendix Figure C10). During late May, daily dissolved gas saturation began to rise and by early June had reached levels well above average at both dams. Daily mean percent dissolved gas saturation was more variable at The Dalles Dam, but still showed the same general pattern of a rise from near-average daily values in April to far above average in early June (Appendix Figure C11).

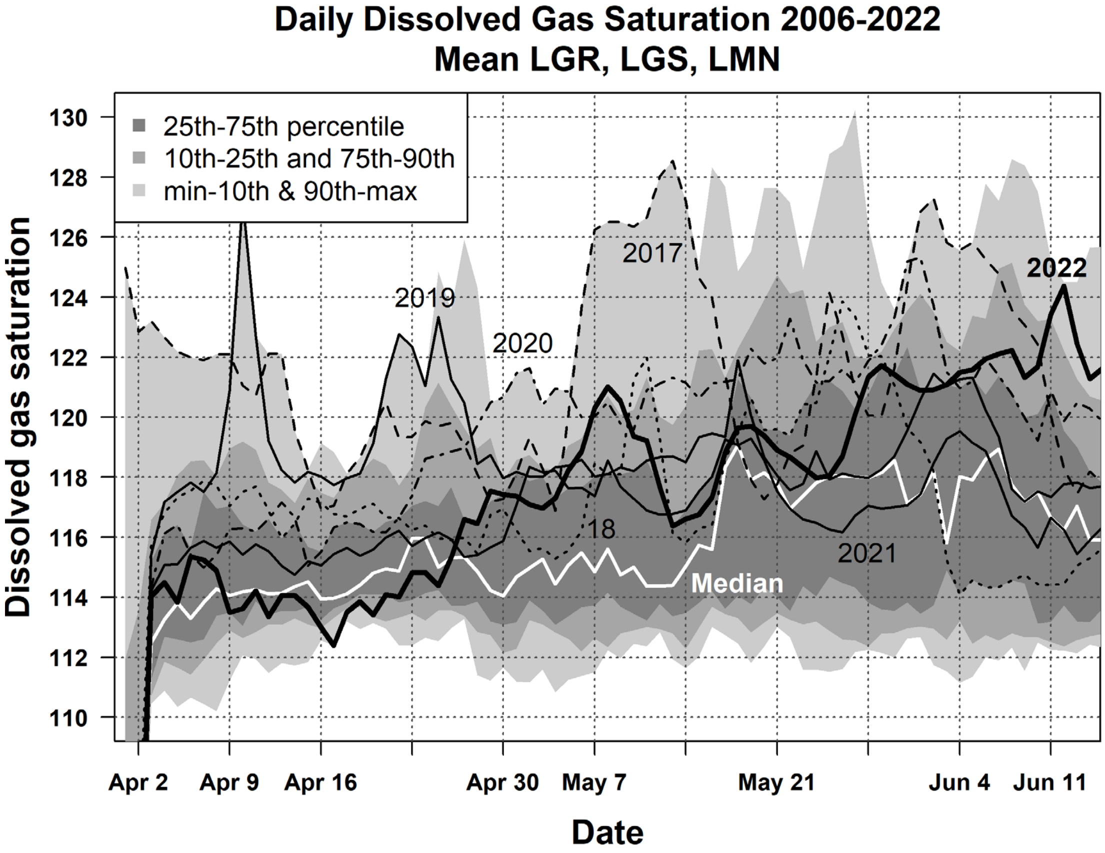
During early June 2022 at The Dalles Dam, daily dissolved gas saturation was higher than in any other recent year. Daily dissolved gas saturation at Bonneville Dam also showed a pattern of steady over the season; however, daily values were below average in April, and rose to only moderately above average in late May (Appendix Figure C11). Dissolved gas information was missing for Bonneville Dam after 7 June 2022.



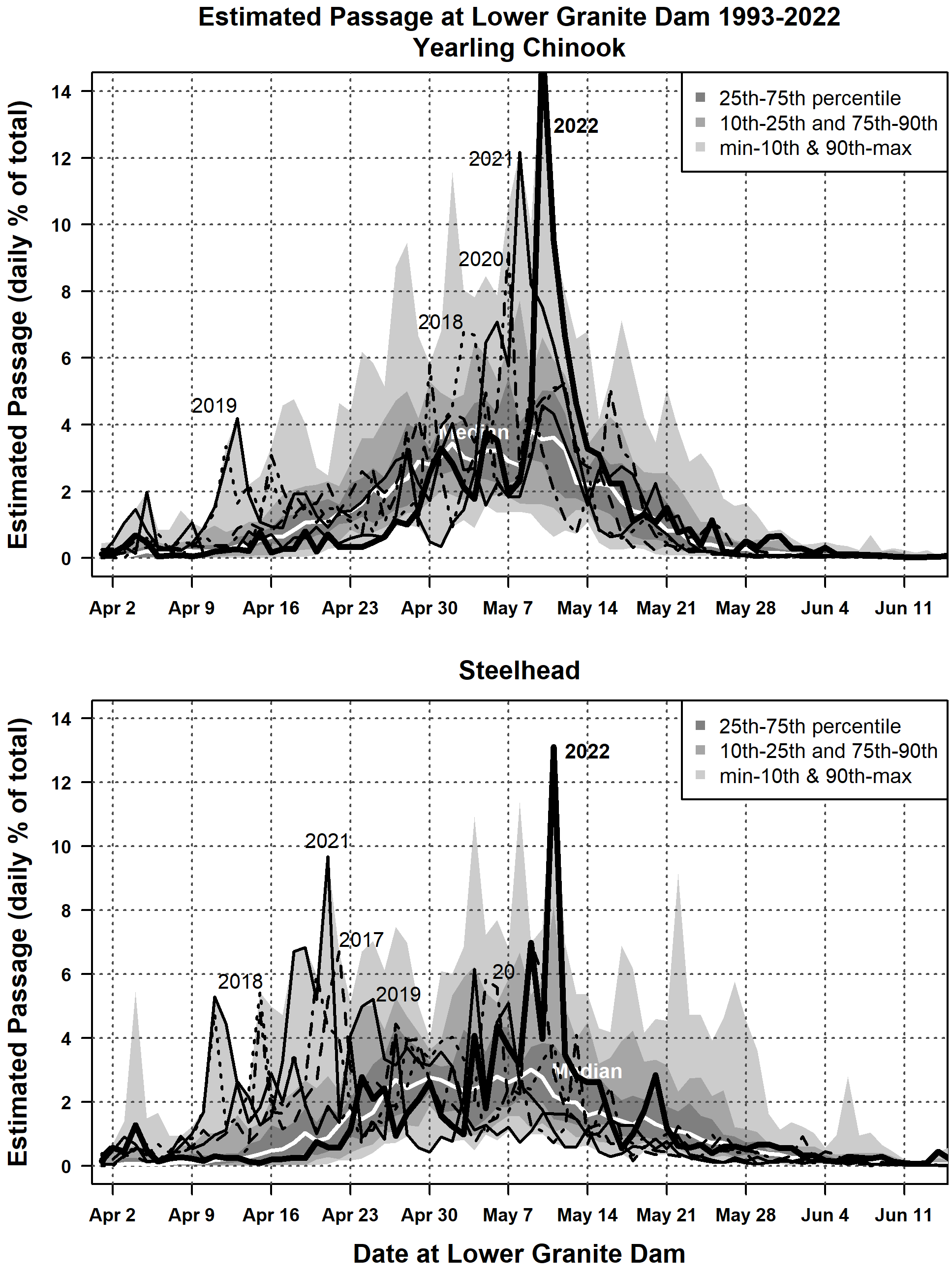
Appendix Figure C1. Upper panel shows daily mean flow at Little Goose Dam from April to mid-June. Lines show daily mean flows for 2022 and selected recent years and long-term median. Shaded areas illustrate daily quantiles for 1989-2022. Lower panel uses the same format to show daily mean temperature at Little Goose Dam. Quantiles for daily temperature are calculated from 1989 to 2022.



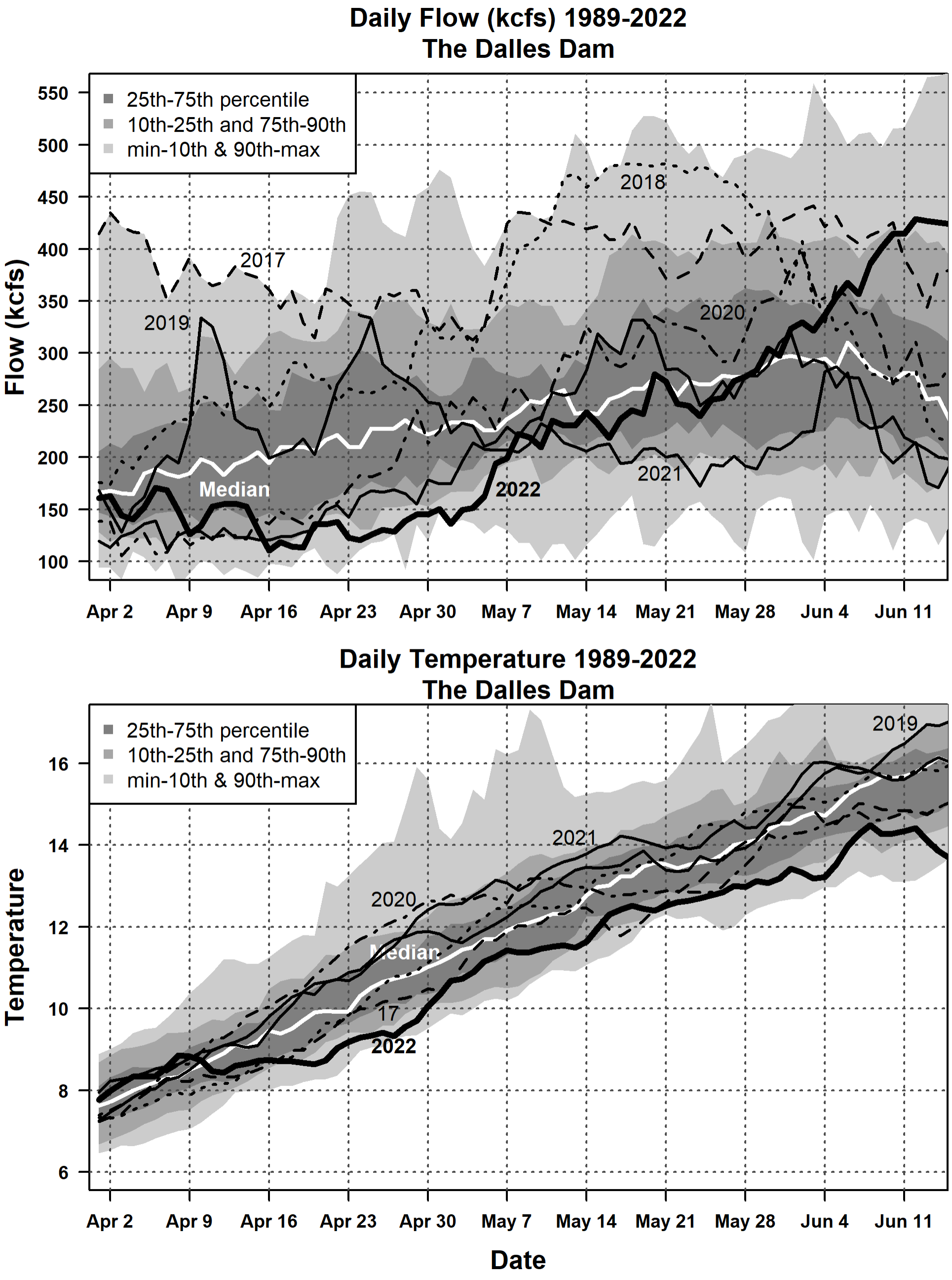
Appendix Figure C2. Upper panel shows daily mean Snake River spill (kcfs) from April to mid-June, averaged across Lower Granite, Little Goose and Lower Monumental Dams. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



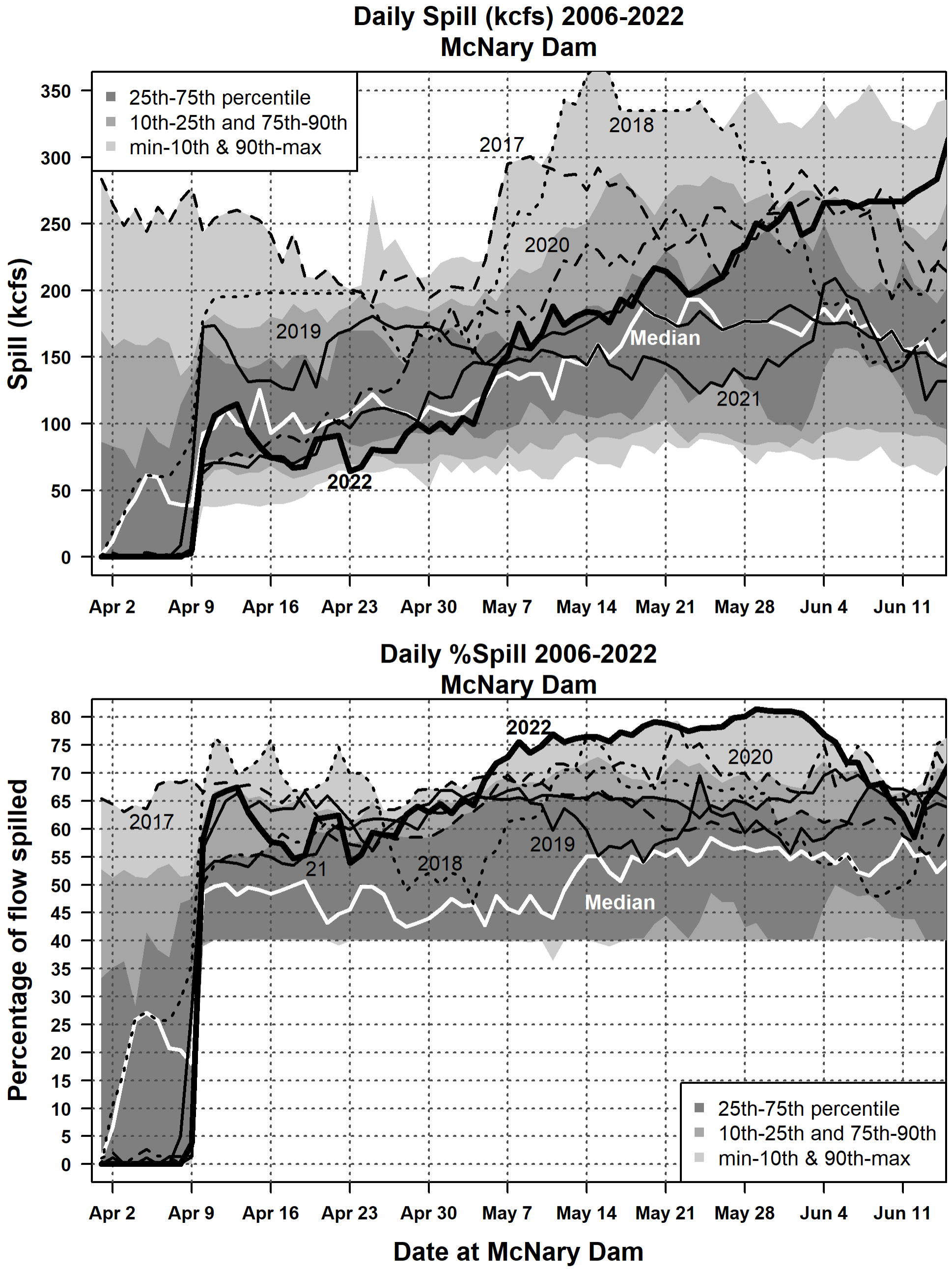
Appendix Figure C3. Daily mean percentage of dissolved gas averaged across Lower Granite, Little Goose and Lower Monumental Dam from April to mid-June 2022. Lines show daily percentage for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



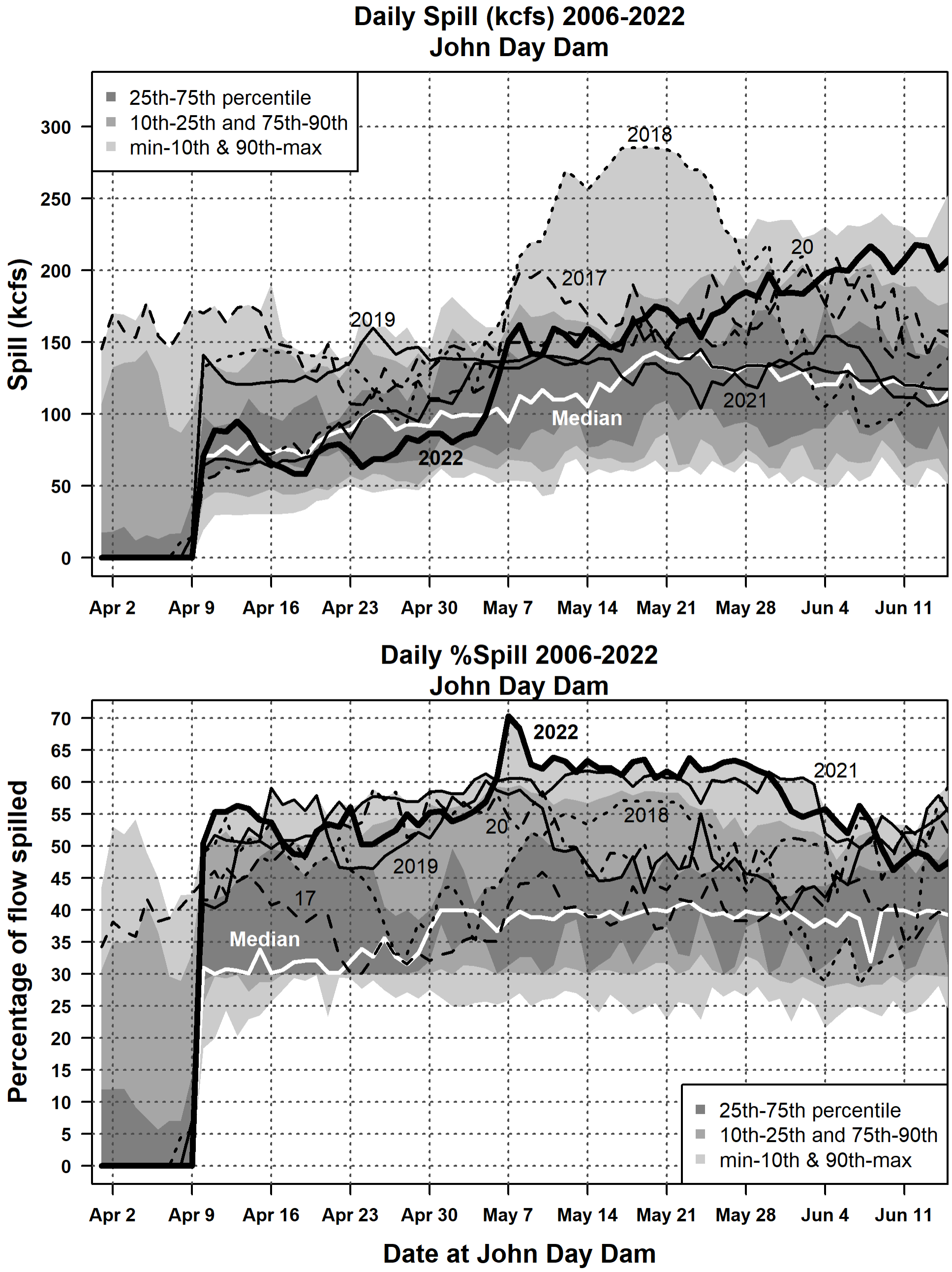
Appendix Figure C4. Estimated daily smolt passage at Lower Granite Dam for yearling Chinook salmon and steelhead. Daily passage is expressed as percentage of the yearly total. Lines indicate daily values for 2022, the long term median, and selected recent years. Shaded areas indicate smolt-passage quantiles from 1993 to 2022.



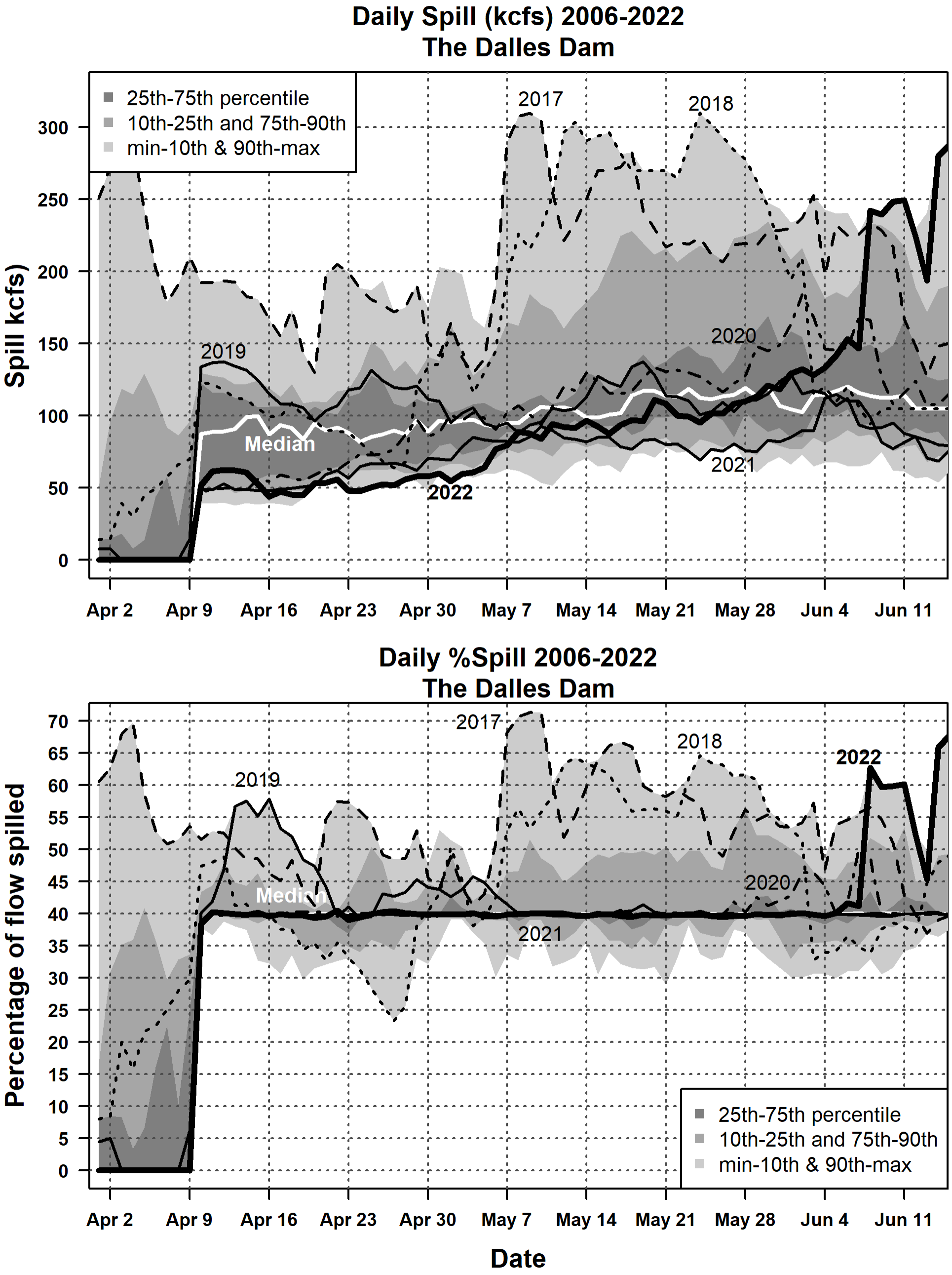
Appendix Figure C5. Upper panel shows daily mean flow at The Dalles Dam from April to mid-June. Lines show daily mean flows for 2022, selected recent years, and the long-term median. Shaded areas illustrate daily quantiles from 1989 to 2022. Lower panel uses the same format to show daily mean temperature at The Dalles Dam. Quantiles for daily temperature are calculated from 1989 to 2022.



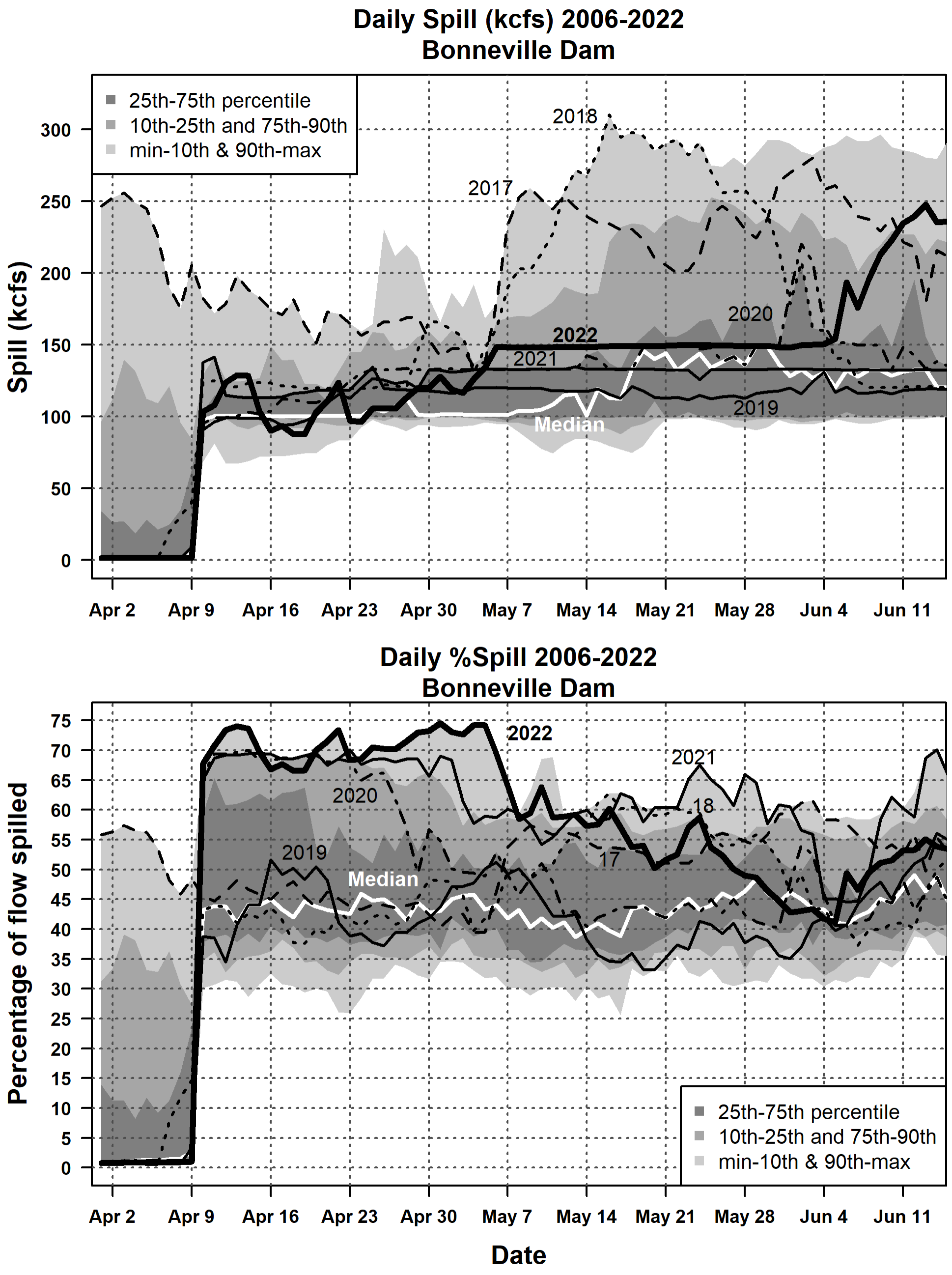
Appendix Figure C6. Upper panel shows daily mean spill (kcfs) from April to mid-June at McNary Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



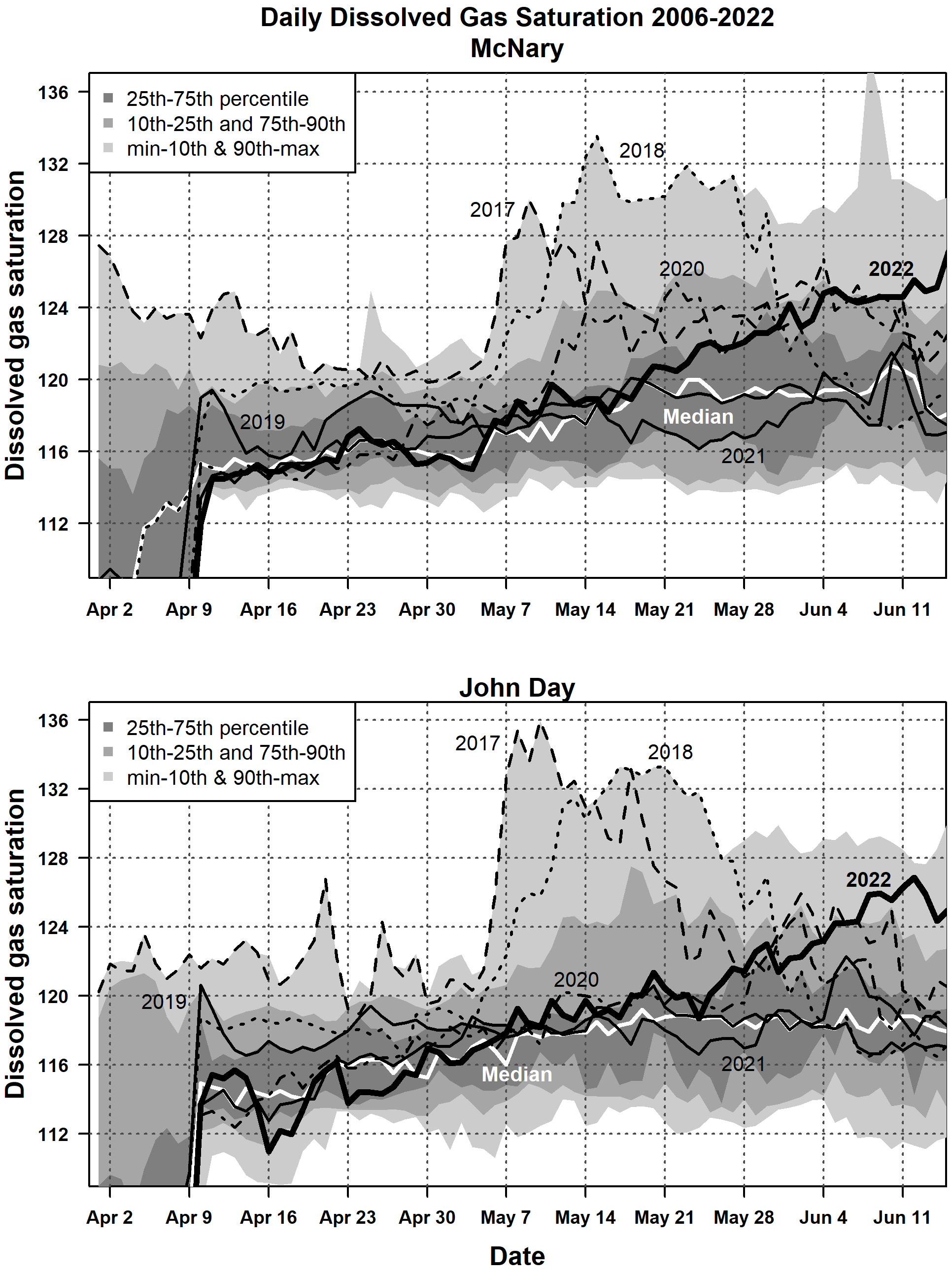
Appendix Figure C7. Upper panel shows daily mean spill (kcfs) from April to mid-June at John Day Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



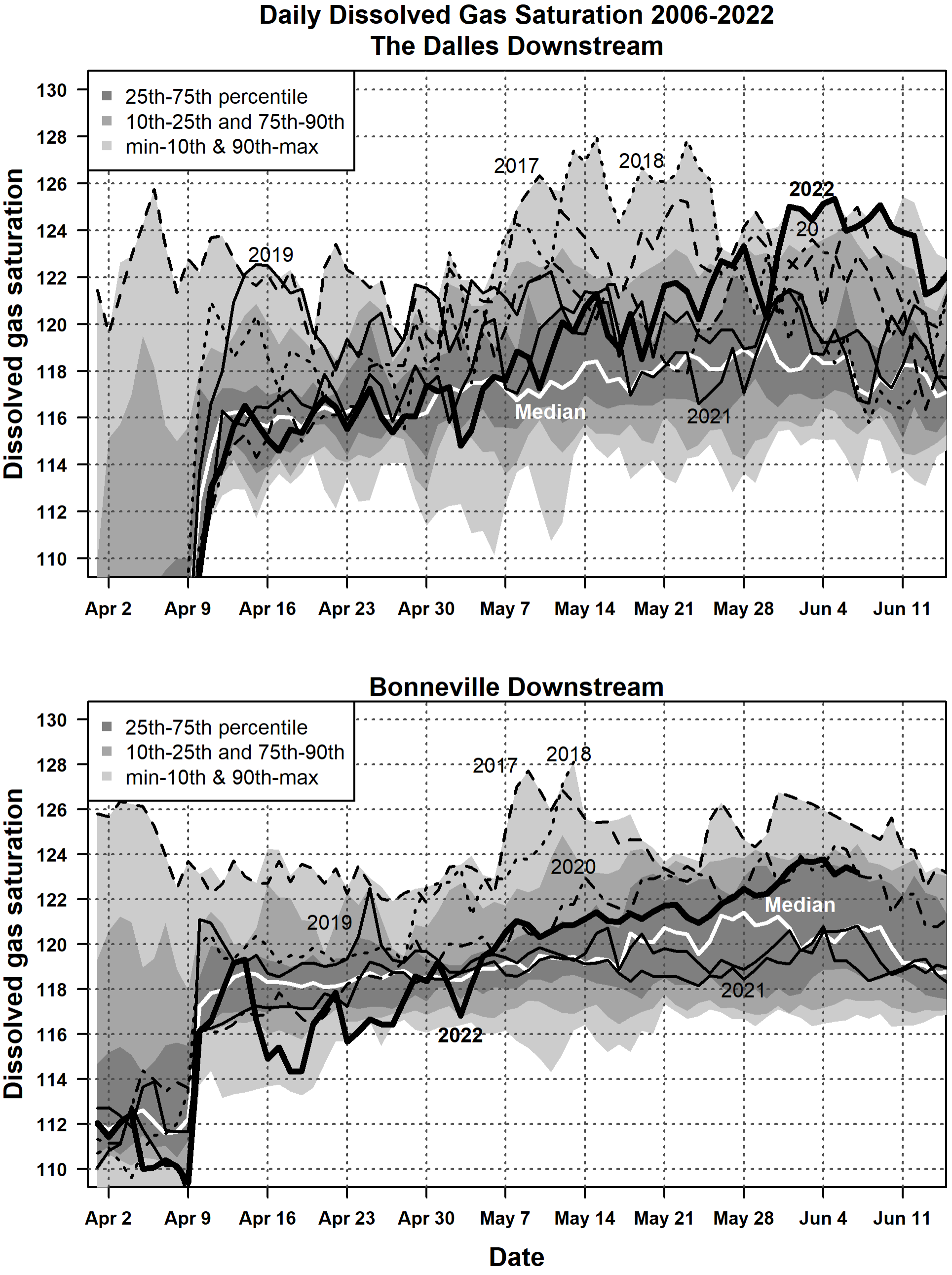
Appendix Figure C8. Upper panel shows daily mean spill (kcfs) from April to mid-June at The Dalles Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



Appendix Figure C9. Upper panel shows daily mean spill (kcfs) from April to mid-June at Bonneville Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



Appendix Figure C10. Daily mean percentage of dissolved gas at McNary and John Day Dam from April to mid-June 2022. Lines show daily percentage for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.



Appendix Figure C11. Daily mean percentage of dissolved gas at The Dalles and Bonneville Dam from April to mid-June 2022. Lines show daily percentage for 2022, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2022.

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce for
Oceans and Atmosphere
Dr. Richard W. Spinrad

Assistant Administrator for Fisheries
Janet Coit

October 2023

fisheries.noaa.gov

OFFICIAL BUSINESS

National Marine
Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, Washington 98112