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Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs, 2023

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Executive Summary

In 2023, we completed the 31st 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 2023 migration season, we tagged and released a total of 19,075 hatchery steelhead *O. mykiss,* 13,677 wild steelhead, and 7,113 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, steelhead, sockeye *O. nerka*, and coho salmon *O. kisutch* 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 system in 2023, resulting in a small sample size of fish detected in the bypass system 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 2023 would not have been possible.

Other than the bypass and spillway systems at Lower Granite, detection sites in 2023 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.

The Columbia River estuary trawl detection system has historically provided the detection information from below Bonneville Dam used for survival estimation to the dam. Starting in 2020, we began using additional sources of detection, and this continued in 2023. We anticipate continuing this approach in future years, as well as revisiting past years where we previously used only data from the trawl. Four sources of data downstream from Bonneville Dam were available in 2023:

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 2023 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 2023, we estimated reach survival and travel time for yearling Chinook salmon, steelhead, and sockeye of both wild and hatchery origin. We also estimated survival and travel time for coho salmon 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 very low because of 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 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 release groups over biweekly periods.

Because detection rates were also extremely low at McNary Dam, no survival estimates were possible from McNary for virtual groups pooled over any detection period there (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 has been necessary in every study year since 2020 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, we estimated that 82.2% of yearling Chinook and 83.1% 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 90% 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 2023. Standard errors in parentheses.

	Yearling Chinook salmon	Steelhead
Snake River Smolt Trap to Lower Granite Dam	0.876 (0.037)	0.942 (0.028)
Lower Granite to Little Goose Dam	0.921 (0.013)	0.958 (0.043)
Little Goose to Lower Monumental Dam	0.995 (0.048)	0.995 (0.063)
Lower Monumental to McNary Dam[a]	0.701 (0.034)	0.776 (0.042)
Lower Monumental to Ice Harbor Dam	0.869 (0.037)	0.912 (0.045)
Ice Harbor to McNary Dam	0.807 (0.031)	0.905 (0.046)
McNary to John Day Dam	0.894 (0.079)	0.963 (0.049)
John Day to Bonneville Dam[b]	0.852 (0.082)	0.936 (0.053)
Snake River Smolt Trap to Bonneville Dam[c]	0.423 (0.033)	0.584 (0.062)

[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 two reaches: Snake River Smolt Trap to Lower Granite Dam and Lower Granite to Bonneville Dam. For combined wild and hatchery fish from the Snake River, average estimated survival through the entire hydropower system was 0.423 (95% CI 0.359-0.487) for yearling Chinook and 0.584 (0.463-0.705) 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 0.542 (SE 0.089) for East Bank Hatchery fish released to the Chelan River to 0.100 (0.028) for East Bank Hatchery fish released from Chiwawa Pond. For Upper Columbia River steelhead, estimated survival from release to Bonneville Dam ranged from 0.476 (0.083) for Wells Hatchery fish released from the hatchery to 0.134 (0.047) for Wells Hatchery fish released to the Twisp River.

Of the run at large that arrived at Lower Granite Dam, we estimated that 34.6% of yearling Chinook and 37.0% of steelhead were transported from a Snake River collector dam (means of separate wild and hatchery estimates). These estimates were slightly above the 2007-2023 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 2023, proportions of fish collected during transport operations were close to average. Mean timing of the run was about average for both Chinook and steelhead, but the run was compressed, resulting in higher-than-average proportions of smolts passing after the start of transportation. The combination of average collection rates and slightly higher proportions of the population passing after the start of transportation resulted in overall transportation rates that were slightly higher than 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 negative relationship between smolt travel times and levels of flow and spill.

During April 2023, spill levels as proportion of flow were very high, greater than 70% for several weeks, but flow was well below average. Travel times during this month were long for both yearling Chinook and steelhead relative to other recent years, which also had high levels of spill. At the end of April, flow began to rise, and flow was very high through the month of May. Spill volume remained high, but spill decreased as proportion of flow. Travel times shortened significantly for both species as flow rose, reaching the shortest travel times on record in mid-May, just 8 days between Lower Granite and Bonneville for Chinook and 6 days for steelhead.

At dams where PIT-tag detection was possible only in the juvenile bypass system, detection probabilities were again very low in 2023. This reduced the quality of survival estimates and required use of alternative methods. 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 2023.

Nearly every dam had a detection rate well below the 2007-2022 average in 2023. The exceptions were Lower Granite Dam, where a spillway detection system was installed before the 2020 migration season, and Bonneville Dam, where a detector has been active in the corner collector route since 2006. These low detection rates resulted in highly imprecise survival estimates for most single-project reaches.

In recent years, the intended result of the management choice of increasing spill is an improvement in environmental conditions for migrating juvenile salmon, leading to increased survival both through the hydropower system and subsequent survival in the ocean after leaving the 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 2023 were not quite as low as those seen in 2021, but were still among the lowest on record, especially at McNary and John Day Dam.

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. If it remains a management goal to reduce uncertainty regarding the status of listed stocks, increased PIT-tag detection will be necessary. Specifically, a way to achieve this would be to 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 2023. 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 estimated mean annual percentage of tagged fish detected was 26.1% for yearling Chinook. In 2023, the estimated overall percentage of tagged yearling Chinook detected was 39.4%, with only 13.9% detected in the bypass system and 25.5% 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.

New statistical methods have been developed with advancements that can help address the challenges facing our customary approaches to survival estimation (Hance et al. 2019). For example, for estimates of survival between Lower Granite and Bonneville Dam, these methods do not require groups of fish to be detected at Lower Granite Dam. Instead, they utilize information from a larger sample size, including migrant fish that pass the dam undetected. Temporal variation in survival and detection probabilities is also accounted for elegantly using these methods. We are in the process of adapting these methods to apply to our annual large-scale data analysis project. While low detection rates at dams are a challenge to any release-recapture model, we anticipate that greater precision in survival estimates will result from conversion to the new methods.

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 juvenile salmonid survival or smolt-to-adult return rates, but it also hinders the ability to identify, evaluate, and document that improvement. Similarly, we are 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

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 2023, 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. 2018-2022, 2023a,b). 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 2023, the 31st year of the study. Research objectives in 2023 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 space-for-time application of the model, downstream detection of a migrating 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 2023 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. 2023).

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 2023, we used detection or recovery data collected by automated systems (dams) or through active efforts (estuary sites) at the following twelve sites (Figure 1; Collis et al. 2001; Prentice et al. 1990a,b,c):

<u>Dams with detection systems</u>

- 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)

<u>Estuary sites of detection or recovery</u>

- Astoria-Megler Bridge (rkm 12)
- Avian colonies (rkm 8-32)
- Pile dike detection systems (rkm 62-82)
- Troutdale transmission towers (rkm 190)
- Pair-trawl system (rkm 65-84)

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

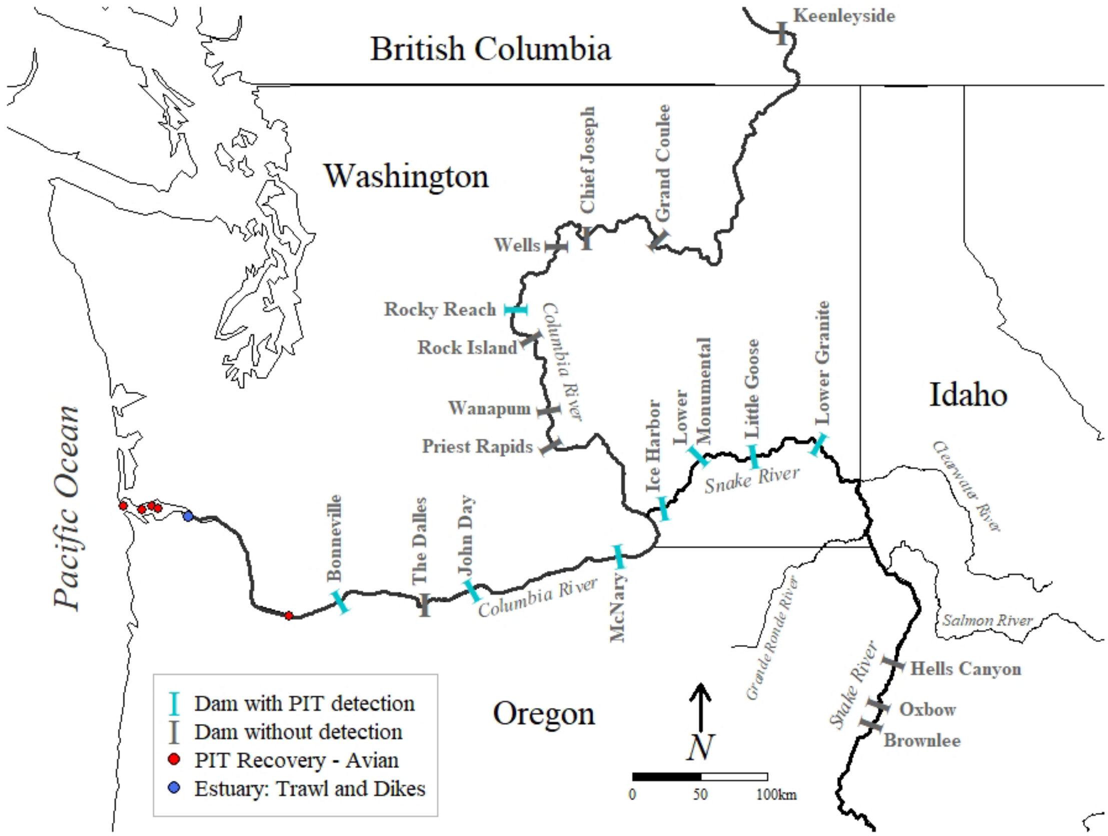

Figure 1. Study area showing PIT-tag detection sites in the Columbia River Basin, 2023. Dams with detection capability are represented by turquoise bars, and those without are represented by gray bars. Pair-trawl operation and pile dikes are in close proximity and represented by a single blue dot. Sites 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 2023. 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 5, 6, 7, and 8. A third source was PIT tags recovered after being deposited by predaceous birds on nesting colonies or roosting areas such as the Astoria-Megler Bridge and the transmission towers near Troutdale, OR (Real Time Research, Inc.; Evans et al. 2024). Our fourth and final data source was detections of precocious juveniles (known as "mini-jacks") migrating upstream and detected in fish ladders at Bonneville Dam. We grouped detections from all four data sources to form a single composite "final detection site."

In 2023, detection probabilities were near average for Bonneville Dam and well above average for the composite final detection site. Data were sufficient to estimate survival to Bonneville Dam for almost all stocks, though many of the resulting estimates were imprecise due to poor rates of detection at McNary and John Day Dam.

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 2023, 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 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 2023, 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 greater proportions of arriving fish 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 were 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 daily "virtual 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 daily virtual group for each day that had detections between 14 March and 31 July 2023.

At Lower Granite Dam, each daily virtual 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 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 and rear types, we were able to obtain survival estimates of sufficient quality only by using a series of biweekly 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, which also contained detections from more than two weeks.

We PIT tagged and released 19,075 hatchery steelhead, 13,677 wild steelhead, and 7,113 wild yearling Chinook salmon at Lower Granite Dam from 11 April through

16 June 2023 (Table 1). From these numbers, respective total tagging mortalities were 8, 7, and 66 for hatchery steelhead, wild steelhead, and wild yearling Chinook salmon. Each of these mortality rates was 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 84,648 yearling Chinook salmon (69,558 hatchery, 15,090 wild) were either collected, tagged, and released to the tailrace or detected and returned to the tailrace. A total of 101,703 steelhead (84,490 hatchery, 17,213 wild) were tagged and released or detected and returned to the tailrace.

We estimated that 90.2% of the overall run of yearling Chinook and 87.9% of the steelhead run was of hatchery origin in 2023. 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 in the juvenile bypass system at Lower Granite Dam (based on tagged fish only). The distinction of hatchery-origin yearling chinook was based on clipped fins (FPC 2021). 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 82.2% for yearling Chinook and 83.1% for steelhead. Thus, our sample contained a slightly greater proportion of wild fish than in 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 2023, the small number of wild smolts entering the bypass system at Lower Granite Dam increased the difficulty of meeting these goals. Although the number of wild steelhead tagged in 2023 was about average, the number of wild Chinook tagged was well below the 10-year average from 2010 to 2020.

As a result of lower tagging and detection rates at Lower Granite Dam, overall sample sizes for wild fish in 2023 were about average for steelhead and moderately below average for Chinook. 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 Chinook.

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 2023. 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
11 Apr	234	-	-	18	-	-	347	27	-
12 Apr	638	-	-	18	-	-	338	7	-
18 Apr	1,207	1	-	138	1	-	492	3	-
19 Apr	621	1	-	242	-	-	465	-	-
24 Apr	744	-	1	96	-	-	294	4	-
25 Apr	774	-	1	111	-	-	249	-	-
26 Apr	776	-	1	67	-	1	693	-	-
27 Apr	729	1	2	102	-	-	425	1	-
1 May	804	-	-	155	-	-	326	8	-
2 May	811	-	1	452	-	-	338	3	-
3 May	861	-	2	560	-	-	252	-	-
4 May	855	-	-	716	-	-	182	1	-
5 May	433	-	-	193	-	-	101	-	-
8 May	772	-	6	641	-	2	128	-	-
9 May	748	-	4	493	1	1	174	-	-
10 May	771	-	2	539	-	3	214	-	-
11 May	719	1	4	762	-	1	297	-	-
12 May	407	-	8	633	1	3	171	-	-
15 May	574	-	-	283	-	-	268	1	-
16 May	560	-	-	352	1	-	278	1	-
17 May	572	1	-	655	-	-	321	1	-
18 May	548	-	-	1,209	-	-	229	2	-
19 May	257	-	1	528	-	3	37	-	-
22 May	418	-	2	783	-	4	105	-	-
23 May	411	-	1	1,122	-	8	134	4	-
24 May	401	-	1	475	-	-	154	2	-
25 May	418	-	2	244	-	2	41	-	-
26 May	108	-	-	368	-	1	60	1	-
30 May	402	-	-	324	1	-			
31 May	307	-	-	426	1	-			
1 Jun	203	-	-	318	-	-			
2 Jun	144	-	-	165	-	1			
5 Jun	151	-	-	113	-	-			
6 Jun	149	1	1	76	-	-			
7 Jun	112	-	-	50	-	-			
8 Jun	108	-	1	47	1	-			
9 Jun	94	1	1	51	-	-			
12 Jun	89	-	-	43	-	-			
13 Jun	63	-	-	47	-	-			
14 Jun	26	-	-	14	-	-			
15 Jun	26	1	-	27	-	-			
16 Jun	30	-	2	21	-	-			
	19,075	8	44	13,677	7	30	7,113	66	0

Releases from McNary Dam—To estimate survival downstream of McNary Dam, our standard methodology before 2000 was to create daily "virtual release groups" at McNary. Virtual groups were formed using yearling Chinook and steelhead released from locations throughout the Snake River Basin according to day of detection at McNary. However, in 2023 detection rates at McNary were too low to generate sample sizes sufficient for survival estimation using this method.

In total, only 6,004 yearling Chinook and 1,967 steelhead of Snake River origin were detected passing McNary Dam in 2023. These detection numbers resulted in very small sample sizes that were similar to those in other years since 2020. From 2020 through 2023, 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 2023 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 2023, 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, coho, 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 during the spring migration period, 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 8 August 2023, and we published a memorandum of preliminary survival estimates on 18 October 2023. At the time that memo was published, data from PIT-tag recoveries on avian colonies throughout the basin were not yet available.

By late November 2023, recovery data from the avian colonies had been uploaded to the PTAGIS database, significantly expanding detection data from below Bonneville Dam (Evans et al. 2024). Accordingly, on 30 November we again downloaded tagging and detection data for the 2023 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 30 November 2023. 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 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 2023 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 estimates. Appendix A contains a detailed discussion of these tests of assumptions, the extent of assumption violations and their implications in 2023, 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 mean of these estimates over the entire migration season. When a series extended across all or most of the season, we considered this weighted mean to be the 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.

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 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 2023 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 calculated the estimated 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 three biweekly groups over six consecutive weeks during 20 April-31 May. We also produced estimates for a pooled early season cohort covering a four-week period from 21 March to 19 April. All fish detected after 31 May were pooled into a late-season cohort covering the period from 1 June to 26 July, but data were insufficient to produce estimates for this cohort (Table 2). Mean estimated survival was 0.921 (SE 0.013) from Lower Granite to Little Goose, 0.995 (0.048) from Little Goose to Lower Monumental, and 0.701 (0.034) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.627 (0.024).

Table 2. Survival probability estimates from Lower Granite to McNary Dam for combined wild and hatchery Snake River yearling Chinook in 2023. 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
21 Mar-19 Apr	11,824	0.912 (0.072)	0.965 (0.135)	0.617 (0.097)	0.543 (0.057)
20 Apr-3 May	29,475	0.905 (0.023)	1.067 (0.053)	0.675 (0.064)	0.652 (0.055)
4-17 May	34,507	0.933 (0.026)	0.958 (0.050)	0.717 (0.057)	0.640 (0.042)
18-31 May	6,703	1.018 (0.092)	0.739 (0.102)	0.912 (0.221)	0.686 (0.150)
1 Jun-26 Jul	1,704	NA	NA	NA	NA
Weighted mean		**0.921 (0.013)**	**0.995 (0.048)**	**0.701 (0.034)**	**0.627 (0.024)**

In 2023, detection rates of yearling Chinook at McNary Dam were too low to create virtual release groups of sufficient sample size there. Thus, we estimated survival and detection probabilities downstream of McNary Dam using the same biweekly groups formed from fish detected or tagged and released at Lower Granite Dam and 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 0.894 (SE 0.079) from McNary to John Day, 0.852 (0.082) from John Day to Bonneville, and 0.751 (0.024) 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 2023. 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
21 Mar-19 Apr	11,824	0.711 (0.098)	0.937 (0.149)	0.666 (0.112)	0.362 (0.048)
20 Apr-3 May	29,475	1.078 (0.120)	0.709 (0.074)	0.764 (0.086)	0.498 (0.038)
4-17 May	34,507	0.875 (0.079)	0.869 (0.092)	0.760 (0.082)	0.487 (0.042)
18-31 May	6,703	0.702 (0.181)	1.183 (0.238)	0.830 (0.219)	0.569 (0.084)
1 Jun-26 Jul	1,704	NA	NA	NA	NA
Weighted mean		**0.894 (0.079)**	**0.852 (0.082)**	**0.751 (0.024)**	**0.483 (0.031)**

For combined wild and hatchery Snake River yearling Chinook, the weighted mean survival estimate from Lower Granite to Bonneville Dam was 0.483 (SE 0.031). For combined wild and hatchery yearling Chinook released from the Snake River Smolt Trap, estimated survival to Lower Granite Dam was 0.876 (0.037). Thus, estimated annual average survival probability through all eight hydropower projects encountered by Snake River yearling Chinook salmon was 0.423 (0.033).

We also estimated probabilities of survival from Lower Granite to McNary Dam separately for hatchery vs. wild yearling Chinook (Table 4). Sample sizes were adequate to estimate survival for most biweekly groups, although low detection rates compelled us to pool the first two biweekly cohorts into four-week cohorts for both rear types. All fish detected after 31 May were pooled into late-season cohorts, but even then, data was not sufficient to produce estimates for these cohorts for either rear type. Annual average estimated survival was lower for hatchery than for wild Chinook salmon, but the difference was not significant ($P = 0.99$).

Table 4. Survival probability estimates from Lower Granite to McNary Dam for Snake River yearling Chinook salmon in 2023. Daily groups were pooled for biweekly estimates for both hatchery and wild fish. 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		
21 Mar-19 Apr	9,785	0.860 (0.082)	1.034 (0.175)	0.639 (0.116)	0.569 (0.065)
20 Apr-3 May	24,500	0.931 (0.029)	1.017 (0.061)	0.681 (0.073)	0.645 (0.060)
4-17 May	30,110	0.986 (0.034)	0.932 (0.059)	0.687 (0.061)	0.631 (0.045)
18-31 May	4,645	1.010 (0.124)	0.781 (0.146)	0.716 (0.190)	0.564 (0.126)
1 Jun-26 Jul	259	NA	NA	NA	NA
Weighted mean		**0.952 (0.020)**	**0.971 (0.035)**	**0.681 (0.010)**	**0.620 (0.017)**
			Wild yearling Chinook		
29 Mar-19 Apr	2,039	1.021 (0.138)	0.771 (0.187)	0.547 (0.180)	0.431 (0.111)
20 Apr-3 May	4,975	0.895 (0.037)	1.075 (0.095)	0.693 (0.151)	0.666 (0.136)
4-17 May	4,397	0.886 (0.040)	0.938 (0.085)	0.809 (0.151)	0.672 (0.114)
18-31 May	2,058	0.992 (0.131)	0.678 (0.138)	NA	NA
1 Jun-22 Jul	1,445	NA	NA	NA	NA
Weighted mean		**0.901 (0.020)**	**0.967 (0.070)**	**0.726 (0.066)**	**0.621 (0.068)**

Data was not sufficient to estimate survival probabilities for daily groups of yearling Chinook salmon in 2023. Even for virtual biweekly groups, the precision of nearly all survival estimates was poor (Table 2). Consequently, it was impossible to effectively assess potential within-season trends in survival during 2023.

Detection Probabilities—Detection probability estimates in 2023 were very 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 2023. 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
21 Mar-19 Apr	11,824	0.089 (0.007)	0.064 (0.008)	0.057 (0.007)
20 Apr-3 May	29,475	0.188 (0.005)	0.139 (0.006)	0.029 (0.003)
4-17 May	34,507	0.153 (0.005)	0.126 (0.006)	0.047 (0.003)
18-31 May	6,703	0.092 (0.009)	0.102 (0.011)	0.017 (0.004)
1 Jun-26 Jul	1,704	0.032 (0.022)	0.010 (0.010)	0.032 (0.022)

Table 6. Detection probability estimates at John Day and Bonneville Dam for combined wild and hatchery Snake River yearling Chinook salmon in 2023. 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
21 Mar-19 Apr	11,824	0.098 (0.010)	0.167 (0.023)
20 Apr-3 May	29,475	0.053 (0.004)	0.172 (0.013)
4-17 May	34,507	0.068 (0.005)	0.154 (0.014)
18-31 May	6,703	0.043 (0.007)	0.202 (0.031)
1 Jun-26 Jul	1,704	0.113 (0.044)	0.060 (0.058)

Table 7. Detection probability estimates at Little Goose, Lower Monumental, and McNary Dam for Snake River yearling Chinook salmon in 2023. Daily groups were pooled for biweekly estimates for both hatchery and wild fish. 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			
21 Mar-19 Apr	9,785	0.082 (0.008)	0.058 (0.008)	0.056 (0.007)
20 Apr-3 May	24,500	0.173 (0.006)	0.130 (0.007)	0.028 (0.003)
4-17 May	30,110	0.134 (0.005)	0.115 (0.006)	0.046 (0.004)
18-31 May	4,645	0.083 (0.011)	0.095 (0.014)	0.021 (0.005)
1 Jun-26 Jul	259	0.106 (0.093)	NA	NA
	Wild yearling Chinook			
29 Mar-19 Apr	2,039	0.128 (0.019)	0.101 (0.022)	0.063 (0.018)
20 Apr-3 May	4,975	0.242 (0.012)	0.193 (0.016)	0.033 (0.007)
4-17 May	4,397	0.243 (0.013)	0.192 (0.016)	0.054 (0.010)
18-31 May	2,058	0.117 (0.017)	0.119 (0.020)	0.008 (0.005)
1 Jun-22 Jul	1,445	0.018 (0.018)	0.012 (0.011)	0.040 (0.028)

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 four biweekly groups over eight consecutive weeks during 20 April-14 June (Table 8). We also produced estimates for a pooled early-season cohort covering a three-week period from 31 March to 19 April. All fish detected after 14 June were pooled into a late-season cohort covering the period from 15 June to 15 July, but data was still not sufficient to produce estimates for this cohort. Mean estimated survival was 0.958 (SE 0.043) from Lower Granite to Little Goose, 0.995 (0.063) from Little Goose to Lower Monumental, and 0.776 (0.042) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, estimated survival averaged 0.718 (0.042).

Table 8. Survival probability estimates from Lower Granite to McNary Dam for combined wild and hatchery Snake River juvenile steelhead in 2023. 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
31 Mar-19 Apr	10,838	0.867 (0.056)	1.233 (0.219)	0.592 (0.121)	0.633 (0.074)
20 Apr-3 May	43,935	0.840 (0.020)	1.151 (0.045)	0.854 (0.087)	0.826 (0.080)
4-17 May	25,564	1.028 (0.018)	0.889 (0.030)	0.730 (0.075)	0.667 (0.066)
18-31 May	14,398	0.963 (0.044)	0.933 (0.066)	0.828 (0.148)	0.743 (0.126)
1-14 Jun	3,600	0.929 (0.110)	0.899 (0.208)	0.640 (0.322)	0.534 (0.247)
15 Jun-15 Jul	504	NA	NA	NA	NA
Weighted mean		**0.958 (0.043)**	**0.995 (0.063)**	**0.776 (0.042)**	**0.718 (0.042)**

In 2023, 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 Dam. Consequently, survival estimates were generally imprecise (Table 9). Mean estimated survival was 0.963 (SE 0.049) from McNary to John Day, 0.936 (0.053) from John Day to Bonneville, and 0.892 (0.076) 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 2023. 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
31 Mar-19 Apr	10,838	1.143 (0.198)	0.890 (0.156)	1.016 (0.171)	0.643 (0.077)
20 Apr-3 May	43,935	0.883 (0.091)	0.980 (0.065)	0.866 (0.097)	0.715 (0.040)
4-17 May	25,564	1.017 (0.111)	1.001 (0.090)	1.018 (0.127)	0.679 (0.052)
18-31 May	14,398	0.842 (0.164)	0.716 (0.085)	0.603 (0.111)	0.448 (0.031)
1-14 Jun	3,600	1.054 (0.849)	0.403 (0.282)	0.425 (0.218)	0.227 (0.051)
15 Jun-15 Jul	504	NA	NA	NA	NA
Weighted mean		**0.963 (0.049)**	**0.936 (0.053)**	**0.892 (0.076)**	**0.620 (0.063)**

For combined wild and hatchery Snake River steelhead, the weighted average survival estimate from Lower Granite to Bonneville Dam was 0.620 (SE 0.063). For combined wild and hatchery steelhead released from the Snake River Smolt Trap, estimated survival probability to Lower Granite Dam tailrace was 0.942 (0.028). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.584 (0.062).

We also estimated probabilities of survival from Lower Granite to McNary Dam separately for hatchery vs. wild steelhead (Table 10). Sample sizes were adequate to estimate survival for most biweekly groups of both hatchery and wild smolts. All fish detected after 14 June were pooled into late-season cohorts, but data was not sufficient to produce estimates for these cohorts for either rear type. Annual average estimated survival was higher for hatchery than for wild steelhead, though the difference was not statistically significant ($P = 0.89$).

Data was not sufficient to estimate survival probabilities for daily groups of steelhead in 2023. Even for virtual biweekly groups, the precision of nearly all survival estimates was poor (Table 8). Consequently, it was impossible to effectively assess potential within-season trends in survival during 2023.

Table 10. Survival probability estimates from Lower Granite to McNary Dam for Snake River juvenile steelhead in 2023. Daily groups were pooled for biweekly estimates for both hatchery and wild fish. 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				
31 Mar-19 Apr	10,347	0.869 (0.058)	1.203 (0.221)	0.583 (0.122)	0.610 (0.072)
20 Apr-3 May	41,390	0.839 (0.021)	1.149 (0.047)	0.855 (0.089)	0.824 (0.082)
4-17 May	19,409	1.046 (0.022)	0.836 (0.032)	0.774 (0.092)	0.677 (0.077)
18-31 May	8,052	1.040 (0.068)	0.888 (0.086)	0.822 (0.196)	0.759 (0.173)
1-14 Jun	2,068	1.099 (0.214)	0.889 (0.323)	0.708 (0.517)	0.692 (0.457)
15 Jun-15 Jul	369	NA	NA	NA	NA
Weighted mean		**0.962 (0.050)**	**0.979 (0.077)**	**0.792 (0.042)**	**0.720 (0.045)**
	Wild steelhead				
3-19 Apr	491	0.894 (0.190)	1.618 (1.104)	1.301 (1.501)	1.882 (1.789)
20 Apr-3 May	2,543	0.808 (0.049)	1.217 (0.164)	0.878 (0.403)	0.863 (0.381)
4-17 May	6,155	0.975 (0.029)	1.058 (0.072)	0.622 (0.129)	0.642 (0.128)
18-31 May	6,346	0.862 (0.056)	1.004 (0.107)	0.834 (0.225)	0.722 (0.184)
1-14 Jun	1,532	0.818 (0.120)	0.817 (0.241)	0.558 (0.386)	0.373 (0.240)
15 Jun-2 Jul	135	NA	NA	NA	NA
Weighted mean		**0.926 (0.035)**	**1.065 (0.045)**	**0.723 (0.068)**	**0.704 (0.102)**

Detection Probabilities—For steelhead, detection probability estimates were low in 2023 at Little Goose and Lower Monumental Dam and extremely low at 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 higher for wild than for hatchery steelhead at Little Goose Dam, but about the same or higher for hatchery steelhead at Lower Monumental and McNary Dam (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 2023. 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
31 Mar-19 Apr	10,838	0.121 (0.008)	0.029 (0.005)	0.036 (0.005)
20 Apr-3 May	43,935	0.131 (0.004)	0.137 (0.004)	0.010 (0.001)
4-17 May	25,564	0.238 (0.005)	0.208 (0.006)	0.017 (0.002)
18-31 May	14,398	0.099 (0.005)	0.137 (0.008)	0.013 (0.002)
1-14 Jun	3,600	0.113 (0.014)	0.086 (0.018)	0.016 (0.008)
15 Jun-15 Jul	504	NA	NA	0.136 (0.073)

Table 12. Detection probability estimates at John Day Dam and Bonneville Dam for combined wild and hatchery Snake River juvenile steelhead in 2023. 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
31 Mar-19 Apr	10,838	0.039 (0.006)	0.138 (0.017)
20 Apr-3 May	43,935	0.095 (0.004)	0.152 (0.009)
4-17 May	25,564	0.113 (0.006)	0.126 (0.010)
18-31 May	14,398	0.045 (0.005)	0.210 (0.016)
1-14 Jun	3,600	0.010 (0.007)	0.234 (0.055)
15 Jun-15 Jul	504	NA	NA

Table 13. Detection probability estimates at Little Goose Dam, Lower Monumental Dam, and McNary Dam for Snake River juvenile steelhead in 2023. Daily groups were pooled for biweekly estimates for both hatchery and wild fish. 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			
31 Mar-19 Apr	10,347	0.118 (0.009)	0.028 (0.005)	0.038 (0.005)
20 Apr-3 May	41,390	0.126 (0.004)	0.137 (0.005)	0.010 (0.001)
4-17 May	19,409	0.228 (0.006)	0.221 (0.008)	0.016 (0.002)
18-31 May	8,052	0.091 (0.007)	0.156 (0.012)	0.012 (0.003)
1-14 Jun	2,068	0.080 (0.017)	0.060 (0.019)	0.012 (0.009)
15 Jun-15 Jul	369	NA	NA	0.056 (0.054)
	Wild steelhead			
3-19 Apr	491	0.169 (0.040)	0.037 (0.025)	0.014 (0.014)
20 Apr-3 May	2,543	0.231 (0.017)	0.130 (0.017)	0.009 (0.005)
4-17 May	6,155	0.273 (0.010)	0.173 (0.012)	0.017 (0.004)
18-31 May	6,346	0.112 (0.008)	0.111 (0.010)	0.013 (0.004)
1-14 Jun	1,532	0.156 (0.025)	0.132 (0.035)	0.023 (0.016)
15 Jun-2 Jul	135	NA	NA	NA

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 2023, detections at Ice Harbor Dam were especially poor and lower than in most recent years (Table 14). Detection probabilities were also low at Lower Monumental Dam and extremely low at McNary Dam.

For yearling Chinook salmon in 2023, mean estimated survival was 0.869 (SE 0.037) from Lower Monumental to Ice Harbor Dam and 0.807 (0.031) from Ice Harbor to McNary Dam. In these same two reaches, mean estimated survival for steelhead was 0.912 (0.045) and 0.905 (0.046), respectively (Table 14).

Table 14. Survival and detection probability estimates from Lower Monumental to McNary Dam, including Ice Harbor Dam, for combined hatchery and wild Snake River yearling Chinook salmon and juvenile steelhead in 2023. Weighted means are of independent estimates for biweekly groups of combined hatchery and wild fish. Standard errors in parentheses.

Date at Lower Granite Dam	Number released	Estimated survival probability: Lower Monumental to Ice Harbor Dam	Estimated survival probability: Ice Harbor to McNary Dam	Detection Probability at Ice Harbor Dam
	Hatchery and wild yearling Chinook salmon			
6-19 Apr	11,428	0.912 (0.171)	0.678 (0.126)	0.023 (0.004)
20 Apr-3 May	29,475	0.821 (0.074)	0.828 (0.097)	0.030 (0.003)
4-17 May	34,507	0.871 (0.077)	0.818 (0.082)	0.028 (0.002)
18-31 May	6,703	1.063 (0.220)	0.896 (0.256)	0.023 (0.005)
Weighted mean		**0.869 (0.037)**	**0.807 (0.031)**	
	Hatchery and wild steelhead			
6-19 Apr	10,745	0.664 (0.147)	0.967 (0.191)	0.017 (0.003)
20 Apr-3 May	43,935	0.975 (0.067)	0.928 (0.107)	0.024 (0.002)
4-17 May	25,564	0.939 (0.064)	0.799 (0.094)	0.040 (0.003)
18-31 May	14,398	0.759 (0.081)	1.072 (0.207)	0.038 (0.004)
1-14 Jun	3,600	0.759 (0.525)	0.800 (0.645)	0.007 (0.005)
Weighted mean		**0.912 (0.045)**	**0.905 (0.046)**	

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 0.931 (SE 0.018) for Clearwater Hatchery fish released to Clear Creek in the Middle Fork Clearwater Basin to 0.347 (0.028) for Lookingglass Hatchery fish released from Grande Ronde River Pond on the Grande Ronde River (Appendix Table B1).

For steelhead, estimated survival to Lower Granite ranged from 0.907 (0.014) for Niagara Springs Hatchery fish released to the Little Salmon River to 0.534 (0.011) for Hagerman Hatchery fish released to the East Fork Salmon River (Appendix Table B2).

For sockeye salmon, only one group of hatchery-origin fish was released in 2023. Estimated survival to Lower Granite Dam was 0.644 (0.008) 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).

Detection probabilities estimated for both wild spring Chinook and wild steelhead from the Salmon River and Snake River Smolt Trap were consistently higher than those for hatchery conspecifics from the same traps. We saw no consistent difference in estimated detection probabilities between wild and hatchery smolts from the Lower Grande Ronde Smolt Trap for either spring Chinook or steelhead.

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 0.542 (SE 0.089) for East Bank Hatchery fish released to the Chelan River to 0.100 (0.028) for East Bank Hatchery fish released from Chiwawa Pond.

For Upper Columbia River steelhead, estimated survival from release to Bonneville Dam ranged from 0.476 (0.083) for Wells Hatchery fish released from the hatchery to 0.134 (0.047) for Wells Hatchery fish released to the Twisp River.

For coho salmon, estimated survival from release to Bonneville Dam ranged from 0.423 (0.099) for Willard Hatchery fish released from Eightmile Pond to 0.137 (0.032) for Prosser Hatchery fish released from the hatchery.

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, virtual daily groups of combined hatchery and wild fish were formed based on detection date at Lower Granite Dam. We calculated the 20th percentile, median, and 80th percentile travel time and migration rate for each daily and weekly group. We calculated a flow exposure index for each daily group (see Appendix C).

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, while rates of spill were extremely high for the entire migration period in 2023, we observed longer-than-usual travel times during the early part of the season, especially for spring Chinook.

During the month of April, travel times for steelhead were longer than average (Figure 2). Travel times for Chinook during this month were among the longest on record. In late April, migration rates for both species began to increase both in absolute terms as well as relative to other years. By early May, travel times for both species were extremely short, reaching the shortest on record for both species in mid-May. In late May and early June, migration rates slowed slightly for steelhead, producing travel times that were slightly longer than average.

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 long travel times observed in April occurred during a period of low flow exposure. A large increase in flow exposure began in late April, roughly corresponding with decreases in travel time. However, a pronounced dip in flow exposure around 10 May did not coincide with any substantial change in travel time (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 2023. 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%
30 Mar-5 Apr	22	6.9	9.4	16.4	0	-	-	-	0	-	-	-
6-12 Apr	397	7.3	10.4	16.0	12	2.8	4.0	6.2	4	5.8	6.8	9.5
13-19 Apr	535	6.1	8.4	16.0	32	1.9	2.8	4.4	5	3.9	4.2	5.0
20-26 Apr	331	6.3	9.3	13.1	25	1.4	1.7	2.1	3	5.3	6.8	9.2
27 Apr-3 May	4,689	2.5	3.1	4.3	428	1.1	1.4	1.9	41	4.1	4.8	6.4
4-10 May	3,552	3.0	4.1	5.9	284	1.2	1.6	2.1	53	2.7	3.2	4.0
11-17 May	1,375	2.0	2.8	3.8	98	1.0	1.2	1.5	32	2.0	2.5	3.5
18-24 May	518	2.2	3.0	3.9	18	0.9	1.0	1.2	3	2.2	2.7	5.0
25-31 May	108	2.0	2.2	2.9	1	1.2	1.2	1.2	0	-	-	-
1-7 Jun	31	2.0	2.2	2.4	0	-	-	-	0	-	-	-

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
30 Mar-5 Apr	19	16.0	17.6	23.1	14	26.9	28.9	36.7
6-12 Apr	187	16.6	20.5	24.3	289	26.0	29.0	33.1
13-19 Apr	136	14.1	17.4	23.8	367	20.7	24.2	27.8
20-26 Apr	71	12.6	17.3	21.8	316	15.6	18.9	22.2
27 Apr-3 May	415	7.9	10.0	13.9	1,890	10.9	12.8	15.5
4-10 May	557	8.9	10.5	12.2	1,269	11.7	13.0	14.7
11-17 May	364	5.3	6.3	7.5	1,037	8.1	8.8	10.2
18-24 May	69	5.0	5.9	7.0	649	8.7	9.7	10.8
25-31 May	4	7.3	7.4	7.7	67	8.9	10.2	11.2
1-7 Jun	6	5.1	5.2	5.3	13	9.1	9.2	9.9

Table 16. Migration rate from Lower Granite to Bonneville Dam for Snake River yearling Chinook salmon in 2023. 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%
30 Mar-5 Apr	22	3.7	6.4	8.7	0	-	-	-	0	-	-	-
6-12 Apr	397	3.7	5.8	8.3	12	7.4	11.5	16.1	4	12.5	17.5	20.6
13-19 Apr	535	3.8	7.1	9.8	32	10.5	16.3	24.2	5	23.6	28.6	30.4
20-26 Apr	331	4.6	6.5	9.6	25	21.6	27.4	33.8	3	13.0	17.4	22.5
27 Apr-3 May	4,689	14.1	19.6	24.3	428	24.6	33.6	41.8	41	18.6	25.1	28.8
4-10 May	3,552	10.2	14.8	20.3	284	22.2	28.2	36.8	53	29.5	37.1	44.7
11-17 May	1,375	15.6	21.1	29.7	98	30.9	37.1	46.0	32	33.7	46.9	59.5
18-24 May	518	15.5	20.2	26.9	18	39.3	47.4	51.7	3	23.9	43.8	53.4
25-31 May	108	20.9	27.0	30.3	1	39.3	39.3	39.3	0	-	-	-
1-7 Jun	31	24.8	27.6	29.3	0	-	-	-	0	-	-	-

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
30 Mar-5 Apr	19	9.7	12.8	14.1	14	12.6	15.9	17.2
6-12 Apr	187	9.2	11.0	13.5	289	13.9	15.9	17.8
13-19 Apr	136	9.5	12.9	16.0	367	16.6	19.0	22.3
20-26 Apr	71	10.3	13.0	17.9	316	20.8	24.4	29.5
27 Apr-3 May	415	16.2	22.6	28.5	1,890	29.8	36.1	42.3
4-10 May	557	18.5	21.4	25.4	1,269	31.4	35.5	39.5
11-17 May	364	30.1	35.7	42.1	1,037	45.2	52.4	56.7
18-24 May	69	32.1	38.1	45.0	649	42.6	47.4	52.8
25-31 May	4	29.1	30.5	30.9	67	41.3	45.4	51.5
1-7 Jun	6	42.2	43.0	44.0	13	46.7	49.9	50.8

Table 17. Travel time and migration rate from McNary to Bonneville Dam for Snake River yearling Chinook salmon in 2023. 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	0	-	-	-	2	1.2	1.3	1.4	0	-	-	-
6-12 Apr	13	4.1	4.4	7.1	33	1.5	1.6	2.2	23	4.6	5.4	6.1
13-19 Apr	11	3.7	3.9	4.2	35	1.4	1.6	1.8	9	4.7	6.1	8.9
20-26 Apr	3	3.4	4.9	6.3	15	1.4	1.5	1.9	13	3.7	4.3	4.8
27 Apr-3 May	30	2.7	3.3	3.9	100	1.4	1.6	1.8	55	3.8	4.3	4.9
4-10 May	38	2.0	2.5	3.2	86	1.2	1.4	1.6	65	3.0	3.4	3.8
11-17 May	19	1.9	2.2	2.5	71	1.1	1.2	1.4	41	2.9	3.2	3.5
18-24 May	1	2.1	2.1	2.1	29	1.3	1.5	1.8	14	3.2	3.4	3.8
25-31 May	0	-	-	-	2	1.6	1.6	1.6	0	-	-	-
	Migration rate (km/d)											
30 Mar-5 Apr	0	-	-	-	2	80.7	85.6	90.4	0	-	-	-
6-12 Apr	13	17.3	27.8	30.2	33	51.8	68.9	76.9	23	38.6	43.5	51.5
13-19 Apr	11	29.5	31.3	33.2	35	63.8	72.0	80.1	9	26.5	38.5	50.1
20-26 Apr	3	19.5	25.2	36.0	15	58.9	74.3	83.1	13	49.6	55.3	63.6
27 Apr-3 May	30	31.6	37.5	45.2	100	62.4	71.1	82.5	55	48.2	54.8	62.1
4-10 May	38	38.9	48.6	61.2	86	72.9	83.1	91.9	65	62.1	70.4	78.9
11-17 May	19	49.4	54.7	63.7	71	83.7	93.4	103.7	41	67.8	74.7	81.7
18-24 May	1	59.7	59.7	59.7	29	63.8	73.9	85.0	14	62.9	70.4	72.6
25-31 May	0	-	-	-	2	69.8	71.5	72.9	0	-	-	-

Table 18. Travel times from Lower Granite to Bonneville Dam for Snake River juvenile steelhead in 2023. 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%
30 Mar-5 Apr	16	4.0	5.1	6.0	1	3.1	3.1	3.1	0	-	-	-
6-12 Apr	105	2.2	3.1	4.0	1	2.2	2.2	2.2	2	4.1	4.1	4.1
13-19 Apr	1,017	3.4	4.2	5.2	30	2.8	5.2	6.3	4	2.8	3.6	6.4
20-26 Apr	1,380	3.1	3.4	4.3	41	2.0	3.2	4.4	8	2.8	3.1	3.4
27 Apr-3 May	3,455	1.9	2.1	2.7	467	1.0	1.4	2.6	19	1.9	2.3	3.5
4-10 May	4,531	1.8	2.0	2.8	569	1.1	1.4	2.2	19	2.0	2.5	3.0
11-17 May	1,735	1.9	2.0	2.5	308	1.0	1.1	1.6	35	1.7	1.8	2.1
18-24 May	951	1.7	1.9	2.2	122	0.9	1.1	1.4	14	1.4	1.6	1.8
25-31 May	425	1.9	2.0	2.3	41	0.9	1.2	1.7	1	2.5	2.5	2.5
1-7 Jun	370	1.9	2.0	2.3	39	1.0	1.1	1.8	7	2.1	2.6	2.8
8-14 Jun	9	1.9	2.1	2.4	1	1.1	1.1	1.1	0	-	-	-

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
30 Mar-5 Apr	2	11.1	11.3	11.5	4	17.0	19.2	20.3
6-12 Apr	44	9.7	11.7	15.2	122	15.6	17.8	20.3
13-19 Apr	190	10.3	11.6	13.7	783	15.2	16.7	18.7
20-26 Apr	265	8.5	9.6	11.1	1,873	11.5	12.8	14.5
27 Apr-3 May	63	5.0	6.4	8.5	2,359	7.9	8.7	9.8
4-10 May	106	5.0	5.9	7.4	1,106	8.3	8.7	9.8
11-17 May	148	4.1	4.9	5.7	860	6.8	7.5	8.4
18-24 May	109	3.9	4.1	4.9	1,060	6.7	7.6	8.5
25-31 May	20	5.2	5.8	6.2	224	7.9	8.7	9.3
1-7 Jun	24	5.1	5.6	6.2	90	9.2	10.3	10.9
8-14 Jun	6	5.1	5.6	6.1	97	9.3	10.7	11.7

Table 19. Migration rate from Lower Granite to Bonneville Dam for Snake River juvenile steelhead in 2023. 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%
30 Mar-5 Apr	16	10.1	11.7	14.9	1	15.0	15.0	15.0	0	-	-	-
6-12 Apr	105	15.1	19.2	27.1	1	20.5	20.5	20.5	2	29.2	29.2	29.2
13-19 Apr	1,017	11.4	14.1	17.7	30	7.3	8.8	16.3	4	18.7	33.1	41.8
20-26 Apr	1,380	14.1	17.9	19.1	41	10.5	14.5	22.4	8	34.9	38.3	43.0
27 Apr-3 May	3,455	22.1	29.1	32.1	467	17.9	33.3	44.7	19	33.9	50.9	62.3
4-10 May	4,531	21.4	29.9	32.8	569	20.6	32.6	42.6	19	39.1	47.6	58.9
11-17 May	1,735	23.9	30.0	32.1	308	29.1	40.4	47.9	35	56.1	64.7	70.0
18-24 May	951	27.3	32.1	35.1	122	31.9	42.2	48.9	14	66.5	75.8	82.1
25-31 May	425	26.4	30.5	32.1	41	27.7	39.3	50.0	1	47.4	47.4	47.4
1-7 Jun	370	26.3	30.5	31.9	39	25.7	40.4	46.0	7	42.8	46.1	57.8
8-14 Jun	9	24.9	27.9	31.2	1	42.2	42.2	42.2	0	-	-	-

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
30 Mar-5 Apr	2	19.6	20.0	20.4	4	22.7	23.9	27.2
6-12 Apr	44	14.8	19.3	23.3	122	22.7	25.8	29.6
13-19 Apr	190	16.4	19.4	21.7	783	24.7	27.7	30.3
20-26 Apr	265	20.3	23.5	26.5	1,873	31.9	36.1	40.1
27 Apr-3 May	63	26.4	35.3	44.7	2,359	46.9	52.7	58.6
4-10 May	106	30.5	38.0	45.0	1,106	46.8	52.7	55.7
11-17 May	148	39.4	46.2	55.0	860	54.7	61.5	68.0
18-24 May	109	46.1	55.0	57.3	1,060	54.2	60.8	68.8
25-31 May	20	36.3	38.9	43.4	224	49.4	53.1	58.3
1-7 Jun	24	36.0	40.2	44.5	90	42.2	44.9	50.0
8-14 Jun	6	36.9	40.2	43.9	97	39.3	43.1	49.3

Table 20. Travel time and migration rates from McNary to Bonneville Dam for Snake River juvenile steelhead in 2023. 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)											
6-12 Apr	5	4.0	4.1	5.9	3	2.6	2.8	3.0	4	6.6	6.7	7.5
13-19 Apr	12	3.1	3.4	4.3	34	1.2	1.4	1.6	25	3.8	4.5	5.7
20-26 Apr	24	2.8	3.3	4.0	196	1.2	1.3	1.5	26	3.4	3.7	4.4
27 Apr-3 May	6	2.0	2.6	3.4	197	1.2	1.3	1.4	5	2.9	3.4	3.5
4-10 May	9	2.2	2.6	2.9	79	1.1	1.2	1.4	15	2.9	3.2	3.5
11-17 May	30	1.9	2.1	2.7	138	1.0	1.0	1.1	15	2.5	2.6	2.9
18-24 May	7	2.3	2.4	3.1	52	1.1	1.2	1.4	17	2.7	3.1	3.5
25-31 May	0	-	-	-	4	1.5	1.6	2.1	2	3.8	3.9	4.1
	Migration rate (km/d)											
6-12 Apr	5	20.7	29.7	31.1	3	37.0	41.1	44.0	4	31.4	35.1	36.0
13-19 Apr	12	28.6	36.2	39.3	34	72.0	79.0	92.6	25	41.3	51.9	61.8
20-26 Apr	24	30.6	36.8	44.4	196	77.4	86.3	93.4	26	53.9	63.6	70.0
27 Apr-3 May	6	36.0	46.4	61.8	197	78.5	89.0	95.0	5	67.4	69.6	81.7
4-10 May	9	42.7	47.3	55.4	79	79.0	92.6	107.6	15	67.8	72.6	80.5
11-17 May	30	45.6	57.2	65.4	138	102.7	111.9	118.9	15	82.2	89.1	95.9
18-24 May	7	39.2	51.0	54.4	52	79.0	91.1	105.6	17	66.5	76.6	87.7
25-31 May	0	-	-	-	4	54.9	70.6	73.9	2	57.8	59.9	61.9

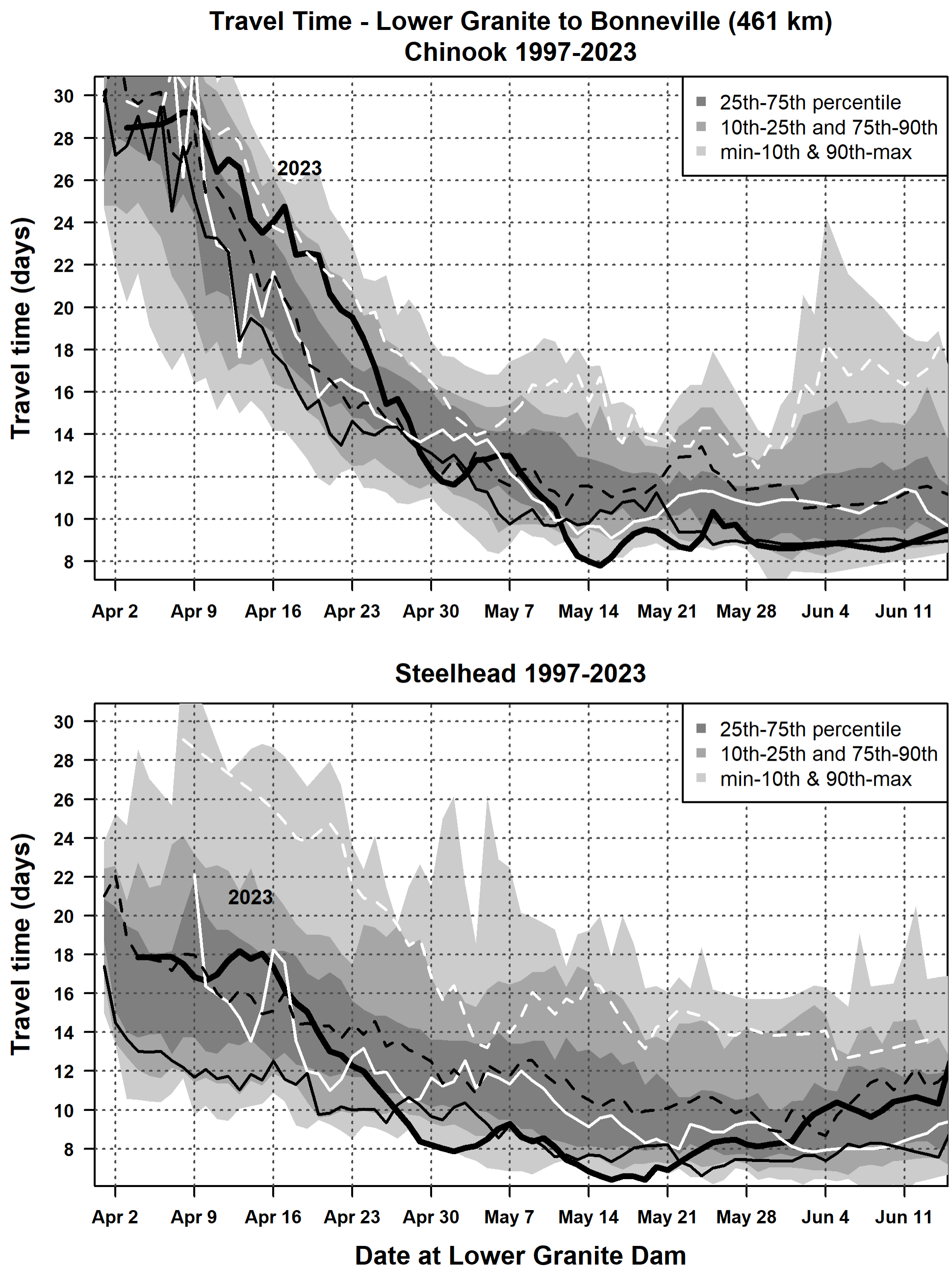

Figure 2. Median travel time (heavy black line) from Lower Granite to Bonneville Dam (461 km) vs. date passing Lower Granite Dam for yearling Chinook salmon and juvenile steelhead. Shaded regions show daily quantiles during 1997-2023 (excluding 2001). Lines show daily medians from selected subsets of years: black lines show low-flow years during the former (dashed; 2004-2005) and present spill regimes (solid; 2007, 2010, 2013, 2015, and 2021); white lines show high-flow years during the former (dashed; 1997 and 2006) and present spill regimes (solid; 2011, 2012, 2017, 2018, and 2019).

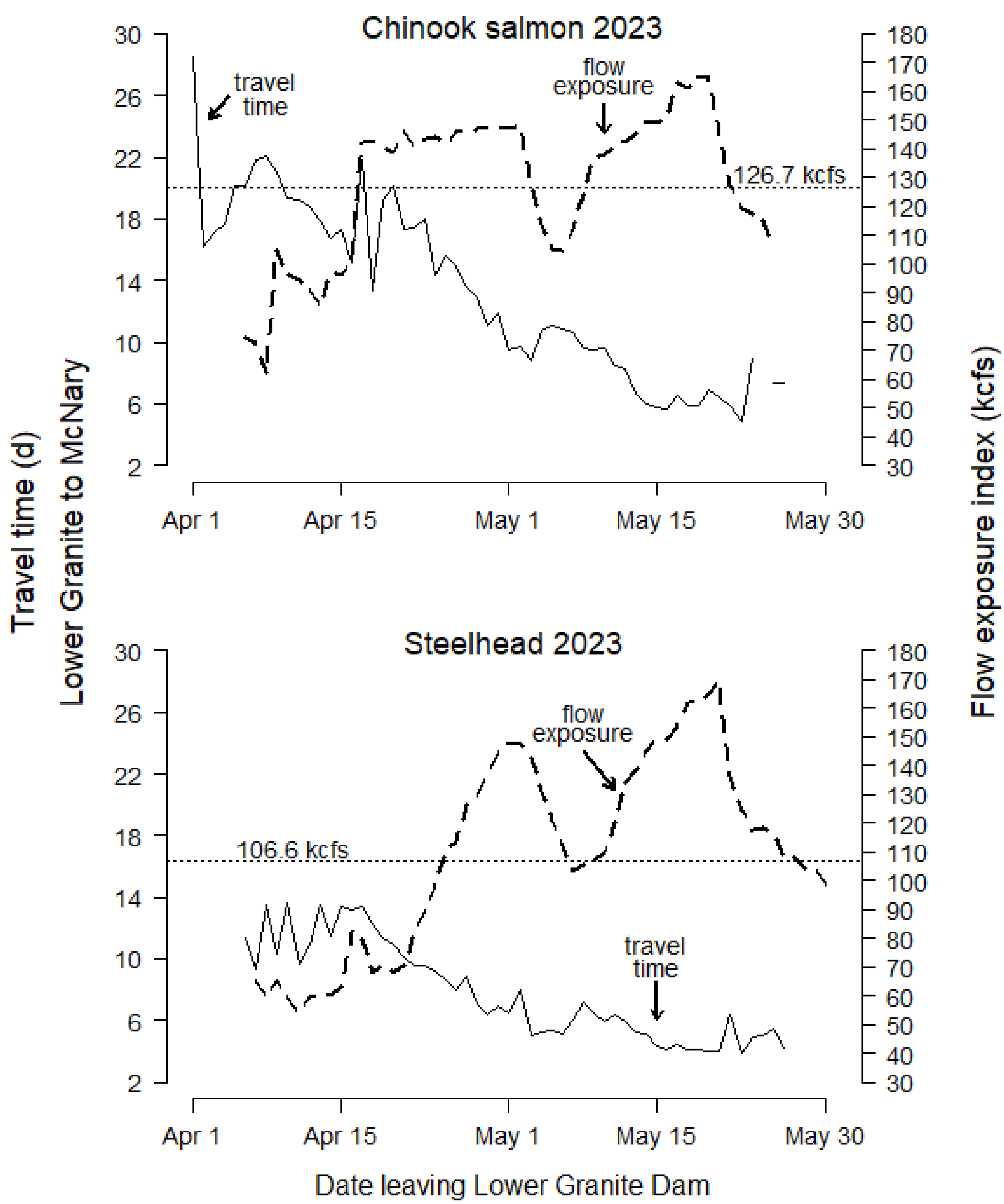

Figure 3. Median travel time (d) from Lower Granite to McNary Dam and index of flow exposure at Little Goose Dam (kcfs) for daily groups of PIT-tagged yearling Chinook salmon and juvenile steelhead during 2023. Dashed horizontal lines represent the mean flow exposure index for the year weighted by the number of PIT-tagged fish in each daily group.

Proportion Transported of Spring Migrants

Methods

To estimate the proportion of fish transported from the run-at-large, 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 2021) 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 2023, 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 the 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 the 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 2023). 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 2023, collection for transportation began at 0700 on 23 April at Lower Granite, Little Goose Dams, and Lower Monumental Dams, and the first barge departed on 24 April. Before that time, smolts that entered 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 2023 season were 37.4% for wild and 31.7% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 41.4% for wild and 32.6% 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 2023 was slightly above average, the highest proportion transported since 2019 (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 2023.

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 2023, collection for transportation began on 23 April. The transportation program has started on or about 24 April since 2018, so the start date in 2023 was typical of recent years. The overall transportation rate was above average in 2023, though only slightly. Given the typical start date, possible causes of an above-average rate in 2023 were a late run, high collection rates in the juvenile bypass, or both.

Run timing in 2023 was typical for both Chinook and steelhead. However, the distribution of the run was more compact than normal, resulting in slightly lower-than-average proportions of fish passing before the start of general transportation. We estimated that 20.2% of wild and 15.8% of hatchery Chinook salmon, and 15.4% of wild and 25.4% of hatchery steelhead had passed Lower Granite prior to the start of transportation. These numbers were slightly lower than in other recent years, which contributed to an increased transportation rates because a slightly greater share of each population was available to be transported.

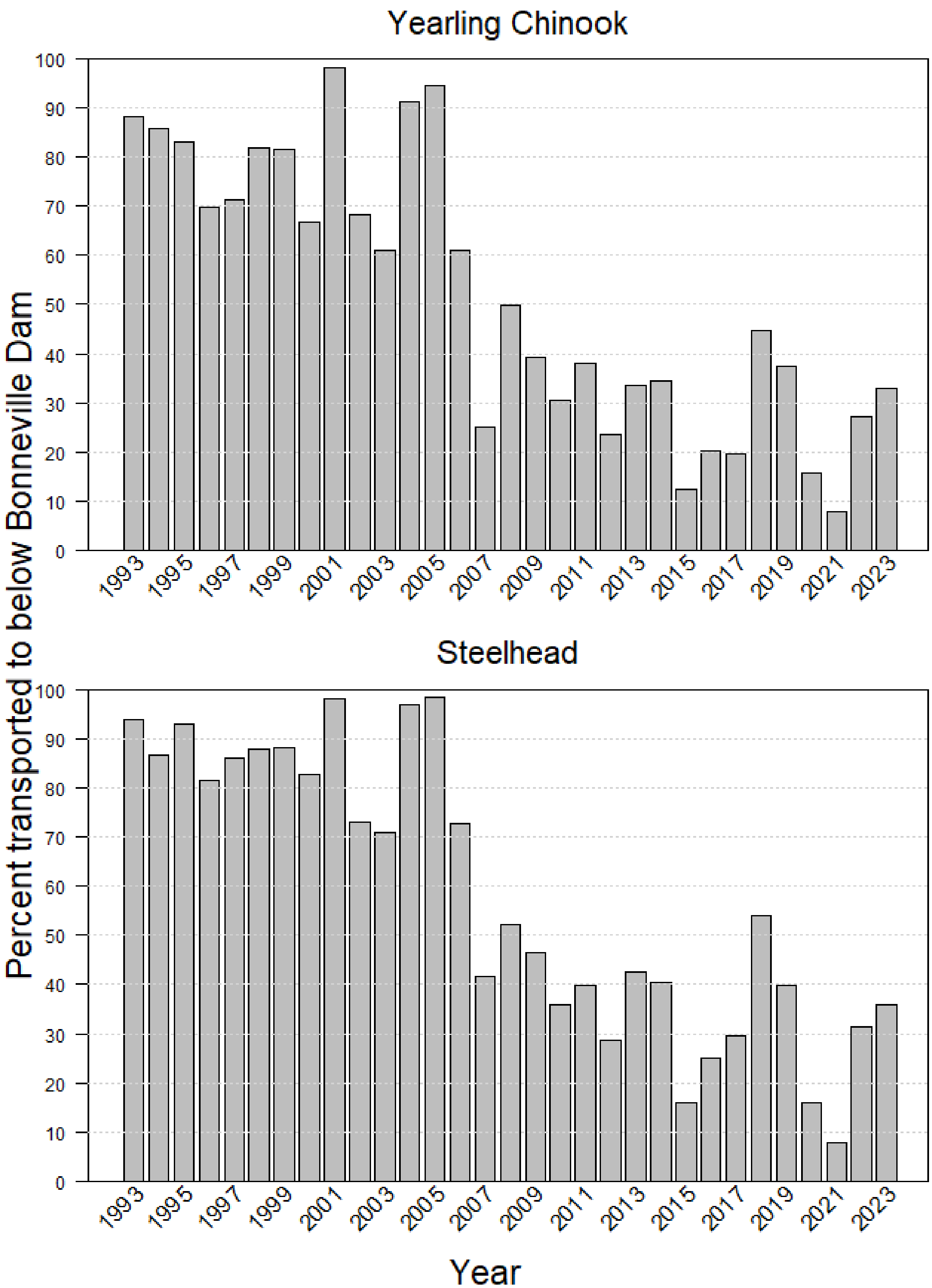

Figure 4. Annual estimated percentages of Snake River yearling Chinook salmon and juvenile steelhead arriving at Lower Granite Dam that were subsequently collected for transportation and released downstream of Bonneville Dam (mean of estimates for hatchery and wild fish), 1993-2023.

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, 1993-2023. Simple arithmetic means are given across all years and for periods with similar transportation schedules (1993-2006 and 2007-2023).

	Estimated percentages of fish transported, 1993-2023 (%)					
	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
2023	30.2	35.7	33.0	31.4	40.5	36.0
Mean						
1993-2023	**49.9**	**53.0**	**51.5**	**55.0**	**60.6**	**57.8**
1993-2006	**76.7**	**80.9**	**78.8**	**86.0**	**86.7**	**86.4**
2007-2023	**27.9**	**30.1**	**29.0**	**29.5**	**39.0**	**34.3**

In 2023, the proportion of passing smolts collected after the start of transportation was slightly below average, but still much higher than in 2020-2022. We estimated that 45.5% of wild and 36.9% of hatchery Chinook and 48.0% of wild and 41.6% of hatchery steelhead that passed during transport operations were collected in a juvenile bypass system and transported. These collection rates were about 4-5% less than the 2007-2023 average. The difference in proportion of wild vs. hatchery fish transported resulted from a difference between origins in the probability of entering a juvenile bypass system.

While a below-average collection rate results in a lower transportation rate, a larger proportion of fish passing during transport operations results in a higher transportation rate. The combination of both of these factors in 2023 offset each other, and the end result was an overall transportation rate that was slightly above the 2007-2023 average.

Comparisons Among Annual Estimates

Comparison Among Years

We made two types of comparisons between annual survival estimates from 2023 and those from the previous 30 study years. First, for Snake River hatchery yearling Chinook, we compared estimated survival to Lower Granite Dam with distance of the respective hatcheries to the dam. Second, for Snake and Columbia River yearling Chinook, steelhead, and sockeye, we compared estimates of mean annual survival through specific reaches in 2023 to those in all previous study years for which these data were available.

We also compared detection probability estimates in 2023 to those from previous study years. For all yearling Chinook salmon released upstream from Lower Granite Dam in 2023, 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 1998-2023.

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 2023, with below-average survival estimated only for fish from Lookingglass and Rapid River Hatchery (Table 22). Survival of fish from Kooskia Hatchery was among the highest on record for that hatchery, while survival of fish from Rapid River Hatchery was close to the lowest on record. For Pahsimeroi Hatchery, we typically report the survival estimate for the Pahsimeroi Weir release group; however, no release of Pahsimeroi Hatchery fish was conducted at that site in 2023. As a substitute, we used the release group of Pahsimeroi Hatchery fish from the tailrace of Hells Canyon Dam.

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 = 0.821, 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, 1993-2023. 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[a] (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.

Year	Dworshak (116 km)	Kooskia (176 km)	Lookingglass[a] (209 km)	Rapid River (283 km)	McCall (457 km)	Pahsimeroi (630 km)	Sawtooth (747 km)	Mean
	Estimated survival of hatchery yearling Chinook salmon (SE)							
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)
2023	0.819 (0.011)	0.806 (0.025)	0.555 (0.009)	0.497 (0.005)	0.660 (0.006)	0.670 (0.052)[b]	0.582 (0.009)	0.656 (0.046)
Mean	**0.776 (0.013)**	**0.675 (0.016)**	**0.655 (0.010)**	**0.686 (0.019)**	**0.618 (0.015)**	**0.527 (0.030)**	**0.497 (0.029)**	**0.633 (0.010)**

a. Released at Imnaha River Weir.

b. Released at the tailrace of Hells Canyon Dam instead of the usual release site at Pahsimeroi Weir.

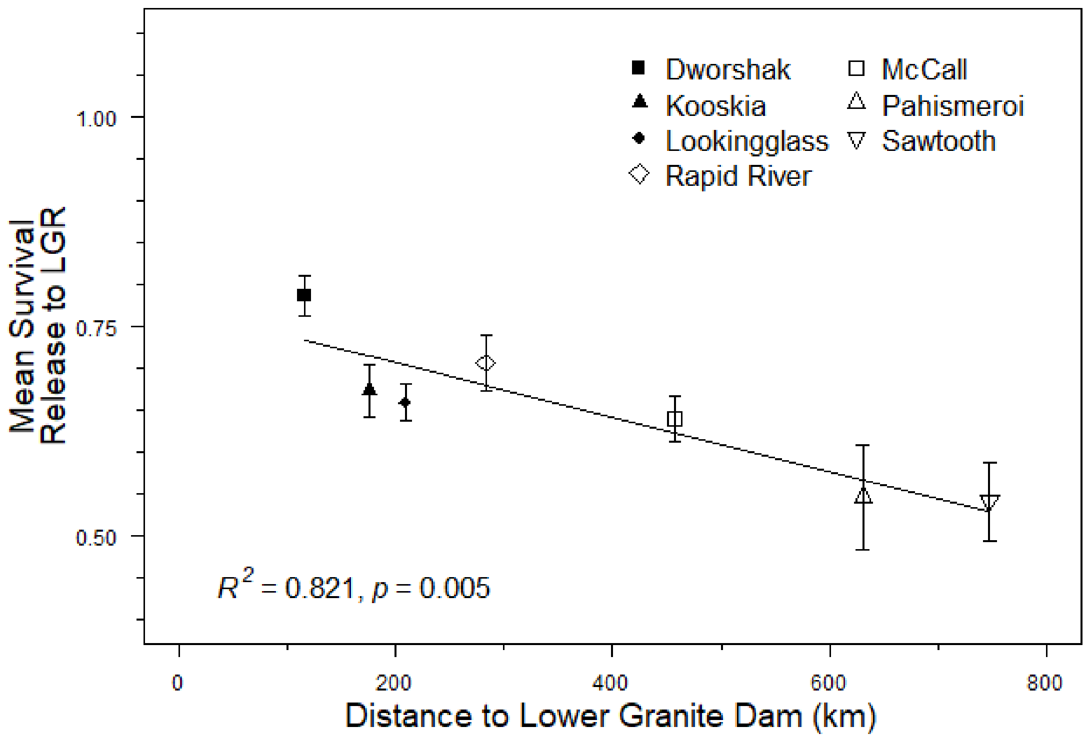

Figure 5. Mean estimated survival probability of yearling Chinook from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2023, vs. distance (km) from release to Lower Granite Dam. The coefficient of determination between survival and migration distance is also shown, along with 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 2023, mean estimated survival was 0.627 (95% CI 0.580-0.674) from Lower Granite to McNary and 0.751 (0.704-0.798) from McNary to Bonneville Dam (Tables 23-24; Figures 6-7). The estimate from Lower Granite to McNary Dam was far below the long-term mean of 0.730, and the difference was statistically significant ($P < 0.01$). The estimate from McNary to Bonneville was moderately above the long-term mean of 0.704, but the difference was not significant ($P = 0.11$). The overall estimate from Lower Granite to Bonneville Dam was 0.483, which was moderately below the long-term mean of 0.523 and not significantly different from it ($P = 0.24$).

For combined wild and hatchery yearling Chinook salmon in 2023, mean estimated survival from the Snake River Smolt Trap to the tailrace of Bonneville Dam was 0.423 (95% CI 0.359-0.487; Table 24). This estimate was below the long-term mean of 0.483 as well as the estimate from 2022 of 0.508, although it was not significantly different from either ($P = 0.09$, 0.12 respectively).

For wild yearling Chinook salmon in 2023, estimated survival from Lower Granite to McNary Dam was 0.648 (95% CI 0.444-0.852). This estimate was below but not significantly different from the long-term average of 0.713 (Table 25; $P = 0.52$). Estimated survival for these fish from McNary to Bonneville Dam was 0.735 (95% CI 0.463-1.007), which was higher than the long-term average of 0.659 (Table 25). However, due to the poor precision of this estimate, the difference was not significant ($P = 0.58$).

For wild Snake River Chinook, estimated survival from Lower Granite to Bonneville Dam was 0.452 (95% CI 0.295-0.609; Table 25), which was slightly below the long-term average of 0.474 and not significantly different from it ($P = 0.79$).

Though only 169 wild yearling Chinook were tagged at the Snake River Smolt Trap in 2023, 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 Lower Granite Dam was 0.885 (95% CI 0.679-1.091; Table 25), which was below the long-term mean of 0.916 but not statistically different from it ($P = 0.77$). Mean estimated survival of wild Chinook from the Snake River Smolt Trap to the tailrace of Bonneville Dam was 0.400 (0.233-0.567); this estimate was also below the long-term mean of 0.445 but not significantly different from it ($P = 0.60$).

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), 1993-2023. 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*
2023	0.876 (0.037)	0.921 (0.013)	0.995 (0.048)	0.701 (0.034)	0.837	0.894 (0.079)*	0.852 (0.082)*	0.923*
Mean	**0.919 (0.009)**	**0.915 (0.008)**	**0.944 (0.013)**	**0.855 (0.011)**	**0.924 (0.006)**	**0.869 (0.017)**	**0.813 (0.020)**	**0.900 (0.011)**

* Estimates for 2020-2023 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), 1993–2023. 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)
2023	0.876 (0.037)	0.627 (0.024)	0.751 (0.024)*	0.483 (0.031)	0.423 (0.033)
Mean	**0.919 (0.009)**	**0.730 (0.011)**	**0.706 (0.017)**	**0.523 (0.016)**	**0.483 (0.016)**

* The estimates for 2020-2023 for the reach between McNary Dam and Bonneville Dam used a different method than in previous years.

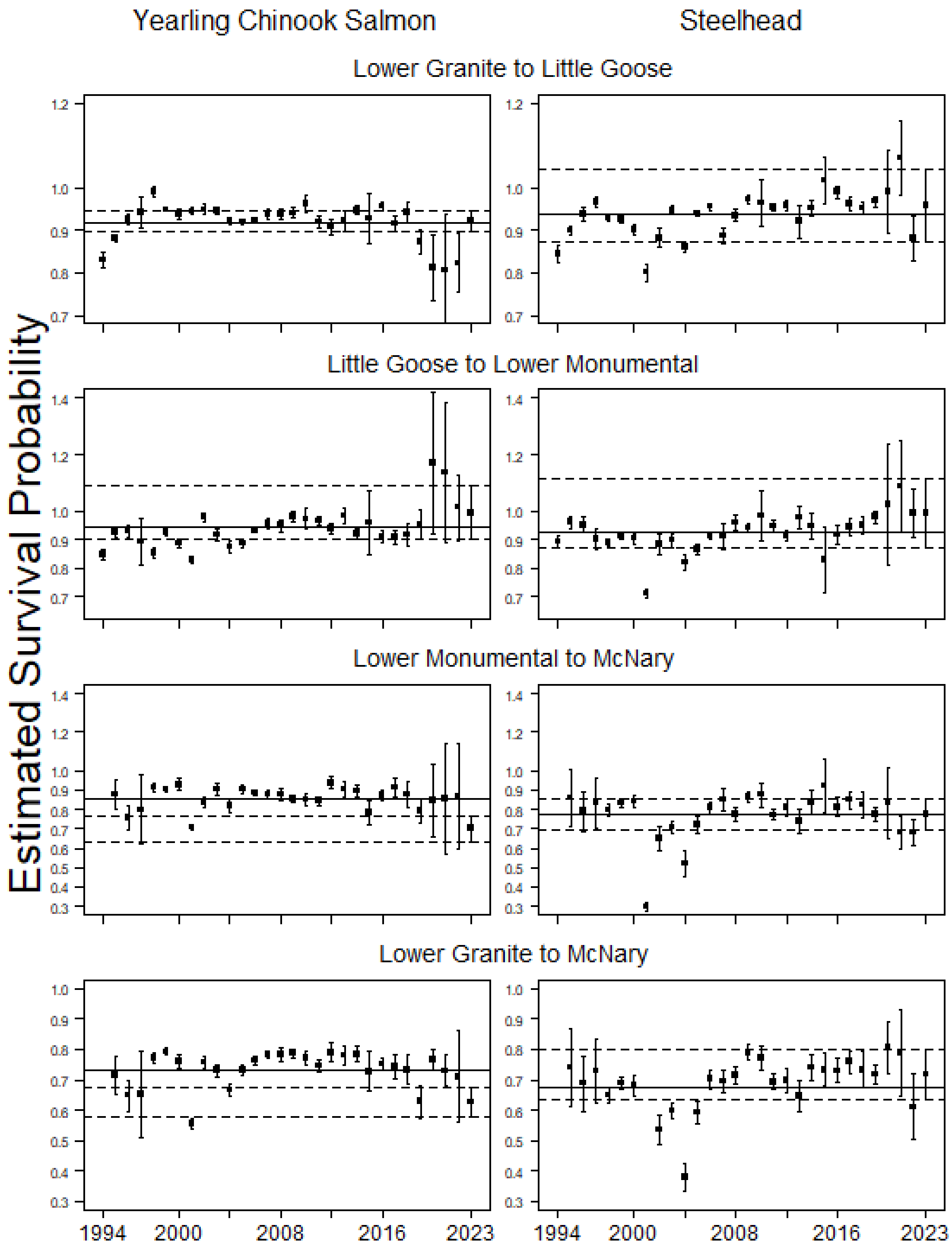

Figure 6. Annual survival probability estimates through Snake River reaches for Snake River yearling Chinook salmon and juvenile steelhead (combined hatchery and wild fish), 1993-2023. Whiskers represent 95% CIs. Dashed lines indicate 95% CI endpoints for 2023 estimates; solid lines indicate long-term means (1993-2023).

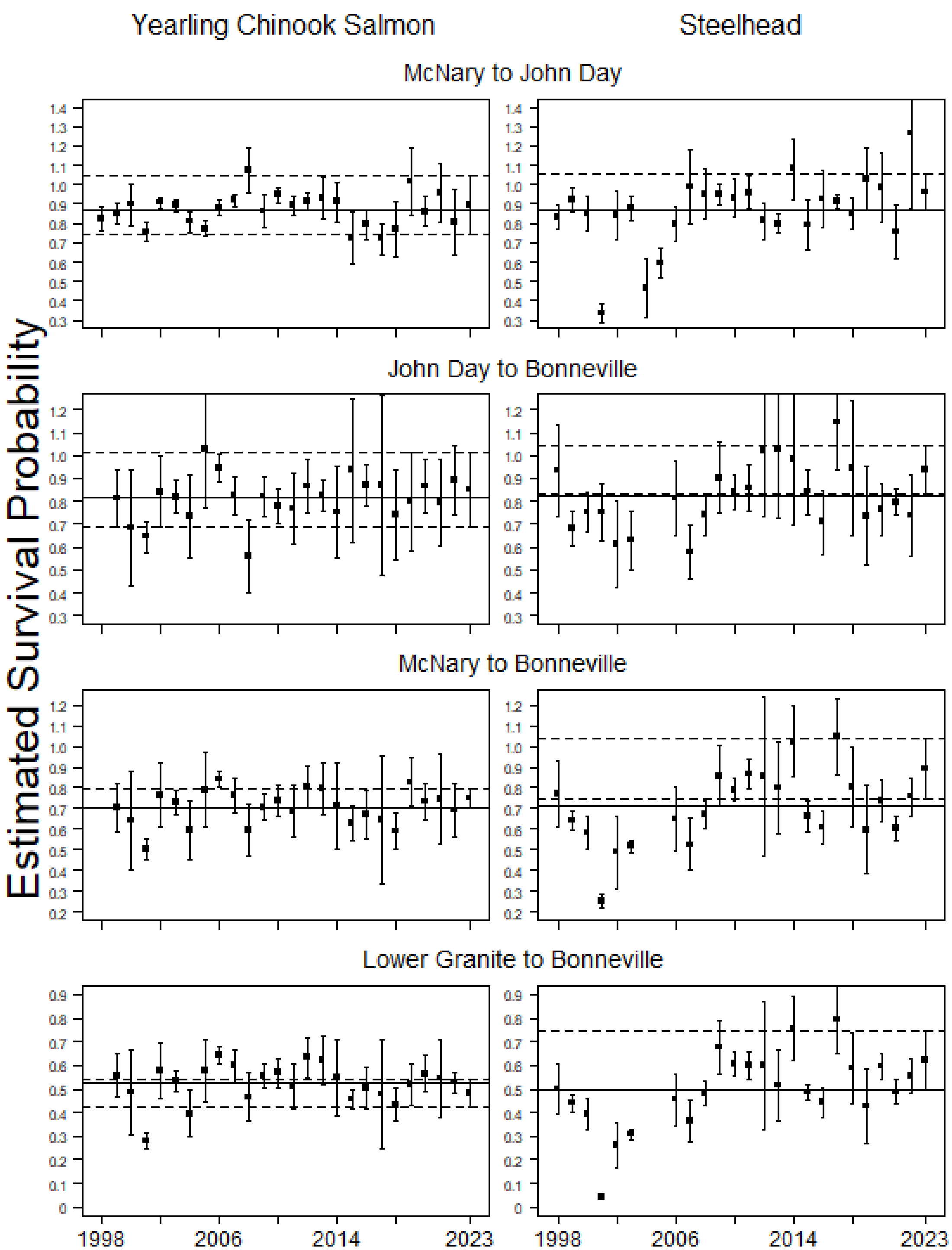

Figure 7. Annual survival probability estimates through Columbia River reaches and from Lower Granite to Bonneville Dam for Snake River yearling Chinook and juvenile steelhead (combined hatchery and wild fish), 1993-2023. Whiskers represent 95% CIs. Dashed lines indicate 95% CI endpoints for 2023 estimates; solid lines indicate long-term means (1993-2023).

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), 1993–2023. 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)
2023	0.885 (0.105)[c]	0.621 (0.068)	0.735 (0.139)	0.452 (0.080)	0.400 (0.085)
Mean	**0.916 (0.015)**	**0.712 (0.013)**	**0.659 (0.029)**	**0.474 (0.024)**	**0.445 (0.025)**

a. Based on a sample size of just 69 tagged fish.
b. Based on a sample size of just 121 tagged fish.
c. Based on a sample size of just 169 tagged fish.

***Steelhead*—**For combined wild and hatchery steelhead, mean estimated survival from Lower Granite to McNary Dam was 0.718 (95% CI 0.636-0.800) in 2023. This estimate was higher than both the 2022 estimate of 0.610 and the long-term average of 0.672, but not significantly different from either (*P* = 0.11, 0.33 respectively; Tables 26-27; Figures 6-7).

Mean estimated survival from McNary to Bonneville Dam for wild and hatchery Snake River steelhead was 0.892 (0.743-1.041) in 2023, which was much higher than both the 2022 estimate of 0.757 and the long-term average of 0.705. Due to the poor precision of the estimates, the difference between the 2023 estimate and the 2022 estimate was not significant (*P* = 0.13). However, the difference between the 2023 estimate and the long-term mean was statistically significant (*P* = 0.02).

Estimated survival from the Snake River Smolt Trap to Bonneville Dam for combined wild and hatchery steelhead was 0.584 (0.463-0.705; Table 27), which was higher than both the estimate of 0.520 from 2022 and the long-term average of 0.468. The difference between estimates for 2022 vs. 2023 was not significant (*P* = 0.38), and the difference between the estimate for 2023 and the long-term average was also not significant (*P* = 0.08).

For wild steelhead, estimated survival in 2023 was 0.704 (95% CI 0.504-0.904; Table 28) from Lower Granite to McNary Dam. This estimate was above the long-term average of 0.649, but not significantly different from it (*P* = 0.59). Estimated survival for wild steelhead from McNary to Bonneville Dam was 0.696 (0.533-0.859), which was above, but not significantly different from, the long-term average of 0.653 (*P* = 0.64).

Though only 166 wild steelhead were tagged at the Snake River Smolt Trap in 2023, 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 Lower Granite Dam was 0.895 (95% CI 0.699-1.091; Table 28), which was below the long-term average of 0.948 but not statistically different from it (*P* = 0.59). Estimated survival for wild steelhead from the Snake River Smolt Trap to Bonneville Dam in 2023 was 0.399 (95% CI 0.250-0.548; Table 28), which was slightly below the long-term average of 0.423. However, the difference was not significant (*P* = 0.76).

Table 26. Annual survival probability estimates from Snake River Smolt Trap to Bonneville Dam for Snake River juvenile steelhead (combined hatchery and wild fish), 1993–2023. 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*
2023	0.942 (0.028)	0.958 (0.043)	0.995 (0.063)	0.776 (0.042)	0.881	0.963 (0.049)*	0.936 (0.053)*	0.967*
Mean	**0.950 (0.009)**	**0.938 (0.010)**	**0.927 (0.013)**	**0.770 (0.023)**	**0.874 (0.015)**	**0.864 (0.036)**	**0.822 (0.029)**	**0.904 (0.016)**

* Estimates for 2020-2023 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), 1993-2023. 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)
2023	0.942 (0.028)	0.718 (0.042)	0.892 (0.076)*	0.620 (0.063)	0.584 (0.062)
Mean	**0.950 (0.009)**	**0.672 (0.024)**	**0.705 (0.035)**	**0.499 (0.032)**	**0.468 (0.031)**

* The 2020-2023 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), 1993–2023. 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)
2023	0.895 (0.100)[d]	0.704 (0.102)	0.696 (0.083)	0.446 (0.069)	0.399 (0.076)
Mean	**0.948 (0.012)**	**0.649 (0.028)**	**0.653 (0.046)**	**0.435 (0.030)**	**0.423 (0.031)**

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.
d. Based on a sample size of just 166 tagged fish.

Sockeye Salmon—For pooled groups of wild and hatchery Snake River sockeye salmon, estimated survival from Lower Granite to McNary Dam was 0.813 in 2023 (95% CI 0.697-0.948; Table 29). This estimate was well below the 2022 estimate of 1.059 but well above the long-term average of 0.672 (1996-2023). The difference between 2023 and 2022 estimates was not significant ($P = 0.17$), but the difference between the 2023 estimate and the long-term mean was statistically significant ($P = 0.04$). Estimated survival from McNary to Bonneville Dam was 0.548 (0.447-0.672) in 2023, which was close to the long-term average of 0.551. For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.445 (0.388-0.510) in 2023. This estimate was slightly above the long-term average of 0.410.

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, 1996-2023. 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)
2023	0.813 (0.064)	0.548 (0.057)	0.445 (0.031)
Mean	**0.672 (0.034)**	**0.551 (0.055)**	**0.410 (0.041)**

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 2022. 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, for which we have survival estimates starting in 2014. We have selected these survival estimates as the index group to report for upper Columbia River sockeye in lieu of estimates from Rock Island (Table 30).

For Upper Columbia River sockeye salmon captured, tagged, and released from the lower Wenatchee River smolt trap in 2023, estimated survival to McNary Dam was 0.578 (95% CI 0.276-1.211; Table 30). This estimate was above both the estimate from 2022 of 0.434 and the long-term average of 0.497 (2014-2023); however, the 2023 estimate was extremely imprecise and not significantly different, either from the 2022 estimate or the long-term average (P = 0.50, 0.70 respectively).

Estimated survival between McNary and Bonneville Dam for upper Columbia River sockeye was 0.666 (0.319-1.390), which was near the long-term average of 0.699 (1998-2023), but also very imprecise. Estimated survival of sockeye from the lower Wenatchee River smolt trap to Bonneville Dam in 2023 was 0.567 (0.242-1.331). This estimate was higher than the 2022 estimate of 0.458 and much higher than the long-term average of 0.296. However, this estimate was very imprecise as well.

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, 1998-2023. 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)
2023	0.578 (0.226)	0.666 (0.259)	0.567 (0.259)
Mean	**0.497 (0.043)**	**0.699 (0.063)**	**0.296 (0.062)**

[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.

Yearling Chinook Salmon—For pooled groups of hatchery yearling Chinook from the Upper Columbia Basin, estimated survival in 2023 from McNary to Bonneville Dam was 0.744 (95% CI 0.661-0.838), which was below the 1999-2023 average of 0.798 but not significantly different from it (P = 0.28; Table 31).

Steelhead—For pooled groups of hatchery steelhead from the Upper Columbia Basin, estimated survival from McNary to Bonneville Dam in 2023 was 0.944 (95% CI 0.811-1.098). This estimate was well above the long-term average of 0.769 (2003-2023) and significantly different from it despite the poor precision of the estimate (P = 0.03; Table 31).

Table 31. Annual survival probability estimates from release to Bonneville Dam for upper Columbia River hatchery yearling Chinook salmon (1999-2023) and hatchery juvenile steelhead (2003-2023). 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)
2023	0.436 (0.018)	0.815 (0.042)	0.913 (0.051)	0.744 (0.045)
Mean	**0.551 (0.011)**	**0.886 (0.019)**	**0.898 (0.033)**	**0.798 (0.025)**

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)
2023	0.341 (0.021)	1.048 (0.074)	0.901 (0.054)	0.944 (0.073)
Mean	**0.397 (0.015)**	**0.931 (0.042)**	**0.840 (0.046)**	**0.769 (0.041)**

Detection Probabilities for Snake River Yearling Chinook

Based on our estimates, the probability of detection for PIT-tagged juvenile Chinook salmon was far below average (1998-2023) at most dams on the Snake and Columbia Rivers during 2023 (Figure 8). At Little Goose and Lower Monumental Dam, detection probabilities in 2023 rebounded slightly relative to 2020 through 2022, but were still comparable to the lowest detection probabilities observed in years prior to 2020.

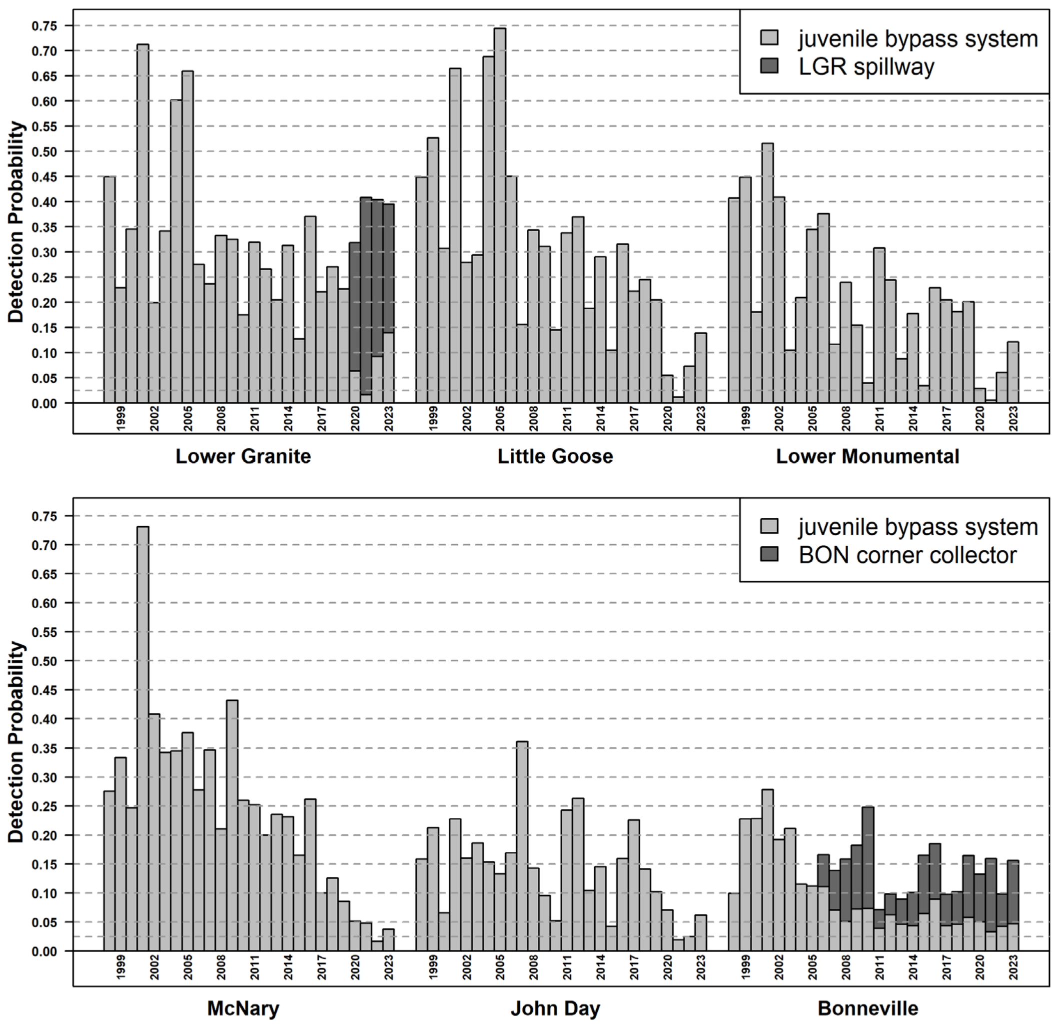

Figure 8. Annual mean detection probability for Snake River yearling Chinook salmon at six major dams on the Snake and Columbia Rivers, 1998-2023. Ice Harbor Dam was excluded because of persistent very low juvenile detection probabilities.

At both McNary and John Day Dam yearling Chinook detection probabilities were extremely low in 2023, though not quite as low as in 2022 (Figure 8). Detection probability at Bonneville Dam has not trended in any consistent direction in recent years, and was close to average in 2023. 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 2023 because of the spillway detection system (Figure 8). Detection in the bypass system at Lower Granite Dam was just under 14% in 2023. 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 well below average in 2023.

Comparison Between Snake and Columbia River Stocks

In 2023, estimated survival from McNary to Bonneville Dam was slightly higher for hatchery and wild yearling Chinook originating in the Snake River (0.751; 95% CI 0.704-0.798; Table 32) than for those originating in the Upper Columbia River Basin (0.733; 0.643-0.823), but the difference was not statistically significant ($P = 0.73$).

For combined hatchery and wild steelhead migrating from McNary to Bonneville during 2023, estimated survival for Snake River fish was 0.892 (0.743-1.041; Table 32). This was slightly lower than estimated survival for Upper Columbia River fish (0.901; 0.774-1.028), but the difference was not statistically significant ($P = 0.93$).

For hatchery and wild sockeye, estimated survival from McNary to Bonneville was lower for stocks originating in the Snake (0.548; 0.447-0.672; Table 32) than in the Upper Columbia River Basin (0.666; 0.319-1.390). However, the difference was not statistically significant, partly owing to the extremely poor precision of the estimate for Upper Columbia River stocks ($P = 0.62$).

Table 32. Annual survival probability estimates from McNary to Bonneville Dam for various spring-migrating salmonid stocks (hatchery and wild combined) in 2023. 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	84,648	0.894 (0.079)	0.852 (0.082)	0.751 (0.024)
Upper Columbia Chinook	Upper Columbia sites[a]	186,415	0.813 (0.044)	0.902 (0.052)	0.733 (0.046)
Upper Columbia Chinook	Yakima River sites[b]	102,686	0.603 (0.048)	1.159 (0.136)	0.698 (0.083)
Upper Columbia Coho	Upper Columbia sites[a]	60,926	1.159 (0.113)	0.797 (0.070)	0.923 (0.083)
Upper Columbia Coho	Yakima River sites[b]	65,392	0.601 (0.129)	0.864 (0.141)	0.519 (0.117)
Snake River Sockeye	Snake River sites[c]	50,001	0.827 (0.089)	0.662 (0.067)	0.548 (0.057)
Upper Columbia Sockeye	Upper Columbia sites[a]	3,997	0.852 (0.301)	0.782 (0.284)	0.666 (0.259)
Snake River Steelhead	Lower Granite Dam tailrace	101,703	0.963 (0.049)	0.936 (0.053)	0.892 (0.076)
Upper Columbia Steelhead	Upper Columbia sites[a]	104,127	1.038 (0.070)	0.867 (0.048)	0.901 (0.065)

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

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

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

Discussion

In 2023, NOAA conducted field work operations as normal, and both the tagging program at Lower Granite Dam and the pair-trawl detection system in the estuary were operated at normal capacity. The number of wild Chinook tagged at Lower Granite Dam was still somewhat below average, but the primary cause of this 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.

Levels of spill were extremely high in 2023, but a strong spring freshet also resulted in very high levels of flow during May, when most fish were passing dams on the Snake and Columbia Rivers. The combination of high levels of both spill and flow resulted in below-average proportions of fish passing via juvenile bypass systems and consequently low detection rates; however, overall rates of detection in 2023 were still not as low as those in 2021 or 2022.

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 2023 was its fourth year of operation. A total of 62,518 yearling Chinook and 57,039 steelhead were detected by the spillway system during the 2023 migration season (Table 33). Of the more than 200,000 smolts used for survival estimation from Lower Granite Dam, 54% were detected in the spillway system, 18% were tagged after collection in the bypass system, and 28% were detected in the bypass system.

The overall sample size for wild steelhead was close to average in 2023. Unfortunately, even with additional data from the spillway detection system, the sample size for wild Chinook was still below average in 2023 (Table 33). The quality of our survival estimates for wild stocks has frequently been impacted by small sample sizes, and this was certainly a factor in 2023.

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, 2010-2023. 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
2023	56,742	5,776	28,884	5,217	274	6,786	85,900	17,779
				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
2023	54,613	2,426	26,465	2,057	19,092	13,738	100,170	18,221

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 this alternative approach, we have continued to use these additional sources of detection information, even as trawl operations resumed. Thus, for 2023 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 four 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 2023 (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.

The most recently developed source of detection information downstream of Bonneville Dam produced a substantial increase in detection numbers during 2023. Since 2011, NMFS has experimented with PIT-tag detection equipment installed on pile dikes in the Columbia River estuary. Two new experimental sites, pile dikes 5 and 8, were installed in 2023 with configurations similar to those of pile dikes 6 and 7, which had been installed in previous years. Pile dikes 5 and 6 were very successful in 2023, with the total number of detections at those two sites nearly equal to those of the estuary trawl (Table 34). Refinement and expansion of this data source will continue in 2024 and beyond.

Table 34. Number of PIT tags detected or recovered at various locations downstream from Bonneville Dam, 2023. Only tags from groups of fish 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 2023 (n)			
Site	Yearling Chinook	Steelhead	Coho	Sockeye
Tags detected in live fish				
Columbia River estuary trawl	2,969	4,935	614	406
Pile dike 5	2,054	1,783	499	107
Pile dike 6	2,818	1,370	188	98
Pile dike 7	187	48	39	2
Pile dike 8	232	71	16	3
Bonneville Dam adult ladders	2,299	7	237	0
Columbia estuary side channels	8	7	4	0
Subtotal	**10,567**	**8,221**	**1,597**	**616**
Tags recovered on avian nesting, loafing, or roosting sites				
East Sand Island	523	2,011	87	24
Rice Island	145	686	47	37
Miller Sands Island	30	7	3	0
Pier 3, Port of Astoria	44	215	1	9
Astoria-Megler Bridge	1,402	1,315	161	148
Troutdale transmission towers	519	537	102	45
Misc. Columbia Estuary	137	185	23	34
Subtotal	**2,800**	**4,956**	**424**	**297**
Total	**13,367**	**13,177**	**2,021**	**913**

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 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*).

Overall, the combined use of alternative methods and data sources introduced a new variable when comparing results from 2020-2023 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 2020-2023 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 2020-2023 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 2023, estimated survival for spring Chinook was far below average in the Snake River but moderately above average in the lower Columbia River. In contrast, estimated survival was well above average in both the Snake and Columbia Rivers for steelhead originating from the Snake River. Precision was generally poor, and most estimates were not statistically significantly different from the long-term average. However, differences from the mean were statistically significant for both the very low estimate of spring Chinook survival in the reach from Lower Granite to McNary and the very high estimate of steelhead survival from McNary to Bonneville.

Salmonids originating in the upper Columbia River displayed a similar pattern. Estimated survival of upper Columbia River spring Chinook was slightly below average in the reach from McNary to Bonneville Dam, while estimated survival of upper Columbia River steelhead was far above average in that reach. While the estimate for Chinook was not statistically different from the mean, the difference between the estimate for steelhead and the long-term average was statistically significant.

Estimated survival to Lower Granite Dam was average or above average in 2023 for most stocks of hatchery Chinook and steelhead (Table 22). However, the annual release from Pahsimeroi Hatchery for which we customarily estimate survival was not conducted in 2023. Instead, we estimated survival for a group released from a different site, which may not be directly comparable to release groups from past years.

The number of returning adults at Pahsimeroi Hatchery in 2021 fell far short of management goals for broodstock and resulted in the number of juveniles produced for migration year 2023 also being far below normal. In order to reduce stress on the limited number of juveniles produced for 2023, fewer Pahsimeroi Hatchery smolts were PIT-tagged, and release protocols were altered. Additionally, since there were not enough Pahsimeroi-origin smolts to occupy all rearing facilities, the unoccupied facilities were used to rear juveniles produced from Rapid River broodstock (Morgan Fife, IDFG, personal communication). The Pahsimeroi-reared smolts released from Pahsimeroi Hatchery in 2023 originated from Pahsimeroi broodstock, while those released into the mainstem Snake River originated from Rapid River broodstock.

We have observed a steep decline in numbers of wild smolts captured and tagged at the Snake River Smolt Trap in recent years. In 2023, only 169 wild Chinook and 166 wild steelhead were tagged there. In years prior to 2019, the typical number of wild smolts tagged at the trap was five to ten times higher than the number tagged in 2023 (Table 35). In every year from 2019 through 2023, the number of wild fish tagged at the trap has been substantially lower than the previous average. The average number of hatchery smolts tagged at the trap has also declined since 2019, but not nearly to the same degree.

Several factors have likely contributed to the decline in the number of wild smolts captured at the Snake River Smolt Trap in recent years. Sediment deposition in the Lower Snake/Clearwater confluence area prompted an increase in forebay elevation of the Lower Granite pool in recent years, and consequent decrease in water velocity at the trap site, reducing the trap's capture efficiency (Jonathan Ebel, IDFG, personal communication). A second factor is related to staffing challenges at the trap itself, both in numbers and experience. Concern for the safety of trap personnel has resulted in suspension of trap operations under some conditions in which the trap could be safely operated in the past. This has resulted in abbreviated tagging seasons and inability to tag fish during parts of the migration season where wild fish are likely abundant (Scott Putnam, IDFG, personal communication).

Fish tagged at the Snake River Smolt Trap provide important data necessary for assessing the impact of the Lower Granite project on threatened salmon, and the region should explore options to increase the number of smolts captured or detected at or near the location of the trap. Actions such as adjusting the trap location, adding additional fish guidance louvers, or supplementing the trap with an additional dipper trap could increase the sample size of captured smolts.

Another possibility would be to supplement trap numbers by installing PIT tag detectors nearby. The pylons of the Interstate Highway Bridge, Red Wolf Bridge, or other locations where migrating fish are concentrated may offer convenient opportunities to detect passing fish that were tagged upstream. For the purpose of survival estimation, either passive detections or releases of tagged fish provide the same critical timestamp and location, and such data could be combined to increase the overall sample size.

Table 35. Number of smolts captured, tagged, and released from the Snake River Smolt Trap, 1998 through 2023.

	Number of smolts tagged at the Snake River Trap (n)			
Year	Hatchery Chinook	Wild Chinook	Hatchery Steelhead	Wild Steelhead
1998	2,303	961	4,274	1,088
1999	4,268	3,624	3,990	923
2000	3,339	1,939	3,698	1,296
2001	382	30	2,440	844
2002	1,901	1,393	5,031	2,518
2003	2,073	1,311	4,177	1,208
2004	2,127	1,389	4,843	1,923
2005	1,014	361	2,625	1,356
2006	5,003	2,661	2,148	502
2007	1,666	379	2,545	964
2008	3,044	1,686	3,541	1,414
2009	4,058	3,818	3,290	1,219
2010	1,783	852	3,430	1,724
2011	3,262	4,985	1,835	515
2012	3,599	3,944	1,465	430
2013	1,192	285	2,864	1,009
2014	1,921	1,963	2,175	1,157
2015	769	103	3,546	995
2016	1,862	1,541	3,209	741
2017	0	6	0	0
2018	2,692	2,776	2,854	456
2019	2,467	503	970	112
2020	1,561	69	1,722	124
2021	528	27	2,406	290
2022	1,024	121	3,475	360
2023	1,432	169	2,180	166
Mean, 1998-2018 (excl. 2017)	**2,415**	**1,738**	**3,093**	**1,066**
Mean, 2019-2023	**1,402**	**178**	**2,151**	**210**

In 2023, environmental conditions presented a migration season with water temperatures that were slightly warmer than average and flows that were close to the long-term mean when averaged across the entire season (Appendix Figure C1). However, the seasonal means were not good representations of daily flows and temperatures in 2023. Daily flow values started far below the daily median at the beginning of April and stayed below average until the end of April. Then, at the beginning of May, daily flow values rose sharply to far above average during an intense spring freshet, which lasted until late May. When the spring freshet ended, daily flow values fell back sharply to below the mean for early June.

Daily water temperatures also varied widely over the course of the 2023 migration season (Appendix Figure C1). Daily water temperatures were about two degrees lower than average for most of April, among the coldest water years for that period. In May, daily water temperatures rose to above average during the peak daily flows of the spring freshet. Daily water temperatures then continued to rise, reaching more than three degrees higher than average in early June. These temperatures were among the highest on record for that period.

Spill discharge levels were well above average in 2023, in terms of both absolute volume and percentage of flow (Appendix Figure C2). During April and early June when daily flows were below average, spill volumes were average to moderately above average, but spill percentages were extremely high. Spill percentages dropped to merely well above average during May when daily flows were reaching the peaks of the spring freshet, but spill volumes rose to far above average. Overall, rates of spill were similar to those in other years since 2020.

These high spill proportions were the result of a management program that began in 2020, known as *Flexible Spill Operation*, which has since been modified at some dams to further increase spill. 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 2023, these very high spill percentages resulted in levels of TDG that were far above average during the period of high flow in May. Daily average TDG values reached a peak of 123% on 5 May and a second, even higher peak of 126% on 23 May. These periods of peak TDG occurred during periods of peak flow because TDG is most directly affected by spill volume rather than spill percent. Lower flows at the beginning and end of the season resulted in spill volumes ranging from below average to moderately above average, and thus levels of TDG were also generally close to average during those periods (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 71-98% of the time, at least 120% for 35-55% of the time, and at least 125% for 0-12% of the time (Table 36). Hourly TDG levels were not measured during the period of high flow in May at Bonneville Dam, and this omission most certainly resulted in underestimates of gas exposure there.

Table 36. Summary of total dissolved gas (TDG) levels from monitors downstream of dams in 2023. 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 actual maximum TDG exposure, which is produced in the immediate tailrace. Distances (km) downstream from the respective tailraces are 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	118.3	128.3	70.7	43.4	8.4
Little Goose	1.1	118.9	128.7	80.9	37.2	11.0
Lower Monumental	1.6	119.0	128.0	93.9	34.6	5.1
Ice Harbor	5.8	118.9	130.1	83.7	39.4	3.9
Columbia River (10 April-15 June)						
McNary	2.1	119.9	127.8	84.4	46.4	8.6
John Day	1.3	118.8	126.0	77.6	36.7	1.8
The Dalles	4.0	119.3	128.0	79.8	46.1	11.9
Bonneville*	0.4	120.0	125.2	98.6	55.1	0.1

* Hourly measurements were missing at the Bonneville Cascade monitor for 216 hours during high flows from 15 to 24 May, so peak hours of gas production were not recorded there.

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 2023, although levels were very high at nearly every dam during the month of May. It is possible that exposure to TDG affected fish, especially those migrating during the spike in daily TDG in the middle of May, which exceeded 125% at several sites. We have no direct evidence that low survival rates for spring Chinook in the reach from Lower Granite to McNary during 2023 were a result of direct mortality due to TDG. However, in early May, incidence of gas bubble trauma in sculpin and other resident fish forced dam managers to temporarily reduce spill rates to reduce levels of TDG. This indicates the possibility that migrating salmonids experienced negative effects of high levels of TDG as well.

Predation by piscivorous fish is another likely contributor to the survival patterns we found for salmonids in 2023. 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 of juvenile salmon consumption have decreased for northern pikeminnow (Porter 2012; Storch et al. 2014). We saw no evidence of this pattern changing in 2023.

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). Counts in the bypass at Snake River dams have not been trending in any particular direction in recent years; however, while the number of smallmouth bass seen in the Lower Granite bypass was very high in 2021 and in 2022, it was far lower in 2023.

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 predation by smallmouth bass 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). Record numbers of walleye were seen in the bypass of both Little Goose and Lower Granite Dam in 2023. Additionally, anecdotal

Table 37. 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
2023	3,178	801	57	37	2,140	1,221	477,814	49,656	3,252

evidence, such as sightings of walleye in the fish ladder and incidental catch of walleye by northern pikeminnow fishermen, have been increasing steadily at Lower Granite Dam (R. Gleason, NMFS, personal communication). These observations suggest the possibility that juvenile salmonids faced increased predation from smallmouth bass and walleye in Snake River reservoirs in 2023.

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.

Although little current information exists for smallmouth bass and walleye population trends in the Columbia River, 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 have no information on whether piscivorous fish predation was high in this reach in 2023, but such a finding would not comport with the higher-than-average survival we found for most salmonid stocks this year in the lower Columbia River.

Wild smolts are smaller than their hatchery counterparts, which increases their vulnerability to gape-limited predators such as fish. Predation by fish may have been a factor in the below-average survival we found in 2023 for wild spring Chinook. 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 2023. Cool water temperatures decrease the metabolic rate and feeding activity of these fish, therefore decreasing rates of predation. Conversely, lower temperatures also reduce the metabolic rate and swimming speed of juvenile salmon, slowing their migration rates and exposing them to predators for longer. Lower flows have also been demonstrated to increase the vulnerability of prey fish to visual predators (Gregory and Levings 1998).

Water was cool and flows low during April 2023, and accordingly, we found smolt travel times were unusually long in April. While the bulk of the migrating population would not pass Lower Granite until May, our survival estimates for spring Chinook that passed in March and April were substantially lower than for later-migrating fish, particularly for wild smolts (Tables 2, 4). Thus, while environmental factors presented a mix of expectations in 2023, it is possible that low flows and long travel times in April increased the exposure of migrating smolts to piscivorous predators, especially in Snake River reaches where we found low survival for spring Chinook.

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. 2024).

In Lake Wallula (McNary Dam reservoir), Crescent Island has 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.*

From 2014 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. From 2021 through 2023, elevations were raised in John Day reservoir to eliminate alternative tern nesting sites. Caspian terns re-established the Crescent Island colony in 2022, and passive dissuasion measures were reinstated in 2023. The Caspian tern colony on Crescent Island was smaller in 2023 than in 2022, but was not fully eliminated; a total of 88 breeding pairs were seen on the island in 2023 (Evans et al. 2024).

Thus, since 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 465 breeding pairs in 2023, which was slightly less than in 2022. However, estimated consumption rates of Caspian terns on salmonid stocks were lower overall in 2023 than in 2022, and were among the lowest since management of tern colonies began in 2014 (Evans et al. 2024).

In addition to Caspian terns, a number of other piscivorous bird colonies were observed in the mid-Columbia Basin in 2023. In addition to several small colonies, large colonies of gulls were seen in Potholes Reservoir, Sprague Lake, and Banks Lake, and on Miller Rocks in Lake Celilo (The Dalles reservoir), Crescent and Badger Islands in Lake

Wallula (McNary reservoir), and Island 20 in the Hanford reach. Small colonies of double-crested cormorants were also observed in Sprague Lake, on Foundation Island, and on several other islands. A sizeable colony of American white pelicans was observed on Badger Island. In general, the estimated consumption rate on salmonids by cormorants and gulls was average to slightly below-average in 2023, but not unusually low compared to consumption rates seen in previous years (Evans et al. 2024).

Avian predation is still a significant source of mortality for Columbia Basin salmonids, particularly steelhead. In 2023, the combined estimated consumption rate across all surveyed waterbird populations was 23.2% for Snake River steelhead and 28.6% for upper Columbia River steelhead. Estimated overall avian consumption rates on Snake River Chinook and sockeye were lower, but far from negligible, at 8.7% and 19.4%, respectively. These overall consumption rate estimates were slightly lower than in 2021 or 2022 for steelhead and Chinook, but the estimate for sockeye was slightly higher (Evans et al. 2024).

We cannot say with certainty to what degree avian predation influenced the overall survival of juvenile salmonids in 2023. The somewhat below-average overall avian consumption rates did seem to comport with the high survival estimates we found for steelhead in most reaches in 2023.

On the other hand, it seems unlikely that avian predation was a major cause of low estimated survival for Snake River Chinook in the reach from Lower Granite to McNary. Steelhead are more vulnerable than Chinook to avian predators, so if avian predation were a major cause of mortality in 2023, we would expect to see low survival for steelhead stocks as well, but that was not the case. Furthermore, the majority of avian predator colonies are located on the mainstem Columbia River from Lake Wallula to the estuary. The majority of avian predation is expected to occur in that reach, but Chinook survival was not low in the lower Columbia River. Thus, while avian predation may have contributed to the below-average estimated survival of Snake River spring Chinook smolts in 2023, 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 2023 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 there is concern that 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 have been observed at Lower Granite Dam in every year since 2020; these counts were substantially higher than counts observed there previously (Table 36). Collection counts were also above average at Little Goose in 2023. This suggests the possibility that salmonids continue to face increased competition from Siberian prawn, at least in Lower Granite reservoir.

Siberian prawns may also affect the survival of migrating salmonids by influencing populations of predacious fish. Anecdotal evidence from fishermen indicates that walleye in particular may be feeding heavily on Siberian prawns in Snake River reservoirs (J. Lamb and R. Gleason, NMFS, personal communication). Interactions between multiple species are difficult to predict; it is possible that Siberian prawns are increasing predation pressure on migrating salmonids by providing a year-round food source that sustains larger populations of predacious fish than would otherwise be possible. However, it is equally possible that Siberian prawns are insulating salmonids from predation by providing an abundant alternative source of prey. More studies on these types of food web interactions would greatly improve our understanding of the mechanisms of mortality for migrating juvenile salmonids.

It is not clear whether Siberian prawn was a factor in the low survival of spring Chinook observed in Snake River reaches during 2023. Both juvenile steelhead and juvenile Chinook consume the same types of prey, and if competition with Siberian prawns were a factor for one species it would likely have been a factor for the other. Nevertheless, unlike Chinook, juvenile steelhead displayed high survival in all reaches in 2023, including the Snake River.

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 continued to increase over the years, travel time has generally become shorter relative to past years during the same point in 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 2023, travel times were quite long for both Chinook and steelhead in April, and also for steelhead in early June. 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 May.

High spill volumes such as those in 2023 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 2023, 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 2023, there was a rebound in the estimated proportion of smolts transported, following several years of low to very low proportions. Distribution of the run contributed to this rebound in transportation rates, but a major cause was an increase in collection rates. While still below the long-term mean, collection rates during transport operations were much higher in 2023 than in the previous three years.

Collection rates are proportional to the number of fish entering juvenile bypass systems at collector dams, and are thus influenced heavily by rates of spill. Spill percentages were overall very high in 2023. However, levels of flow during May were so high that dam managers reduced spill percentages at Snake River dams because of gas bubble trauma in non-salmonid stocks, thus increasing the number of fish that passed via juvenile bypass systems and could be transported. This combination of events is infrequent, and as long as elevated spill rates continue, we anticipate that transportation rates in future years are likely to be substantially lower than those observed in 2023.

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. Spill rates were very high in 2023, and detection rates were well below average. Furthermore, there is evidence that surface spill is disproportionately attractive to fish at lower flow levels. During April 2023, extremely high levels of spill combined with low flows resulted in very low detection rates. 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 the norm 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 more 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, using our current estimation methods and detection infrastructure, 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, we have identified two ways in which we can maintain or improve precision in survival estimates, both of which would be valuable to implement.

The first is to adopt alternative statistical approaches to allow the use of additional tag data and the incorporation of information from tags recovered on avian colonies in the interior basin. The second is to increase rates of detection by developing PIT-tag monitoring systems for fish-passage routes other than juvenile bypass systems.

Our customary method for estimating survival between Lower Granite and

Bonneville dams relies on "virtual" release groups of fish tagged or detected at Lower Granite Dam. Tagged fish that passed Lower Granite without detection could still provide information at other dams further downstream, but our customary methods cannot use this information.

In data-poor circumstances, we have occasionally estimated survival for reaches starting at Lower Granite using pooled groups of fish released upstream of Lower Granite. However, applying the traditional CJS model to large groups of pooled fish in this way does not account for changes in survival and detection that occur throughout the season, violating an assumption of the model and potentially producing bias in survival estimates. At best, our customary approach does not fully exploit all of the information contained in the data.

Recent development of the temporally stratified space-for-time Cormack-Jolly-Seber (TSCJS) method (Hance et al. 2019) offers the possibility of overcoming several challenges we have faced using customary methods. This approach can use all fish tagged upstream of Lower Granite Dam in a way that uses temporal stratification to simultaneously account for, and estimate, time-varying survival and detection probabilities and travel times.

We have developed a version of this model that also incorporates recovery of tags from dead fish that were deposited at avian nesting or roosting sites upstream of Bonneville Dam. We are in the process of developing the comprehensive workflow required to utilize these methods in future reports and to apply them retrospectively to past migration years.

While advanced statistical methods promise to improve precision of survival estimates compared to customary models of the same data, they will still be hampered to some degree by low detection probabilities at most dams caused by very high volumes of spill. 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 have resulted in overall detection probabilities that have been both above average and extremely stable in every year since the spillway detection system was installed.

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 spillways are ideal locations 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.

If regional managers decide to invest in increased detection, we believe that the priority should be 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 towed 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) Utilize and further refine temporally stratified mark-recapture-recovery models that incorporate as many tagged fish as possible and account for interior bird island recoveries. This approach can be used to maximize precision and accuracy of survival and detection probability estimates under the current level of tag detection infrastructure.

2) 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.

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

4) Investigate the feasibility of expanding tagging rates or installing PIT-tag detection at the location of the Snake River smolt trap, or elsewhere near the head of Lower Granite pool.

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

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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 expected values 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., the proportions 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 2023, there were more significant overall tests (sum of Tests 2 and 3) than expected by chance alone for steelhead (5% are expected by chance alone with $\alpha = 0.05$; Appendix Table A1). There were five biweekly groups of yearling steelhead, and the overall sum of χ^2 test statistics was significant for 3 of them (60%). The overall test was not significant for any of the 4 individual yearling Chinook groups; however, the summed χ^2 statistic across all groups was significant. For both yearling Chinook and steelhead, sums of Test 2 were the major driving factor for significant overall tests. Test 2 results generally had larger χ^2 statistics compared to those from Test 3, and there were many more statistically significant component tests within Test 2.

Among all individual component tests (i.e., 2.C2, 3.SR3, etc.), 2 out of 44 (5%) were significant for yearling Chinook salmon and 8 out of 53 (15%) were significant for steelhead (Appendix Tables A2-A5). There was a 65% chance of 2 or more tests out of 44 being significant if the true test-wise probability of a "false positive" result was $\alpha = 0.05$. For steelhead, the chance of having 8 or more significant tests out of 53 was less than 1%.

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 almost certainly not due to chance. Due to the 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 were two significant component tests for Test 2.C2. In one case, fish detected at Little Goose Dam had relatively fewer first detections at John Day Dam than fish not detected at Little Goose Dam. In the other case, fish detected at Little Goose Dam had relatively more first detections or recoveries downstream of Bonneville Dam than fish not detected at Little Goose Dam.

For steelhead, there were six 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.Sm4). For all but two 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 exceptions were for two instances of Test 2.C2, for which relatively fewer detected fish were re-detected downstream.

For the significant Test 3.SR3, fish detected at both Lower Monumental and Little Goose Dam were more likely to be detected or recovered downstream than fish detected at Lower Monumental but not at Little Goose. For the significant Test 3.Sm4, fish detected at both McNary and Lower Monumental Dam were more likely to be detected at John Day Dam than fish detected at McNary but not at Lower Monumental Dam.

Discussion

In 2023, 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 2023 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 in the bypass 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 2023. 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 2023.

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 2023. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for biweekly groups for tests.

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

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 2023. 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
21 Mar-19 Apr	29.75	0.074	15.86	0.104	8.53	0.074
20 Apr-3 May	29.61	0.076	16.39	0.089	9.58	**0.048**
4-17 May	17.77	0.603	12.14	0.276	8.14	0.086
18-31 May	28.47	0.099	25.01	**0.005**	14.61	**0.009**
Total (df)	105.60 (80)	**0.029**	69.40 (40)	**0.003**	40.86 (16)	**0.001**

	Test 2.C3		Test 2.C4		Test 2.C5	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
21 Mar-19 Apr	4.16	0.244	1.46	0.482	1.71	0.191
20 Apr-3 May	2.62	0.454	4.16	0.125	0.03	0.871
4-17 May	3.61	0.307	0.35	0.841	0.04	0.849
18-31 May	8.35	0.066	1.90	0.548	0.15	0.694
Total (df)	18.74 (12)	0.095	7.87 (8)	0.446	1.93 (4)	0.749

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 2023. 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
21 Mar-19 Apr	13.89	0.178	0.16	0.689	7.62	0.110	0.03	0.794
20 Apr-3 May	13.22	0.212	2.55	0.111	7.51	0.057	0.73	0.393
4-17 May	5.63	0.845	0.00	0.984	1.58	0.665	0.22	0.638
18-31 May	3.46	0.968	0.45	0.554	0.75	0.700	0.49	0.674
Total (df)	36.20 (40)	0.642	3.16 (4)	0.531	17.46 (12)	0.133	1.47 (4)	0.832

	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
21 Mar-19 Apr	2.17	0.431	0.22	0.637	0.14	0.710	3.55	0.060
20 Apr-3 May	1.52	0.413	0.75	0.385	0.13	0.715	0.03	0.857
4-17 May	1.53	0.437	1.98	0.159	0.26	0.607	0.06	0.813
18-31 May	0.15	1.000	0.79	0.373	0.02	1.000	0.81	0.367
Total (df)	5.37 (8)	0.717	3.74 (4)	0.442	0.55 (4)	0.968	4.45 (4)	0.349

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 2023. 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
31 Mar-19 Apr	48.72	**<0.001**	27.62	**0.002**	2.70	0.610
20 Apr-3 May	84.46	**<0.001**	72.96	**<0.001**	61.40	**<0.001**
4-17 May	21.51	0.368	14.60	0.147	2.60	0.626
18-31 May	25.27	0.191	20.60	**0.024**	16.02	**0.003**
1-14 Jun	41.47	**0.001**	36.97	**<0.001**	21.13	**<0.001**
Total (df)	221.43 (97)	**<0.001**	172.75 (50)	**<0.001**	103.85 (20)	**<0.001**

	Test 2.C3		Test 2.C4		Test 2.C5	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
31 Mar-19 Apr	19.42	**<0.001**	5.21	0.074	0.29	0.592
20 Apr-3 May	3.17	0.366	7.44	**0.024**	0.95	0.329
4-17 May	5.83	0.120	5.87	0.053	0.30	0.582
18-31 May	1.42	0.700	3.02	0.197	0.14	0.705
1-14 Jun	13.25	**0.008**	1.42	1.000	1.17	0.357
Total (df)	43.09 (15)	**<0.001**	22.96 (10)	**0.011**	2.85 (5)	0.723

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 2023. 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
31 Mar-19 Apr	21.10	**0.020**	0.52	0.502	6.04	0.195	1.22	0.268
20 Apr-3 May	11.50	0.320	4.48	**0.034**	2.22	0.573	1.79	0.181
4-17 May	6.91	0.734	0.09	0.768	4.08	0.253	1.26	0.261
18-31 May	4.67	0.912	0.44	0.507	0.74	0.919	0.14	1.000
1-14 Jun	4.50	0.721	0.75	0.541	0.50	1.000	1.40	0.548
Total (df)	48.68 (47)	0.405	6.28 (5)	0.280	13.58 (15)	0.558	5.81 (5)	0.325

	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
31 Mar-19 Apr	8.56	**0.023**	1.46	0.227	0.53	0.703	2.77	0.096
20 Apr-3 May	0.87	0.703	0.02	0.890	2.04	0.154	0.08	0.775
4-17 May	0.67	0.749	0.06	0.806	0.02	0.886	0.73	0.394
18-31 May	2.76	0.403	0.26	0.609	0.02	1.000	0.31	0.579
1-14 Jun	-	-	0.30	1.000	-	-	1.55	0.199
Total (df)	12.86 (8)	0.117	2.10 (5)	0.835	2.61 (4)	0.625	5.44 (5)	0.365

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 2023. 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	9,782	0.931 (0.018)	1.074 (0.068)	0.852 (0.083)	0.751 (0.126)	0.639 (0.095)
Powell Pond	22,216	0.644 (0.011)	0.967 (0.049)	0.886 (0.074)	0.713 (0.099)	0.393 (0.048)
Red River Pond	16,957	0.818 (0.014)	1.049 (0.083)	0.851 (0.111)	0.586 (0.100)	0.427 (0.057)
Selway River	16,983	0.608 (0.016)	0.992 (0.110)	0.889 (0.161)	0.673 (0.133)	0.361 (0.048)
N Fork Clearwater R	16,982	0.930 (0.020)	0.821 (0.060)	1.016 (0.127)	0.794 (0.123)	0.616 (0.070)
Dworshak Hatchery						
N Fork Clearwater R	41,852	0.819 (0.011)	0.951 (0.051)	0.845 (0.067)	0.760 (0.070)	0.500 (0.035)
Kooskia Hatchery						
Kooskia	6,000	0.806 (0.025)	1.308 (0.194)	0.753 (0.171)	0.603 (0.162)	0.479 (0.096)
Lookingglass Hatchery						
Catherine Creek Pond	20,955	0.587 (0.010)	1.071 (0.084)	0.786 (0.095)	1.073 (0.170)	0.530 (0.067)
Grande Ronde Pond	2,105	0.347 (0.028)	1.083 (0.251)	0.726 (0.247)	1.034 (0.604)	0.282 (0.148)
Imnaha Weir	20,946	0.555 (0.009)	0.957 (0.057)	0.898 (0.094)	0.685 (0.102)	0.326 (0.039)
Lookingglass Hatchery	4,985	0.449 (0.018)	0.978 (0.092)	0.865 (0.128)	1.080 (0.424)	0.410 (0.154)
Lostine Pond	5,997	0.457 (0.015)	1.038 (0.101)	0.822 (0.122)	0.627 (0.135)	0.244 (0.044)
McCall Hatchery						
Knox Bridge	51,827	0.660 (0.006)	0.914 (0.036)	0.966 (0.065)	0.756 (0.067)	0.441 (0.030)
Johnson Creek	2,077	0.539 (0.032)	0.646 (0.086)	1.962 (0.584)	0.588 (0.310)	0.402 (0.181)
Nez Perce Tribal Hatchery						
Nez Perce Hatchery	5,200	0.770 (0.030)	0.953 (0.077)	0.813 (0.101)	1.045 (0.286)	0.623 (0.159)
Sweetwater Creek	600	0.665 (0.108)	0.797 (0.199)	0.838 (0.266)	NA	NA

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			
Pahsimeroi Hatchery						
Hells Canyon Dam	999	0.670 (0.052)	0.879 (0.174)	0.665 (0.182)	0.776 (0.415)	0.304 (0.151)
Rapid River Hatchery						
Rapid River Hatchery	51,674	0.497 (0.005)	0.923 (0.034)	0.944 (0.068)	0.850 (0.112)	0.369 (0.042)
Sawtooth Hatchery						
Alturas Lake Creek	990	0.506 (0.033)	0.900 (0.135)	0.990 (0.265)	0.556 (0.260)	0.250 (0.102)
Sawtooth Hatchery	18,780	0.582 (0.009)	0.885 (0.047)	1.025 (0.108)	0.756 (0.122)	0.400 (0.052)
Yankee Fork	8,474	0.386 (0.014)	1.119 (0.196)	0.588 (0.156)	0.856 (0.259)	0.217 (0.049)

Appendix Table B2. Survival probability estimates for juvenile steelhead released from Snake River Basin hatcheries in 2023. 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	10,781	0.804 (0.011)	0.971 (0.057)	1.084 (0.121)	0.561 (0.105)	0.475 (0.075)
Newsome Creek	15,866	0.853 (0.008)	0.965 (0.046)	0.971 (0.075)	0.625 (0.142)	0.500 (0.109)
S Fork Clearwater R	4,694	0.803 (0.021)	1.033 (0.122)	0.880 (0.185)	0.656 (0.172)	0.479 (0.093)
Dworshak Hatchery						
Clear Creek	4,985	0.838 (0.021)	1.036 (0.122)	1.148 (0.296)	0.761 (0.317)	0.759 (0.260)
S Fork Clearwater R	8,074	0.773 (0.012)	0.924 (0.061)	1.065 (0.125)	0.510 (0.104)	0.388 (0.068)
Mainstem Clearwater R	19,754	0.846 (0.009)	0.805 (0.049)	1.105 (0.119)	0.878 (0.121)	0.661 (0.069)
Hagerman Hatchery						
East Fork Salmon R	8,562	0.534 (0.011)	0.890 (0.075)	0.954 (0.147)	0.652 (0.263)	0.296 (0.112)
Sawtooth Hatchery	15,367	0.709 (0.009)	0.968 (0.067)	1.119 (0.133)	0.610 (0.123)	0.468 (0.083)
Irrigon Hatchery						
Big Canyon Facility	6,800	0.764 (0.018)	0.926 (0.078)	1.040 (0.159)	1.122 (0.370)	0.827 (0.250)
Little Sheep Facility	15,000	0.683 (0.009)	1.002 (0.052)	0.855 (0.066)	0.762 (0.118)	0.446 (0.063)
Wallowa Hatchery	10,800	0.768 (0.012)	1.024 (0.081)	0.838 (0.107)	0.770 (0.151)	0.507 (0.085)
Lyons Ferry Hatchery						
Cottonwood Pond	5,999	0.688 (0.015)	1.088 (0.114)	0.806 (0.152)	1.007 (0.323)	0.608 (0.168)

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	4,392	0.630 (0.014)	0.871 (0.079)	1.038 (0.151)	NA	NA
Pahsimeroi R Trap	11,324	0.739 (0.009)	1.128 (0.067)	0.960 (0.105)	0.592 (0.115)	0.474 (0.081)
Sawtooth Hatchery	5,676	0.792 (0.012)	1.159 (0.103)	0.868 (0.111)	NA	NA
Yankee Fork	13,212	0.674 (0.009)	1.051 (0.062)	0.782 (0.078)	0.897 (0.304)	0.496 (0.163)
Niagara Springs Hatchery						
Hells Canyon Dam	8,576	0.840 (0.014)	0.828 (0.056)	1.113 (0.140)	0.819 (0.182)	0.634 (0.122)
Little Salmon R	5,081	0.907 (0.014)	1.077 (0.073)	0.821 (0.093)	0.404 (0.110)	0.324 (0.083)
Pahsimeroi R Trap	8,981	0.817 (0.011)	1.065 (0.086)	0.947 (0.116)	0.706 (0.279)	0.582 (0.223)

Appendix Table B3. Survival probability estimates for juvenile Sockeye and Coho salmon released from Snake River Basin hatcheries for migration year 2023. 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	2-3 May 2023	49,846	0.644 (0.008)	1.165 (0.141)	0.898 (0.154)	0.777 (0.112)	0.813 (0.064)	0.523 (0.041)
Coho salmon								
Cascade Hatchery								
Lostine River	15 March 2023	5,000	0.534 (0.022)	0.908 (0.274)	1.362 (0.987)	0.348 (0.249)	0.431 (0.115)	0.230 (0.061)
Eagle Creek Hatchery								
Kooskia Hatchery	10 April 2023	4,989	0.362 (0.015)	1.357 (0.439)	0.818 (0.457)	0.613 (0.337)	0.680 (0.211)	0.246 (0.076)
N Lapwai Valley Pd	28 March 2023	4,994	0.450 (0.016)	0.985 (0.209)	0.842 (0.347)	1.831 (1.074)	1.519 (0.713)	0.683 (0.320)
Kooskia Hatchery								
Kooskia Hatchery	23 March 2023	5,000	0.342 (0.015)	1.022 (0.171)	0.848 (0.221)	1.106 (0.462)	0.958 (0.352)	0.328 (0.120)

Appendix Table B4. Detection probability estimates for yearling Chinook salmon released from Snake River Basin hatcheries in 2023. 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	9,782	0.384 (0.009)	0.116 (0.008)	0.119 (0.010)	0.027 (0.005)
Powell Pond	22,216	0.382 (0.007)	0.129 (0.007)	0.121 (0.009)	0.034 (0.005)
Red River Pond	16,957	0.392 (0.008)	0.113 (0.009)	0.113 (0.012)	0.031 (0.005)
Selway River	16,983	0.341 (0.010)	0.075 (0.008)	0.063 (0.009)	0.043 (0.006)
N F Clearwater R	16,982	0.305 (0.007)	0.105 (0.008)	0.082 (0.009)	0.038 (0.005)
Dworshak Hatchery					
N F Clearwater R	41,852	0.314 (0.005)	0.093 (0.005)	0.107 (0.006)	0.039 (0.003)
Kooskia Hatchery					
Kooskia	6,000	0.343 (0.012)	0.089 (0.013)	0.097 (0.017)	0.037 (0.008)
Lookingglass Hatchery					
Catherine Cr Pd	20,955	0.425 (0.008)	0.106 (0.008)	0.114 (0.011)	0.033 (0.005)
Grande Ronde Pd	2,105	0.372 (0.033)	0.100 (0.024)	0.110 (0.031)	0.041 (0.023)
Imnaha Weir	20,946	0.406 (0.008)	0.173 (0.010)	0.147 (0.013)	0.046 (0.006)
Lookingglass H	4,985	0.364 (0.017)	0.152 (0.015)	0.151 (0.020)	0.022 (0.009)
Lostine Pond	5,997	0.447 (0.016)	0.118 (0.012)	0.119 (0.015)	0.054 (0.011)
McCall Hatchery					
Knox Bridge	51,827	0.432 (0.005)	0.140 (0.006)	0.126 (0.007)	0.043 (0.003)
Johnson Creek	2,077	0.408 (0.027)	0.158 (0.023)	0.069 (0.020)	0.031 (0.015)
Nez Perce Tribal Hatchery					
Nez Perce H	5,200	0.257 (0.012)	0.152 (0.012)	0.139 (0.015)	0.031 (0.008)
Sweetwater Creek	600	0.165 (0.032)	0.167 (0.038)	0.154 (0.045)	0.041 (0.028)
Pahsimeroi Hatchery					
Hells Canyon D	999	0.382 (0.034)	0.144 (0.030)	0.202 (0.045)	0.044 (0.025)
Rapid River Hatchery					
Rapid River H	51,674	0.465 (0.005)	0.198 (0.007)	0.148 (0.009)	0.027 (0.003)
Sawtooth Hatchery					
Alturas Lake Cr	990	0.463 (0.035)	0.207 (0.034)	0.153 (0.039)	0.053 (0.026)
Sawtooth H	18,780	0.473 (0.008)	0.206 (0.011)	0.140 (0.013)	0.041 (0.006)
Yankee Fork	8,474	0.430 (0.017)	0.103 (0.018)	0.108 (0.022)	0.037 (0.010)

Appendix Table B5. Detection probability estimates for juvenile steelhead released from Snake River Basin hatcheries in 2023. 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	10,781	0.521 (0.009)	0.157 (0.010)	0.118 (0.012)	0.022 (0.004)
Newsome Creek	15,866	0.592 (0.007)	0.151 (0.008)	0.183 (0.011)	0.008 (0.002)
S Fork Clearwater R	4,694	0.467 (0.014)	0.116 (0.014)	0.078 (0.014)	0.031 (0.007)
Dworshak Hatchery					
Clear Creek	4,985	0.470 (0.014)	0.113 (0.014)	0.063 (0.015)	0.013 (0.005)
S Fork Clearwater R	8,074	0.556 (0.010)	0.166 (0.012)	0.147 (0.015)	0.024 (0.005)
Mainstem Clearwater	19,754	0.540 (0.007)	0.113 (0.007)	0.080 (0.007)	0.025 (0.003)
Hagerman Hatchery					
East Fork Salmon R	8,562	0.539 (0.012)	0.187 (0.016)	0.187 (0.024)	0.011 (0.005)
Sawtooth Hatchery	15,367	0.548 (0.008)	0.117 (0.009)	0.101 (0.010)	0.015 (0.003)
Irrigon Hatchery					
Big Canyon Facility	6,800	0.434 (0.012)	0.130 (0.012)	0.088 (0.012)	0.011 (0.004)
Little Sheep Facility	15,000	0.537 (0.008)	0.139 (0.008)	0.181 (0.011)	0.022 (0.004)
Wallowa Hatchery	10,800	0.527 (0.010)	0.108 (0.009)	0.090 (0.010)	0.019 (0.004)
Lyons Ferry Hatchery					
Cottonwood Pond	5,999	0.521 (0.013)	0.119 (0.013)	0.094 (0.015)	0.015 (0.005)
Magic Valley Hatchery					
Little Salmon R	4,392	0.574 (0.015)	0.167 (0.017)	0.200 (0.024)	0.002 (0.002)
Pahsimeroi R Trap	11,324	0.556 (0.008)	0.173 (0.011)	0.126 (0.012)	0.019 (0.004)
Sawtooth Hatchery	5,676	0.600 (0.011)	0.120 (0.012)	0.197 (0.018)	NA
Yankee Fork	13,212	0.544 (0.008)	0.182 (0.011)	0.200 (0.016)	0.007 (0.003)
Niagara Springs Hatchery					
Hells Canyon Dam	8,576	0.515 (0.010)	0.157 (0.011)	0.114 (0.012)	0.021 (0.005)
Little Salmon R	5,081	0.543 (0.011)	0.211 (0.015)	0.229 (0.021)	0.013 (0.005)
Pahsimeroi Trap	8,981	0.564 (0.009)	0.118 (0.010)	0.155 (0.014)	0.005 (0.002)

Appendix Table B6. Detection probability estimates for juvenile Sockeye and Coho salmon released from Snake River Basin hatcheries for migration year 2023. 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	2-3 May	49,846	0.414 (0.006)	0.03 (0.004)	0.034 (0.004)	0.032 (0.003)
			Coho salmon			
Cascade Hatchery						
Lostine River	15 March	5,000	0.503 (0.021)	0.077 (0.024)	0.025 (0.017)	0.035 (0.011)
Eagle Creek Hatchery						
Kooskia Hatchery	10 April	4,989	0.492 (0.022)	0.085 (0.028)	0.048 (0.022)	0.037 (0.013)
N Lapwai Valley Pd	28 March	4,994	0.501 (0.020)	0.125 (0.027)	0.054 (0.019)	0.013 (0.007)
Kooskia Hatchery						
Kooskia Hatchery	23 March	5,000	0.497 (0.023)	0.072 (0.013)	0.056 (0.013)	0.020 (0.008)

Appendix Table B7. Survival probability estimates for juvenile salmonids released from traps in Snake River Basin in 2023. 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	23 Mar-01 May	52	169	0.885 (0.105)	1.341 (0.781)	0.436 (0.429)	NA	NA
Grande Ronde	16 Mar-25 May	100	1,520	0.902 (0.046)	0.962 (0.169)	0.735 (0.206)	1.200 (0.682)	0.765 (0.397)
Imnaha	08 Feb-30 May	142	1,750	0.711 (0.041)	1.009 (0.142)	0.998 (0.263)	0.586 (0.235)	0.419 (0.137)
Lolo Creek	24 Mar-31 May	159	468	0.703 (0.112)	1.010 (0.632)	0.532 (0.548)	1.100 (1.387)	0.415 (0.378)
Salmon	15 Mar-01 May	233	1,242	0.747 (0.031)	1.186 (0.181)	1.151 (0.441)	0.610 (0.451)	0.621 (0.398)
Lookingglass Cr	10 Feb-19 Apr	235	190	0.360 (0.062)	1.407 (1.150)	0.301 (0.303)	0.400 (0.219)	NA
Minam	12 Mar-24 May	246	638	0.646 (0.063)	1.494 (0.656)	0.470 (0.286)	0.838 (0.634)	0.380 (0.238)
Lostine	10 Feb-19 May	274	521	0.768 (0.072)	0.885 (0.234)	0.883 (0.434)	1.099 (1.110)	0.659 (0.603)
Catherine Creek	08 Mar-31 May	362	1,075	0.480 (0.068)	0.620 (0.272)	0.885 (0.645)	0.706 (0.609)	0.186 (0.112)
U. Grande Ronde	12 Apr-31 May	397	948	0.777 (0.119)	NA	NA	NA	NA
S. Fork Salmon	22 Mar-28 Apr	408	413	0.741 (0.079)	0.750 (0.204)	1.014 (0.529)	1.018 (1.022)	0.573 (0.506)
Secesh River	08 Apr-14 May	411	153	0.572 (0.125)	0.747 (0.375)	0.421 (0.289)	NA	NA
Johnson Creek	04 Mar-09 May	436	787	0.528 (0.032)	0.981 (0.145)	0.861 (0.245)	NA	NA
Big Creek	28 Mar-28 Apr	489	288	0.921 (0.178)	0.577 (0.285)	0.943 (0.879)	NA	NA
Lower Lemhi R.	14 Apr-20 May	553	236	0.762 (0.080)	1.293 (0.537)	0.727 (0.507)	NA	NA
Upper Lemhi R.	07 Apr-31 May	595	279	0.740 (0.077)	0.946 (0.375)	1.141 (0.809)	NA	NA
Pahsimeroi	15 Mar-31 May	621	367	0.653 (0.108)	0.382 (0.218)	0.905 (0.707)	NA	NA
Marsh Creek	19 Mar-29 Apr	630	205	0.459 (0.064)	NA	NA	NA	NA
Sawtooth	19 Mar-01 May	747	442	0.630 (0.074)	0.802 (0.249)	1.090 (0.657)	0.629 (0.634)	0.346 (0.281)

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	01 Apr-01 May	52	166	0.895 (0.100)	0.548 (0.172)	1.635 (1.048)	0.287 (0.210)	0.230 (0.096)
Asotin Creek	02 Feb-31 May	64	948	0.881 (0.035)	0.943 (0.152)	1.194 (0.401)	0.453 (0.254)	0.450 (0.210)
Grande Ronde	10 Apr-25 May	100	499	0.923 (0.053)	1.252 (0.335)	0.652 (0.275)	1.396 (1.349)	1.051 (0.953)
Imnaha	11 Feb-30 May	142	1,184	0.853 (0.041)	1.014 (0.194)	0.993 (0.340)	NA	NA
Lolo Creek	11 Apr-30 May	159	184	0.967 (0.215)	NA	NA	NA	NA
Lochsa River	18 Mar-30 May	208	144	0.784 (0.087)	1.164 (0.473)	NA	NA	NA
Salmon	28 Mar-01 May	233	58	0.828 (0.184)	NA	NA	NA	NA
Minam	17 Mar-28 May	246	259	0.552 (0.076)	0.352 (0.065)	NA	NA	NA
Catherine Creek	08 Mar-31 May	362	226	0.258 (0.041)	NA	NA	NA	NA
U. Grande Ronde	12 Apr-31 May	397	445	0.545 (0.048)	0.773 (0.329)	0.718 (0.382)	NA	NA
Pahsimeroi	15 Mar-31 May	621	480	0.091 (0.022)	NA	NA	NA	NA
Sawtooth	28 Mar-01 May	747	130	0.417 (0.051)	1.448 (0.703)	NA	NA	NA
				Hatchery Chinook Salmon				
Snake	19 Mar-01 May	52	1,432	0.875 (0.039)	1.031 (0.127)	0.842 (0.163)	0.518 (0.150)	0.393 (0.096)
Grande Ronde	16 Mar-16 May	100	1,400	0.643 (0.037)	1.113 (0.186)	0.888 (0.250)	0.716 (0.290)	0.454 (0.152)
Salmon	15 Mar-01 May	233	3,969	0.725 (0.020)	0.987 (0.072)	1.075 (0.148)	1.066 (0.396)	0.819 (0.289)
				Hatchery steelhead				
Snake	31 Mar-01 May	52	2,180	0.946 (0.029)	0.753 (0.082)	1.307 (0.247)	0.904 (0.429)	0.842 (0.376)
Grande Ronde	08 Apr-24 May	100	1,385	0.860 (0.028)	1.895 (0.370)	0.377 (0.087)	1.146 (0.511)	0.705 (0.303)
Salmon	14 Apr-01 May	233	373	0.916 (0.055)	0.995 (0.197)	0.731 (0.199)	0.617 (0.450)	0.411 (0.290)

Appendix Table B8. Detection probability estimates for juvenile salmonids released from fish traps in Snake River Basin in 2023. 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	23 Mar-01 May	52	169	0.488 (0.070)	0.164 (0.097)	0.191 (0.152)	NA
Grande Ronde	16 Mar-25 May	100	1,520	0.390 (0.024)	0.165 (0.030)	0.170 (0.038)	0.021 (0.012)
Imnaha	08 Feb-30 May	142	1,750	0.312 (0.022)	0.185 (0.026)	0.130 (0.031)	0.053 (0.019)
Lolo Creek	24 Mar-31 May	159	468	0.334 (0.058)	0.096 (0.060)	0.112 (0.094)	0.046 (0.044)
Salmon	15 Mar-01 May	233	1,242	0.476 (0.024)	0.225 (0.036)	0.132 (0.047)	0.023 (0.016)
Lookingglass Cr	10 Feb-19 Apr	235	190	0.541 (0.097)	0.153 (0.129)	0.255 (0.148)	0.111 (0.105)
Minam	12 Mar-24 May	246	638	0.388 (0.044)	0.100 (0.045)	0.140 (0.061)	0.056 (0.038)
Lostine	10 Feb-19 May	274	521	0.392 (0.043)	0.204 (0.055)	0.134 (0.059)	0.026 (0.026)
Catherine Creek	08 Mar-31 May	362	1,075	0.327 (0.050)	0.081 (0.037)	0.082 (0.052)	0.044 (0.031)
U. Grande Ronde	12 Apr-31 May	397	948	0.320 (0.052)	NA	0.053 (0.034)	NA
S. Fork Salmon	22 Mar-28 Apr	408	413	0.412 (0.051)	0.250 (0.068)	0.172 (0.081)	0.033 (0.033)
Secesh River	08 Apr-14 May	411	153	0.400 (0.098)	0.214 (0.110)	0.182 (0.116)	NA
Johnson Creek	04 Mar-09 May	436	787	0.529 (0.037)	0.252 (0.041)	0.164 (0.045)	NA
Big Creek	28 Mar-28 Apr	489	288	0.279 (0.060)	0.261 (0.121)	0.192 (0.148)	NA
Lower Lemhi R.	14 Apr-20 May	553	236	0.484 (0.061)	0.128 (0.057)	0.154 (0.092)	NA
Upper Lemhi R.	07 Apr-31 May	595	279	0.509 (0.061)	0.128 (0.055)	0.124 (0.077)	NA
Pahsimeroi	15 Mar-31 May	621	367	0.484 (0.084)	0.103 (0.064)	0.158 (0.096)	NA
Marsh Creek	19 Mar-29 Apr	630	205	0.542 (0.082)	0.100 (0.090)	NA	NA
Sawtooth	19 Mar-01 May	747	442	0.399 (0.053)	0.164 (0.053)	0.186 (0.102)	0.030 (0.030)

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	01 Apr-01 May	52	166	0.558 (0.073)	0.169 (0.064)	0.132 (0.082)	0.091 (0.061)
Asotin Creek	02 Feb-31 May	64	948	0.564 (0.028)	0.188 (0.033)	0.137 (0.042)	0.030 (0.017)
Grande Ronde	10 Apr-25 May	100	499	0.515 (0.037)	0.139 (0.040)	0.151 (0.052)	0.015 (0.015)
Imnaha	11 Feb-30 May	142	1,184	0.456 (0.026)	0.152 (0.030)	0.125 (0.037)	NA
Lolo Creek	11 Apr-30 May	159	184	0.343 (0.084)	NA	NA	NA
Lochsa River	18 Mar-30 May	208	144	0.478 (0.068)	0.238 (0.101)	NA	0.091 (0.087)
Salmon	28 Mar-01 May	233	58	0.562 (0.140)	NA	NA	NA
Minam	17 Mar-28 May	246	259	0.483 (0.074)	0.244 (0.064)	0.169 (0.081)	NA
Catherine Creek	08 Mar-31 May	362	226	0.633 (0.094)	0.064 (0.061)	0.135 (0.123)	NA
U. Grande Ronde	12 Apr-31 May	397	445	0.593 (0.055)	0.113 (0.053)	0.257 (0.084)	NA
Pahsimeroi	15 Mar-31 May	621	480	0.616 (0.136)	NA	NA	NA
Sawtooth	28 Mar-01 May	747	130	0.701 (0.077)	0.203 (0.111)	NA	NA
Hatchery Chinook salmon							
Snake	19 Mar-01 May	52	1,432	0.410 (0.023)	0.148 (0.020)	0.149 (0.026)	0.064 (0.019)
Grande Ronde	16 Mar-16 May	100	1,400	0.416 (0.028)	0.126 (0.023)	0.101 (0.026)	0.064 (0.023)
Salmon	15 Mar-01 May	233	3,969	0.456 (0.015)	0.174 (0.014)	0.126 (0.016)	0.019 (0.007)
Hatchery steelhead							
Snake	31 Mar-01 May	52	2,180	0.550 (0.020)	0.120 (0.015)	0.085 (0.015)	0.012 (0.006)
Grande Ronde	08 Apr-24 May	100	1,385	0.573 (0.023)	0.064 (0.013)	0.160 (0.023)	0.016 (0.008)
Salmon	14 Apr-01 May	233	373	0.544 (0.041)	0.148 (0.034)	0.195 (0.045)	0.013 (0.013)

Appendix Table B9. Survival probability estimates for yearling Chinook, steelhead, and Coho salmon released from upper-Columbia River hatcheries in 2023. 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	16,008	0.327 (0.040)	0.684 (0.106)	1.321 (0.300)	0.903 (0.217)	0.296 (0.061)
Easton Pond	11,996	0.282 (0.047)	0.694 (0.146)	1.026 (0.271)	0.712 (0.203)	0.201 (0.047)
Jack Creek Pond	12,004	0.130 (0.022)	0.836 (0.233)	0.902 (0.370)	0.753 (0.290)	0.098 (0.034)
Yakima River km267	3,999	0.190 (0.102)	0.534 (0.400)	0.931 (0.776)	0.497 (0.420)	0.095 (0.062)
East Bank Hatchery						
Chelan River	10,193	0.649 (0.095)	1.017 (0.233)	0.822 (0.199)	0.836 (0.184)	0.542 (0.089)
Chiwawa Pond	9,860	0.166 (0.050)	0.850 (0.319)	0.704 (0.255)	0.598 (0.245)	0.100 (0.028)
Dryden Pond	8,844	0.711 (0.092)	0.797 (0.137)	0.950 (0.182)	0.758 (0.153)	0.539 (0.083)
Nason Acclimation F.	9,921	0.384 (0.062)	0.923 (0.201)	0.867 (0.247)	0.800 (0.234)	0.308 (0.075)
Entiat Hatchery						
Entiat Hatchery	19,934	0.499 (0.066)	0.818 (0.153)	0.894 (0.184)	0.732 (0.150)	0.365 (0.057)
Leavenworth Hatchery						
Leavenworth NFH	45,946	0.520 (0.037)	0.827 (0.074)	0.768 (0.074)	0.636 (0.068)	0.330 (0.026)
Methow Hatchery						
Chewuch Pond	4,998	0.408 (0.100)	1.130 (0.355)	0.934 (0.288)	1.056 (0.361)	0.431 (0.103)
Methow Hatchery	4,997	0.574 (0.214)	0.558 (0.234)	1.247 (0.427)	0.695 (0.326)	0.399 (0.114)
Twisp Pond	4,882	0.479 (0.150)	1.185 (0.516)	0.613 (0.226)	0.726 (0.273)	0.348 (0.073)
Prosser Hatchery						
Buckskin Slough Pond	11,133	0.143 (0.034)	0.886 (0.343)	2.314 (2.362)	2.052 (2.058)	0.294 (0.286)
Prosser Hatchery	20,498	0.472 (0.044)	0.518 (0.069)	1.071 (0.219)	0.555 (0.113)	0.262 (0.048)
Roza Dam Tailrace	11,152	0.318 (0.136)	0.670 (0.430)	0.508 (0.339)	0.341 (0.216)	0.108 (0.050)
Wells Hatchery						
Wells Hatchery	10,963	0.554 (0.109)	0.616 (0.168)	1.307 (0.408)	0.806 (0.257)	0.446 (0.112)
Winthrop Hatchery						
Winthrop NFH	19,943	0.423 (0.066)	0.885 (0.163)	1.115 (0.158)	0.987 (0.185)	0.417 (0.043)

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	15,481	0.457 (0.074)	0.850 (0.152)	0.899 (0.124)	0.764 (0.150)	0.349 (0.040)
Wenatchee River	14,798	0.313 (0.042)	0.926 (0.145)	0.979 (0.152)	0.906 (0.173)	0.284 (0.038)
Wells Hatchery						
Antoine Creek	4,995	0.250 (0.086)	1.175 (0.462)	0.864 (0.265)	1.016 (0.423)	0.254 (0.061)
Methow Hatchery	4,986	0.373 (0.059)	1.592 (0.350)	0.661 (0.144)	1.052 (0.231)	0.393 (0.061)
Salmon Creek	4,987	0.249 (0.056)	1.281 (0.353)	1.277 (0.399)	1.636 (0.565)	0.408 (0.108)
Similkameen Pond	4,994	0.280 (0.122)	0.990 (0.493)	1.670 (0.685)	1.654 (0.904)	0.463 (0.154)
St. Marys Pond	4,989	0.654 (0.186)	0.748 (0.244)	0.711 (0.164)	0.532 (0.176)	0.348 (0.058)
Twisp River	2,485	0.325 (0.173)	0.319 (0.203)	1.295 (0.636)	0.413 (0.263)	0.134 (0.047)
Wells Hatchery	4,992	0.702 (0.198)	0.760 (0.236)	0.893 (0.195)	0.678 (0.225)	0.476 (0.083)
Winthrop NFH	2,329	0.178 (0.053)	2.219 (1.112)	0.569 (0.300)	1.262 (0.559)	0.225 (0.075)
Winthrop Hatchery						
Twisp Pond	4,544	0.244 (0.103)	0.883 (0.407)	1.327 (0.412)	1.172 (0.571)	0.286 (0.071)
Winthrop NFH	25,406	0.276 (0.034)	1.301 (0.190)	0.868 (0.100)	1.129 (0.170)	0.311 (0.027)

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	2,495	0.319 (0.110)	1.479 (0.838)	0.752 (0.400)	1.113 (0.492)	0.355 (0.100)
Rolfing Pond	19,999	0.412 (0.062)	0.767 (0.153)	1.001 (0.170)	0.768 (0.142)	0.317 (0.034)
Twisp Pond	2,359	0.264 (0.091)	NA	NA	NA	NA
Eagle Hatchery						
Prosser Hatchery	5,104	0.853 (0.470)	0.316 (0.184)	1.103 (0.354)	0.349 (0.213)	0.298 (0.078)
Leavenworth Hatchery						
Leavenworth NFH	9,998	0.367 (0.044)	1.355 (0.244)	0.599 (0.111)	0.811 (0.142)	0.298 (0.038)
Melvin R. Sampson Hatchery						
Yakima River	7,530	0.302 (0.081)	0.993 (0.339)	0.906 (0.299)	0.899 (0.331)	0.272 (0.069)
Prosser Hatchery						
Prosser Hatchery	5,161	0.378 (0.142)	0.614 (0.269)	0.593 (0.191)	0.364 (0.160)	0.137 (0.032)
Wells Hatchery						
Twisp Pond	2,457	0.302 (0.091)	2.618 (1.342)	0.377 (0.178)	0.987 (0.370)	0.298 (0.067)
Willard Hatchery						
Coulter Creek Pond	9,981	0.356 (0.072)	1.052 (0.269)	0.904 (0.180)	0.951 (0.224)	0.339 (0.042)
Eightmile Pond	2,495	0.271 (0.101)	1.145 (0.565)	1.809 (0.958)	1.430 (0.492)	0.562 (0.235)
Winthrop Hatchery						
Early Winters Pond	4,975	0.340 (0.080)	1.281 (0.405)	0.950 (0.268)	1.218 (0.367)	0.414 (0.078)
Midvalley Pond	4,987	0.402 (0.108)	1.192 (0.420)	0.670 (0.186)	0.799 (0.250)	0.321 (0.052)

Appendix Table B10. Detection probability estimates for yearling Chinook salmon, steelhead, and Coho salmon released from upper-Columbia River hatcheries in 2023. 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	16,008	0.052 (0.007)	0.115 (0.012)	0.111 (0.023)
Easton Pond	11,996	0.043 (0.008)	0.093 (0.013)	0.165 (0.039)
Jack Creek Pond	12,004	0.094 (0.018)	0.083 (0.020)	0.121 (0.043)
Yakima River rkm 267	3,999	0.041 (0.023)	0.052 (0.029)	0.111 (0.074)
East Bank Hatchery				
Chelan River	10,193	0.036 (0.006)	0.031 (0.006)	0.117 (0.020)
Chiwawa Pond	9,860	0.030 (0.010)	0.071 (0.018)	0.162 (0.047)
Dryden Pond	8,844	0.040 (0.006)	0.066 (0.008)	0.147 (0.023)
Nason Acclimation F.	9,921	0.042 (0.008)	0.075 (0.012)	0.130 (0.032)
Entiat Hatchery				
Entiat Hatchery	19,934	0.035 (0.005)	0.044 (0.006)	0.105 (0.017)
Leavenworth Hatchery				
Leavenworth NFH	45,946	0.034 (0.003)	0.079 (0.005)	0.182 (0.015)
Methow Hatchery				
Chewuch Pond	4,998	0.023 (0.006)	0.046 (0.010)	0.178 (0.043)
Methow Hatchery	4,997	0.014 (0.006)	0.053 (0.012)	0.163 (0.047)
Twisp Pond	4,882	0.017 (0.006)	0.021 (0.007)	0.217 (0.046)
Prosser Hatchery				
Buckskin Slough Pond	11,133	0.060 (0.016)	0.056 (0.018)	0.044 (0.043)
Prosser Hatchery	20,498	0.077 (0.008)	0.109 (0.011)	0.107 (0.020)
Roza Dam Tailrace	11,152	0.023 (0.010)	0.025 (0.012)	0.105 (0.050)
Wells Hatchery				
Wells Hatchery	10,963	0.031 (0.006)	0.038 (0.008)	0.096 (0.024)
Winthrop Hatchery				
Winthrop NFH	19,943	0.016 (0.003)	0.047 (0.005)	0.151 (0.016)

Appendix Table B10. Continued.

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Steelhead		
Chiwawa Hatchery				
Chiwawa River	15,481	0.018 (0.003)	0.103 (0.009)	0.147 (0.017)
Wenatchee River	14,798	0.029 (0.005)	0.135 (0.012)	0.136 (0.019)
Wells Hatchery				
Antoine Creek	4,995	0.017 (0.007)	0.075 (0.016)	0.144 (0.036)
Methow Hatchery	4,986	0.039 (0.008)	0.068 (0.012)	0.167 (0.027)
Salmon Creek	4,987	0.031 (0.008)	0.085 (0.016)	0.105 (0.029)
Similkameen Pond	4,994	0.012 (0.006)	0.047 (0.013)	0.080 (0.027)
St. Marys Pond	4,989	0.018 (0.006)	0.069 (0.012)	0.178 (0.031)
Twisp River	2,485	0.030 (0.017)	0.054 (0.024)	0.207 (0.075)
Wells Hatchery	4,992	0.015 (0.005)	0.086 (0.012)	0.149 (0.027)
Winthrop NFH	2,329	0.046 (0.017)	0.043 (0.019)	0.149 (0.052)
Winthrop Hatchery				
Twisp Pond	4,544	0.013 (0.006)	0.071 (0.016)	0.146 (0.037)
Winthrop NFH	25,406	0.019 (0.003)	0.070 (0.006)	0.151 (0.014)
		Coho salmon		
Cascade Hatchery				
Eightmile Pond	2,495	0.029 (0.012)	0.021 (0.010)	0.164 (0.047)
Rolfing Pond	19,999	0.022 (0.004)	0.029 (0.004)	0.188 (0.021)
Twisp Pond	2,359	0.035 (0.014)	0.007 (0.007)	0.105 (0.057)
Eagle Hatchery				
Prosser Hatchery	5,104	0.008 (0.005)	0.077 (0.016)	0.130 (0.035)
Leavenworth Hatchery				
Leavenworth NFH	9,998	0.045 (0.006)	0.054 (0.008)	0.224 (0.029)
Melvin R. Sampson Hatchery				
Yakima River	7,530	0.026 (0.008)	0.054 (0.012)	0.115 (0.030)
Prosser Hatchery				
Prosser Hatchery	5,161	0.022 (0.009)	0.077 (0.019)	0.190 (0.046)
Wells Hatchery				
Twisp Pond	2,457	0.027 (0.010)	0.023 (0.010)	0.241 (0.056)
Willard Hatchery				
Coulter Creek Pond	9,981	0.016 (0.004)	0.030 (0.006)	0.245 (0.031)
Eightmile Pond	2,495	0.025 (0.011)	0.040 (0.015)	0.088 (0.038)
Winthrop Hatchery				
Early Winters Pond	4,975	0.022 (0.006)	0.036 (0.009)	0.181 (0.035)
Midvalley Pond	4,987	0.019 (0.006)	0.032 (0.008)	0.233 (0.039)

Appendix C: Environmental Conditions and Salmonid Passage Timing

Methods

In August 2023 we obtained data on daily flow, temperature, spill, and total 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 2021).

Using these data, we created plots to compare daily measures of flow, temperature, spill, and TDG in 2023 vs. in selected recent years. We plotted conditions in 2023 against long-term daily quantiles using values from 1989-2023 for flow and temperature and from 2006-2023 for spill and TDG. Periods selected for flow and temperature quantiles were based on available data. For spill and TDG we did not use data from 1989-2005 because court-ordered spill began in 2006.

We combined collection count data with daily estimated proportions of fish that used the juvenile bypass system (equivalent to daily estimated 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 2023 resulted in a spring freshet that reached very high levels of flow for a portion of the season, but levels of flow outside the freshet period were quite low. Water temperatures rose from cooler than average in the early season to much warmer than average late in the season, 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 93.0 kcfs, which was close to the long-term mean of 91.5 kcfs (1993-2023). Daily flow values were below long-term daily medians for almost all of April and in early June. However, during the month of May, a strong spring freshet drove daily flow values to far above the long-term daily median, with two distinct peaks around 5 May and 23 May (Appendix Figure C1).

At Little Goose Dam, mean water temperature during the 2023 migration period was 11.3°C, which was barely above the long-term mean of 11.2°C (1993-2023). However, although daily water temperatures started more than two degrees cooler than the long-term daily median at the beginning of April, they rose steadily throughout the season and reached three degrees warmer than the long-term daily median by the second week of June. There were two peaks in daily water temperature during the month of May, roughly corresponding with peaks in flow at similar times (Appendix Figure C1).

At Snake River dams, mean spill discharge during the 2023 migration was 48.5 kcfs, which was well above the 2006-2023 mean of 37.0 kcfs and was the fourth highest rate of spill discharge in the past 30 years. Daily spill discharge was near average only for the first week of April and for a short period in late May, and otherwise was well above average. The pattern of daily spill discharge roughly followed patterns in daily flow during May, with two peaks in spill discharge corresponding with peaks in flow (Appendix Figure C2).

Spill as a percentage of flow at Snake River dams averaged 54.3% in 2023, considerably greater than the long-term mean of 40.1% (2006-2023). Spill proportions in 2023 were about 5 to 8% below those from 2020-2022, but 2023 still had the fourth highest mean spill percent on record. Daily mean spill percentages in 2023 were stable and extremely high for all of April, but fell somewhat in May during the periods of high flow (Appendix Figure C2).

Daily mean percent dissolved gas saturation was substantially above the long-term median for most of 2023 (Appendix Figure C3). Daily mean percent dissolved gas saturation was actually slightly below the long-term median during the first week of

April when both flow and spill were low, but rose sharply in the second week of April and stayed well above the long-term daily median until early June. Two large peaks in daily dissolved gas occurred in May, corresponding with the peaks in flow during that month. The peaks in daily dissolved gas around 5 May reached approximately 123% TDG, while the peak around 23 May briefly exceeded 125%, nearly reaching 126%.

Peaks in both Chinook and steelhead passage at Lower Granite Dam were about equal to average timing in 2023. However, the distribution of passage timing was extremely condensed for Chinook, with few fish passing prior to 30 April or later than 10 May. This massive spike in Chinook passage corresponded very well with the first major peak in daily flow in the first half of May (Appendix Figure C4). Passage distribution was more protracted for steelhead than for Chinook; however, it was still relatively condensed compared to other years, with the vast majority of steelhead passing between 12 April and 7 May.

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 2023 were far below the long-term median for the entire month of April, among the lowest on record for that period. At the start of May, daily flow levels rose sharply to levels far above the long-term median. Flow levels then dropped sharply in late May to once again reach levels far below long-term daily median.

Daily water temperature values in 2023 were about one degree cooler than the long-term daily median for the first half of April, rising slowly through late April to reach the median by the start of May. Daily water temperature stayed close to the long-term median through most of May, then started rising again in late May to reach one to two degrees warmer than the long-term median in early June (Appendix Figure C5).

Daily and seasonal spill patterns varied widely among the four lower Columbia River dams in 2023. At McNary Dam, daily spill volumes were at or below the median during most of April, rose to among the highest on record for most of May, and finally dropped to slightly below the median again in early June (Appendix Figure C6). However, spill as a percentage of flow at McNary Dam was well above average for the entire migration period, and during the first half of May it was the highest yet seen at McNary.

Spill patterns at John Day Dam largely mirrored those at McNary in 2023. Very similar to spill volumes at McNary, daily spill volumes at John Day started slightly below average during April, rose sharply in early May to far above average, and dropped in late May to slightly below average in early June (Appendix Figure C7). In contrast, spill as a percentage of flow at John Day was well above the long-term median for the entire migration season, while not quite as exceptional compared to past years as that at McNary. For a brief period right at the start of May, daily spill volumes were the highest ever recorded at John Day.

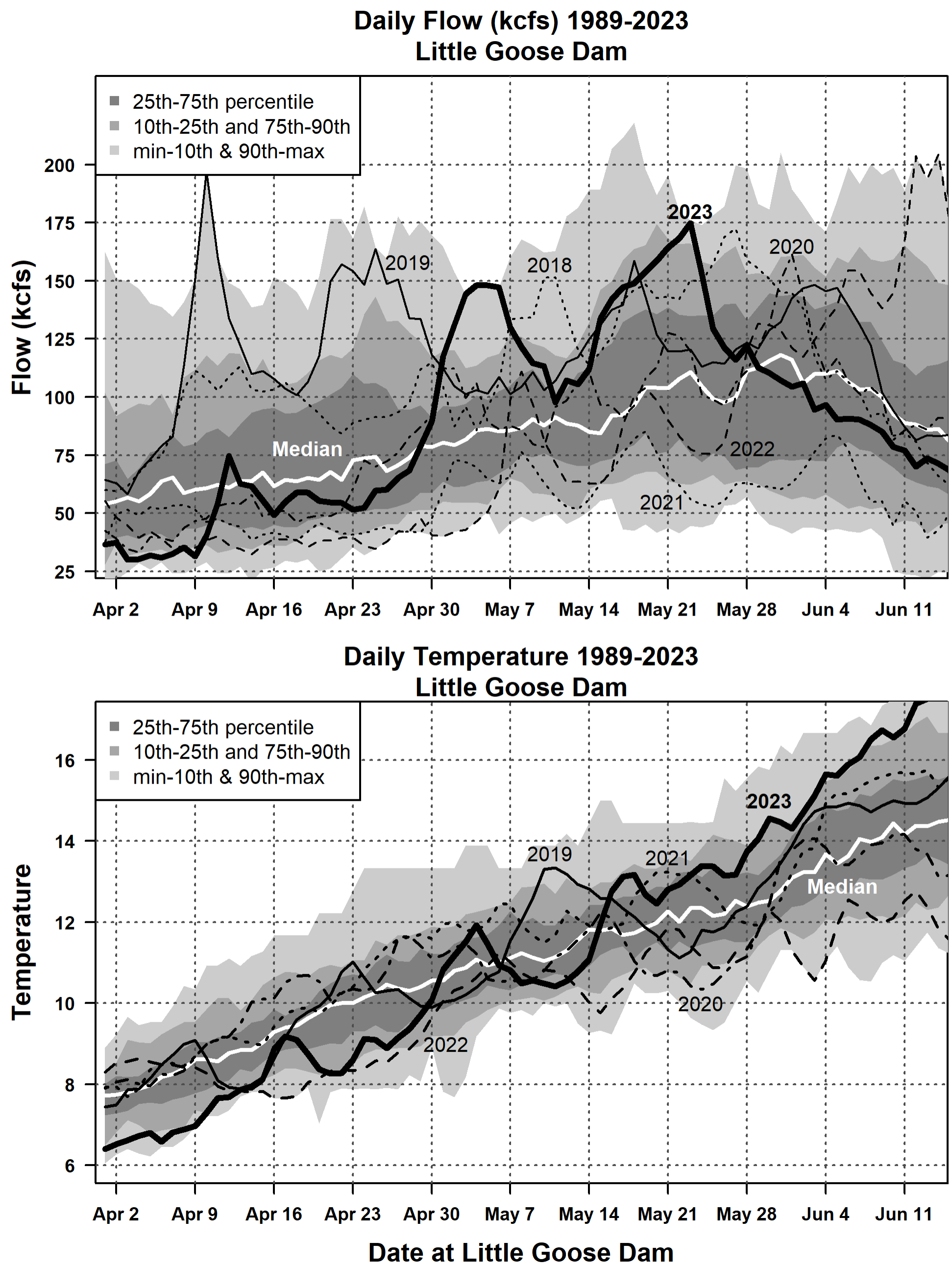
Spill operations at The Dalles Dam are less variable from year to year than at other dams, primarily because of operations designed to match a constant target of 40% spill. This spill percentage was matched almost exactly for most of 2023 (Appendix Figure C8). As this spill percentage target was followed, patterns in spill volume closely followed those in overall flow, with below-average spill discharge early and late in the season and above-average spill discharge in May. For a period in mid-May, levels of flow were so high that dam managers were forced to spill more than 40% at The Dalles, with resulting peaks in spill discharge at that time.

At Bonneville Dam, daily spill volumes do not exceed 150 kcfs wherever possible. This rule was followed through most of 2023, with spill volumes close to the long-term median in April and modestly above the long-term median for most of May. However, high flows in mid-May forced spill volumes above 150 kcfs, reaching well above average during that period (Appendix Figure C9). Spill as a percentage of flow was extremely high at Bonneville Dam during April and in early June, but was close to the long-term median for most of May.

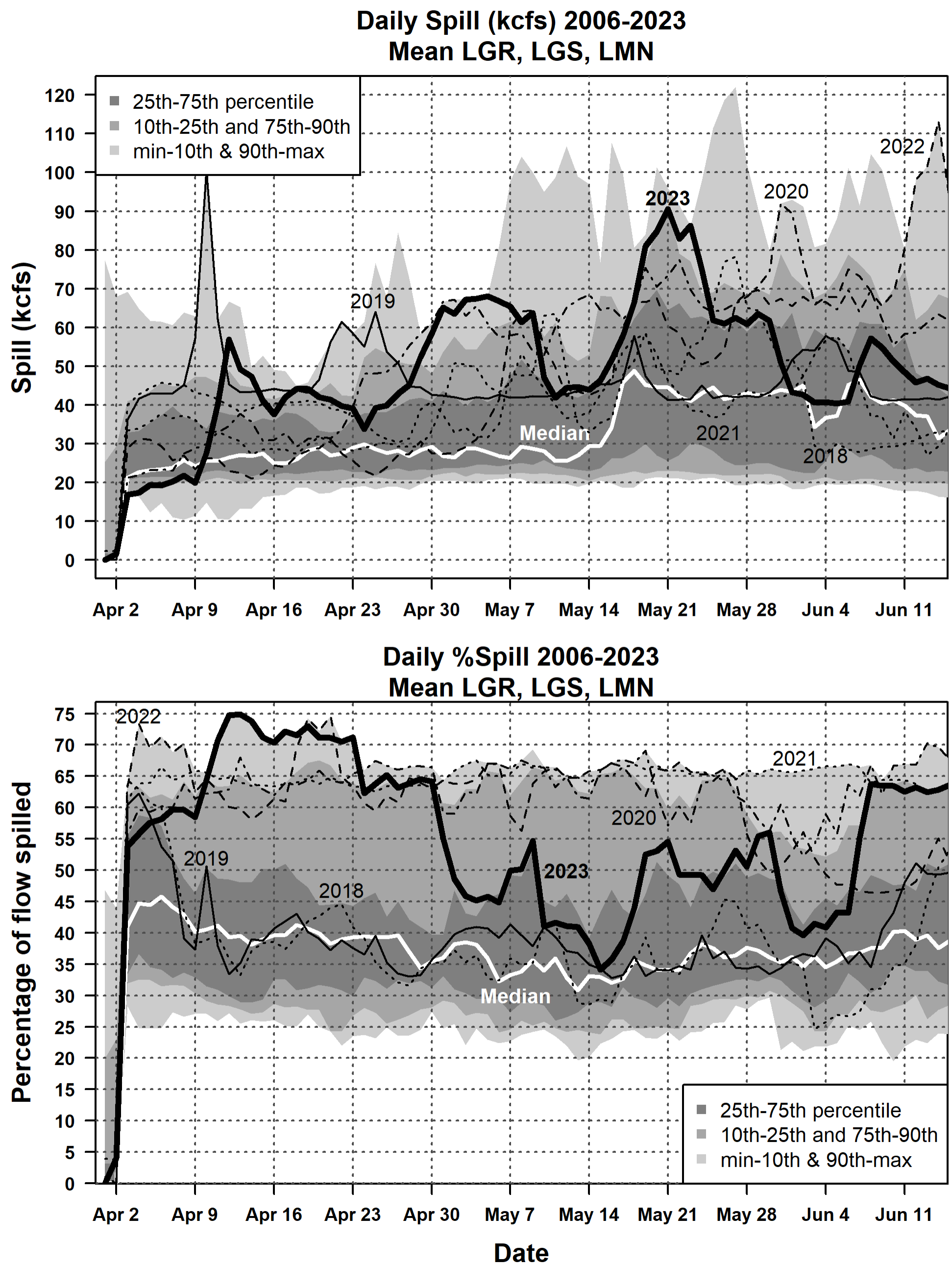
Daily mean percent dissolved gas saturation stayed close to the long-term median in April and in early June of 2023 at both McNary and John Day Dam (Appendix Figure C10). However, high levels of flow and spill at both dams during May drove daily dissolved gas saturation to levels well above average. During May, daily mean percent TDG reached a steady level of 124% at McNary and the same to one or two percentage points less at John Day.

Daily mean percent dissolved gas saturation was more variable at The Dalles Dam, but still showed the same general pattern of near-average TDG in April and early June but much higher TDG during May. Daily TDG levels reached 126% for more than a week at The Dalles in mid-May, very nearly the highest on record for that period (Appendix Figure C11).

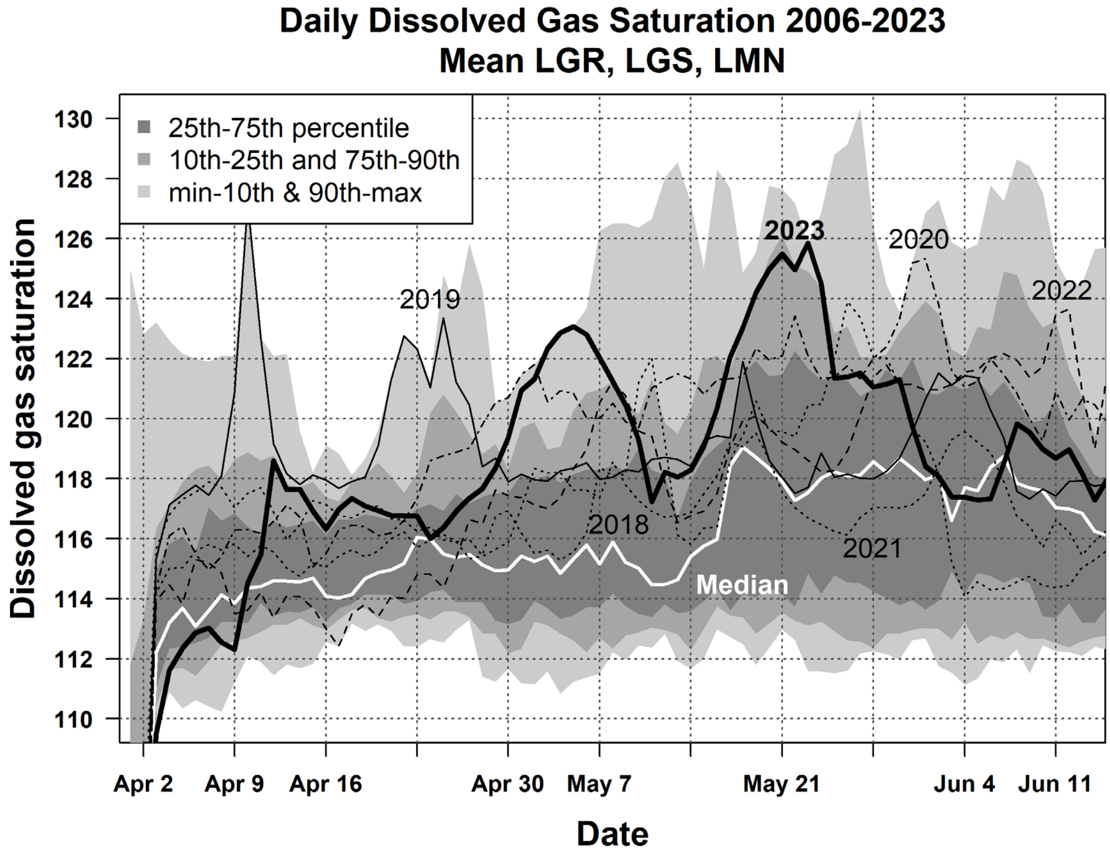
Daily dissolved gas saturation at Bonneville Dam also showed a pattern of lower TDG (either near average or below average) in April and early June, and higher TDG in May. Daily mean TDG values at Bonneville varied from 122 to 124% during May, ranging far above average (Appendix Figure C11).



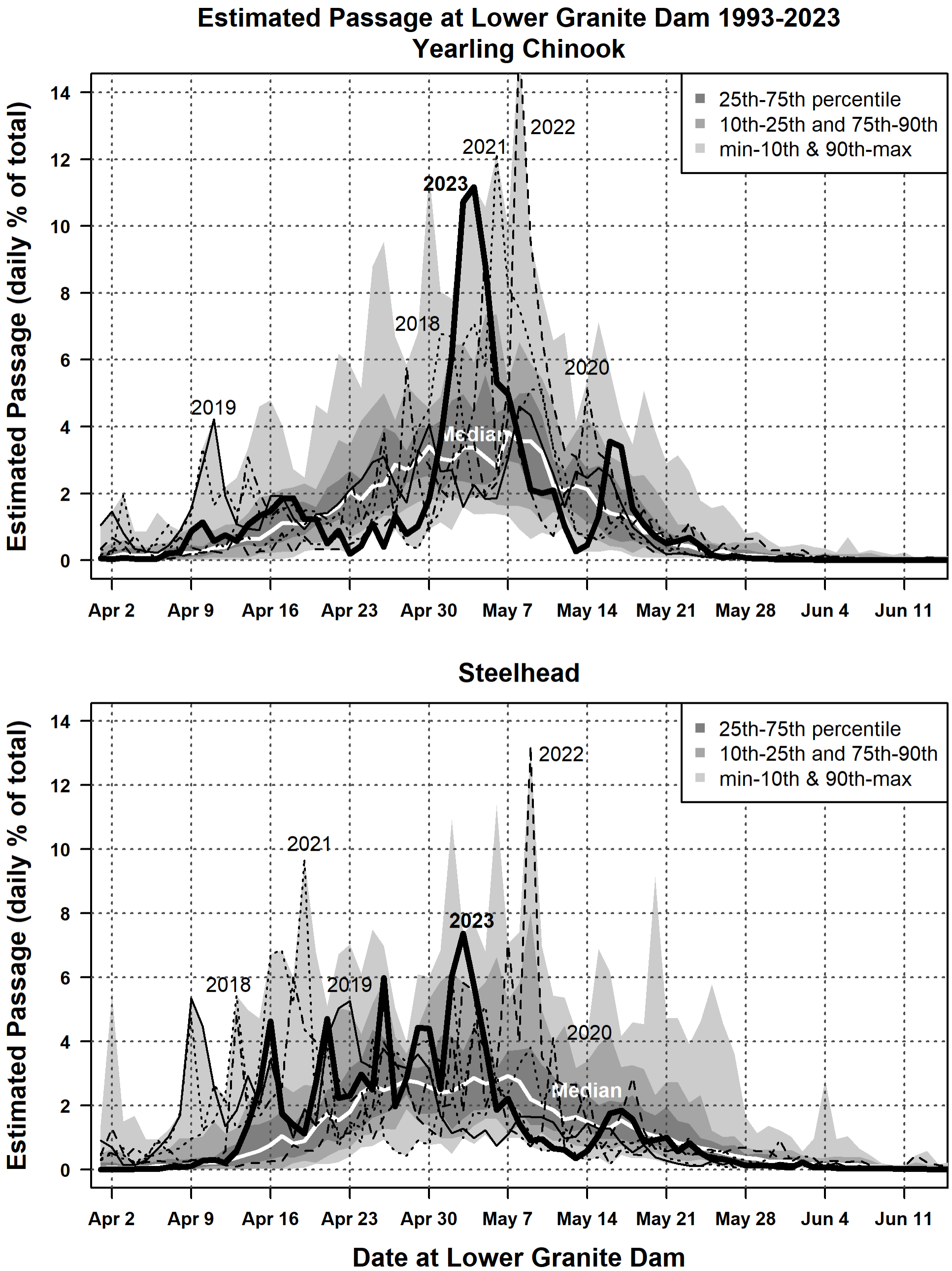
Appendix Figure C1. Upper panel shows daily mean flow at Little Goose Dam from April to mid-June. Lines show daily mean flow for 2023, selected recent years, and long-term median. Shaded areas illustrate daily quantiles for 1989-2023. Lower panel uses the same format to show daily mean temperature at Little Goose Dam. Quantiles for daily temperature are calculated from 1996 to 2023.



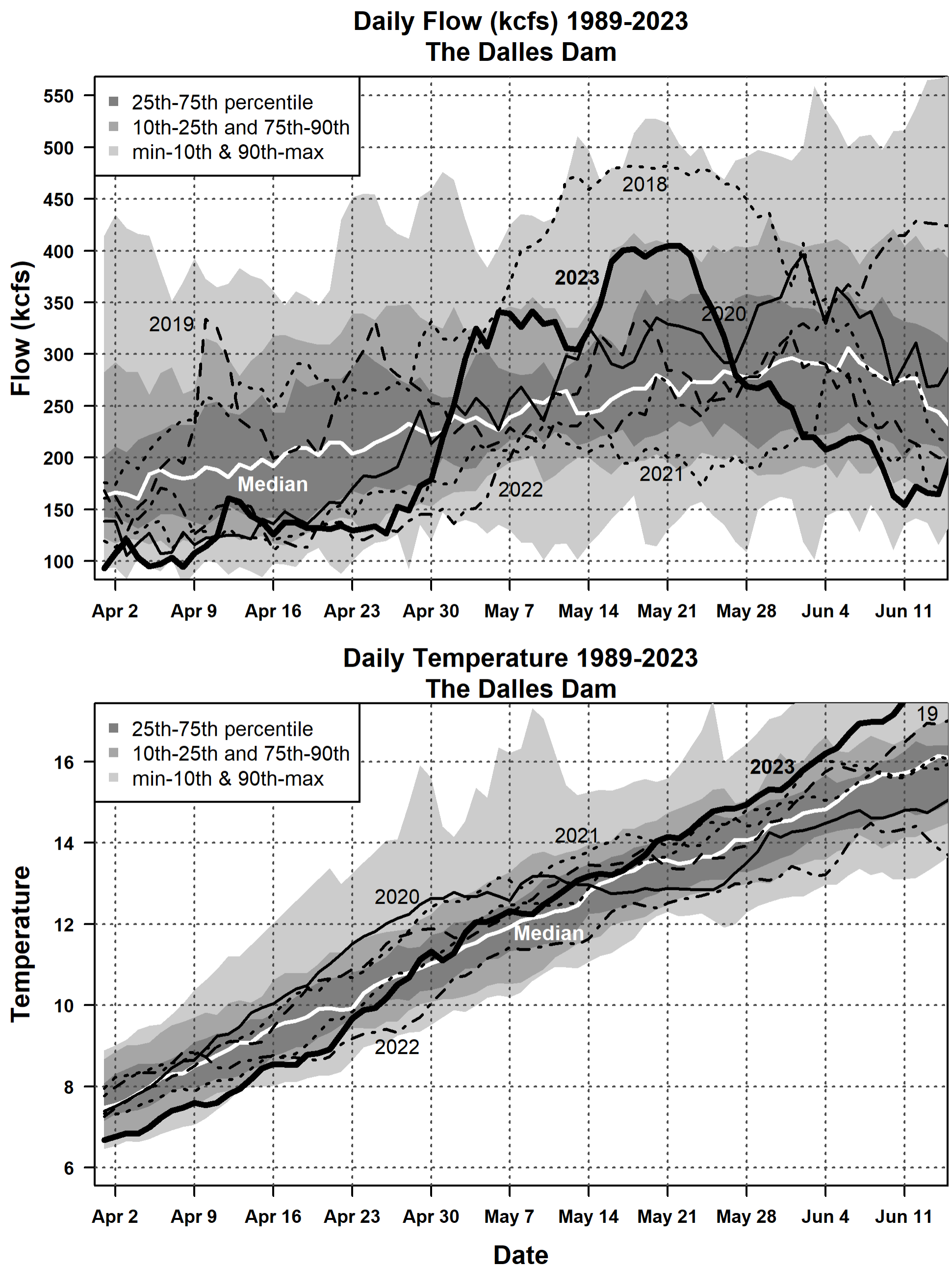
Appendix Figure C2. Upper panel shows daily mean Snake River spill (kcfs) from April to mid-June averaged across Lower Granite, Little Goose and Lower Monumental Dams. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.



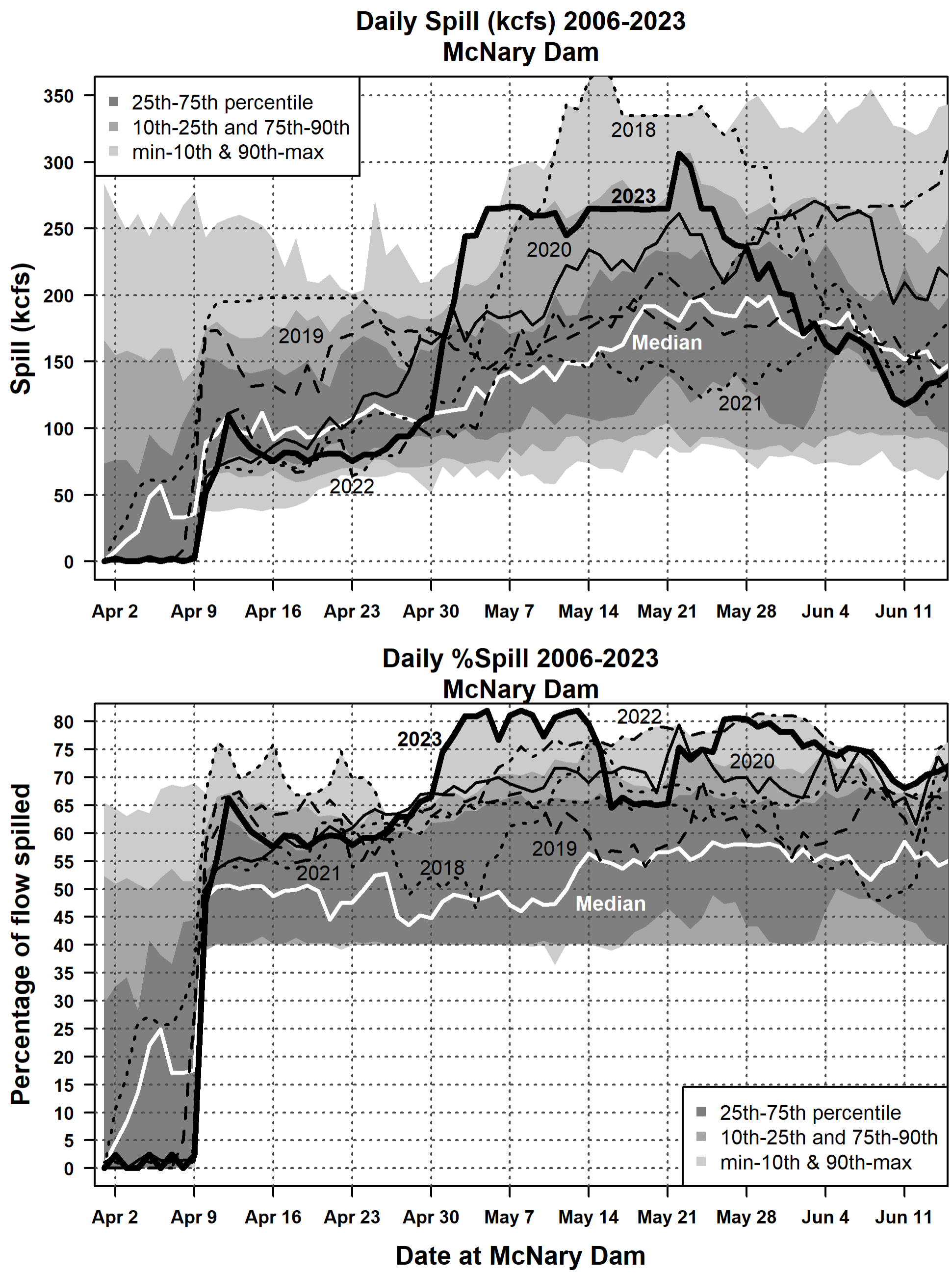
Appendix Figure C3. Daily mean percentage of dissolved gas averaged across Lower Granite, Little Goose and Lower Monumental Dam from April to mid-June 2023. Lines show daily percentage for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006 to 2023.



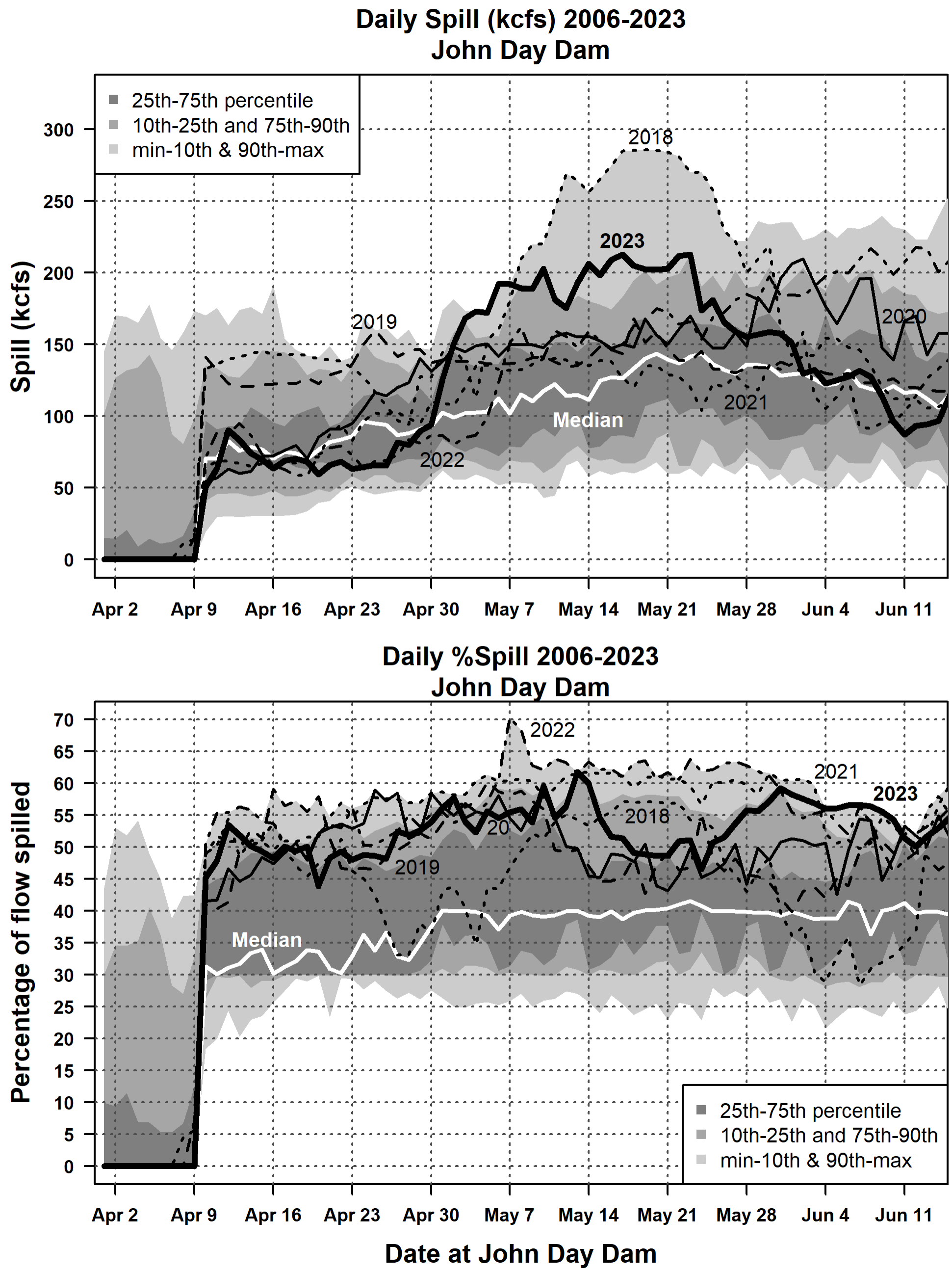
Appendix Figure C4. Estimated daily smolt passage at Lower Granite Dam for yearling Chinook salmon and steelhead. Daily passage is expressed as percentage of the yearly total. Lines indicate daily values for 2023, the long term median, and selected recent years. Shaded areas indicate smolt-passage quantiles from 1993 to 2023.



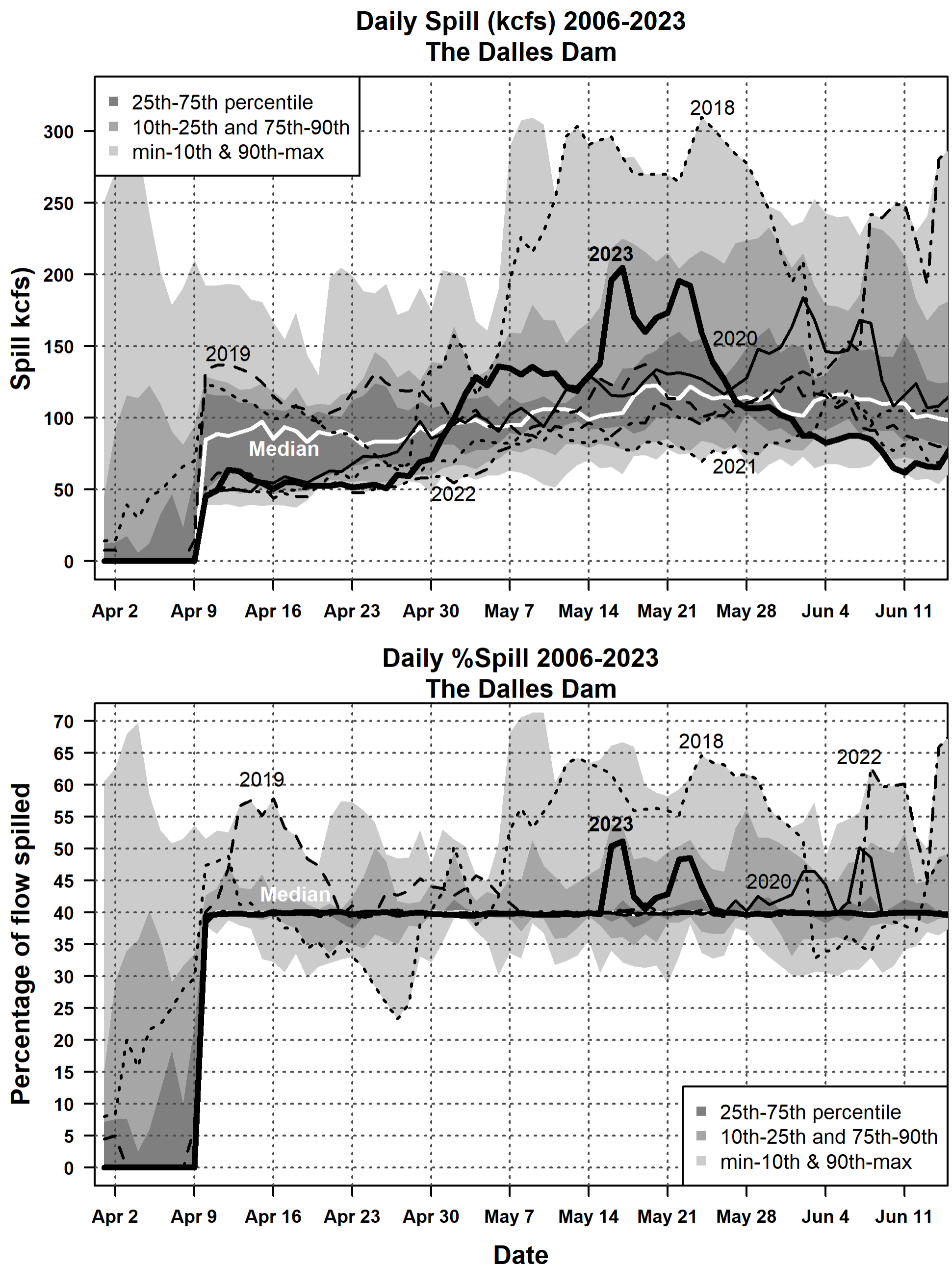
Appendix Figure C5. Upper panel shows daily mean flow at The Dalles Dam from April to mid-June. Lines show daily mean flows for 2023, selected recent years, and the long-term median. Shaded areas illustrate daily quantiles from 1989 to 2023. Lower panel uses the same format to show daily mean temperature at The Dalles Dam. Quantiles for daily temperature are calculated from 1989 to 2023.



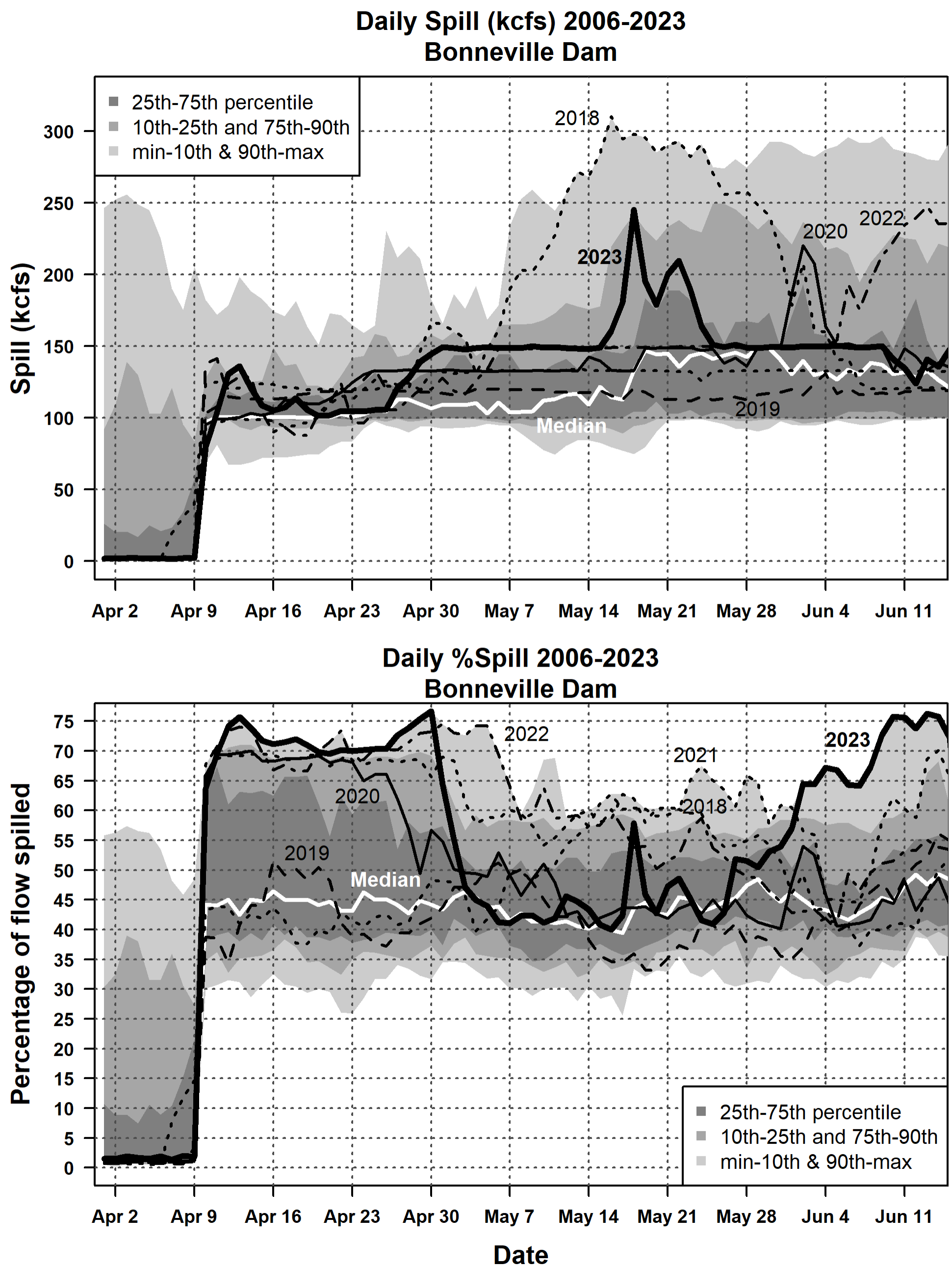
Appendix Figure C6. Upper panel shows daily mean spill (kcfs) from April to mid-June at McNary Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.



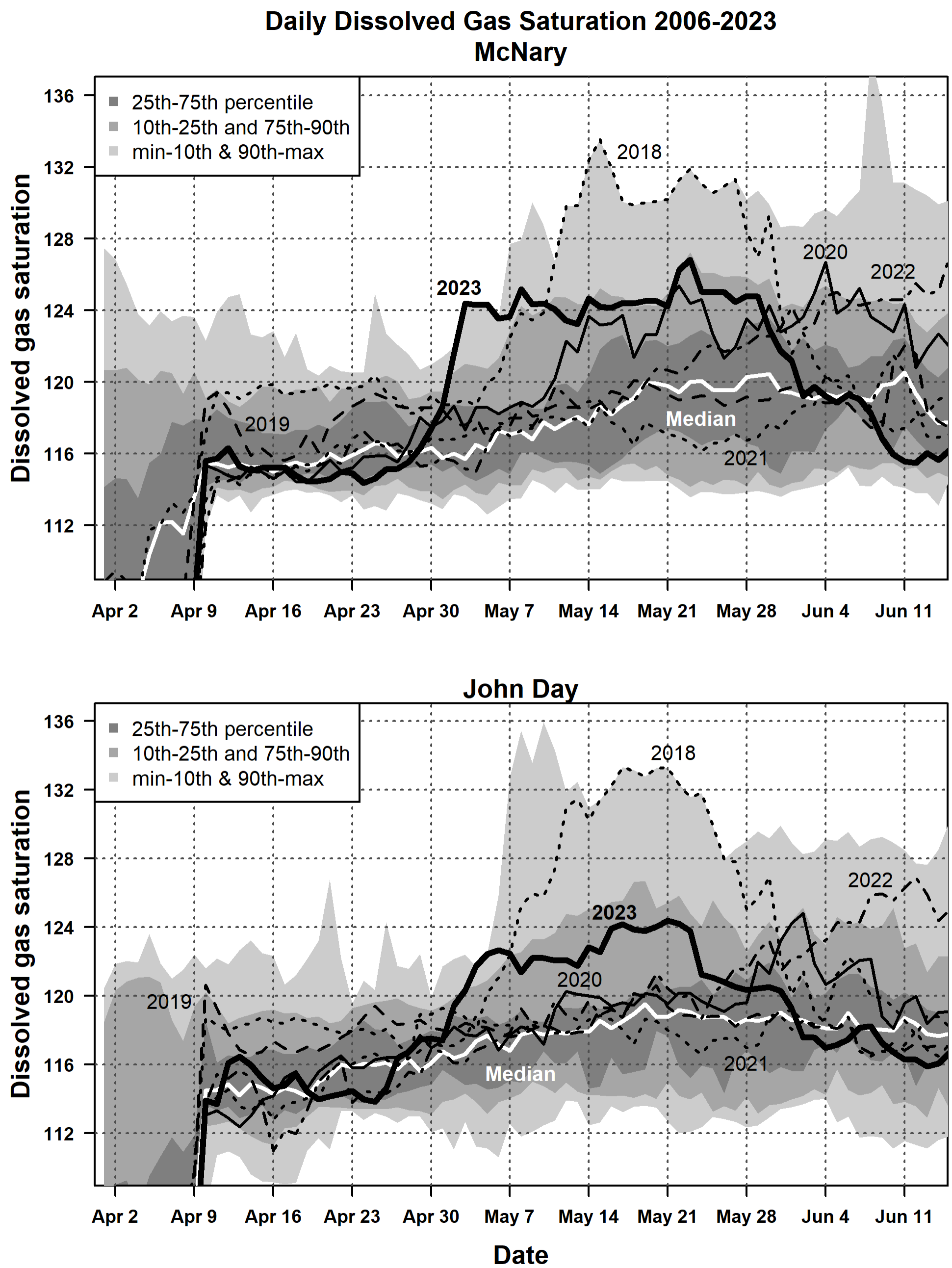
Appendix Figure C7. Upper panel shows daily mean spill (kcfs) from April to mid-June at John Day Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.



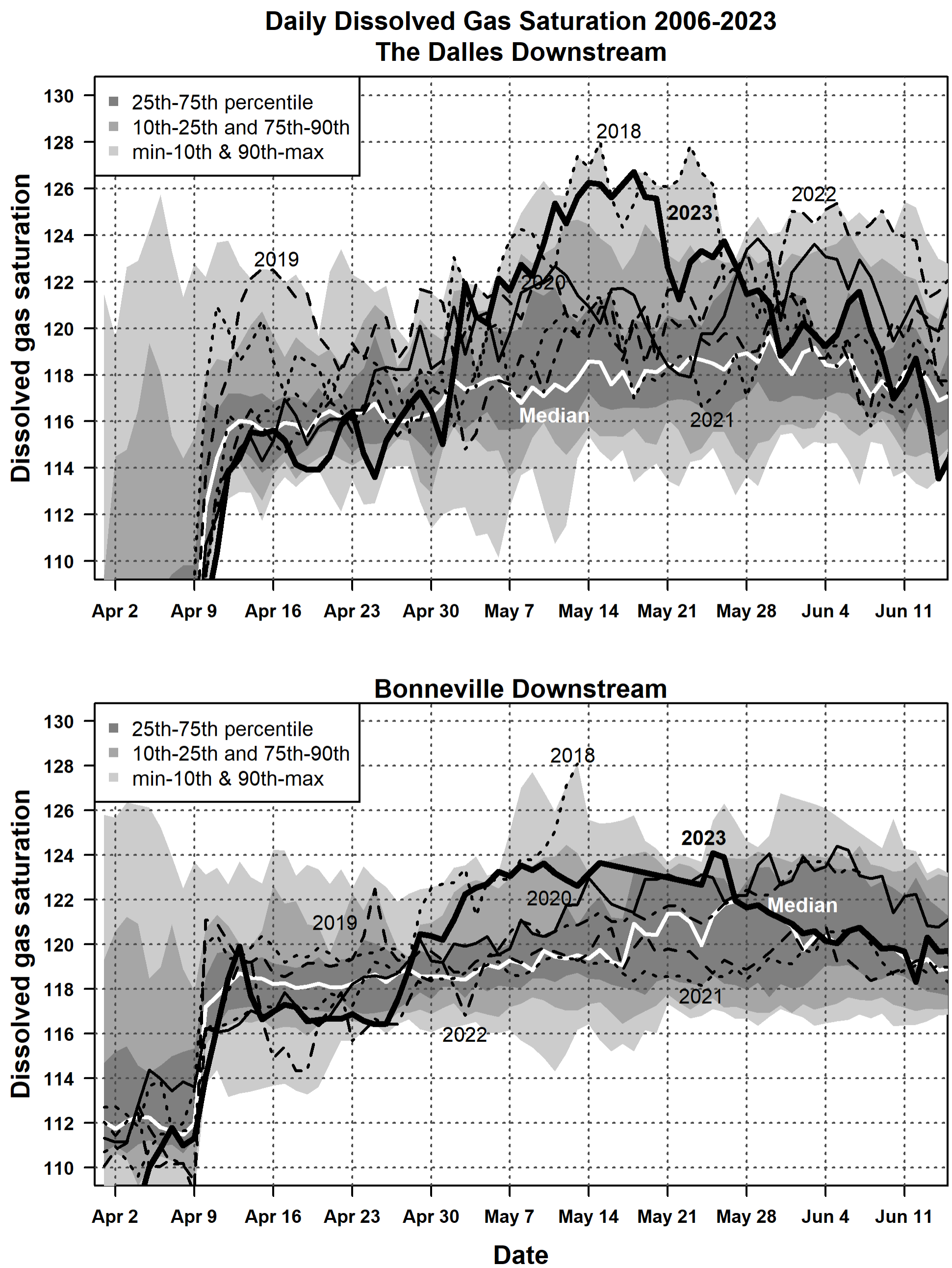
Appendix Figure C8. Upper panel shows daily mean spill (kcfs) from April to mid-June at The Dalles Dam. Lower panel shows daily spill as a percentage of total flow. Lines show daily values for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.



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 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.



Appendix Figure C10. Daily mean percentage of dissolved gas at McNary and John Day Dam from April to mid-June 2023. Lines show daily percentage for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.



Appendix Figure C11. Daily mean percentage of dissolved gas at The Dalles and Bonneville Dam from April to mid-June 2023. Lines show daily percentage for 2023, selected recent years, and the long-term median. Shaded areas indicate daily quantiles for 2006-2023.

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