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# Survival Estimates for the Passage of Spring-migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs, 2020

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# Survival Estimates for the Passage of Spring-migrating Juvenile Salmonids Through Snake and Columbia River Dams and Reservoirs, 2020

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# Executive Summary

In 2020, we completed the 28th year of a study to estimate survival and travel time of juvenile Pacific salmon *Oncorhynchus* spp. passing dams and reservoirs on the Snake and Columbia Rivers. All estimates were derived from detections of fish tagged with passive integrated transponder (PIT) tags.

The COVID-19 pandemic severely limited our field work and that of other agencies during the 2020 migration season. Many planned activities did not take place. For this study, we normally tag steelhead *O. mykiss* and Chinook salmon *O. tshawytscha* at Lower Granite Dam, but tagging was not possible in 2020. Thus, estimates of survival and other statistics in this report are based on fish tagged by other researchers upstream from Lower Granite Dam and fish tagged at hatcheries and traps on the Snake and Columbia Rivers.

Loss of the tagging operation at Lower Granite Dam in 2020 resulted in sample sizes for survival estimation that were smaller than anticipated. This deficit was partially compensated for by the successful inauguration of a new PIT-tag detection system in a spillway at Lower Granite Dam. Without data from the new spillway system, most survival estimates in 2020 would not have been possible.

In addition to the new spillway system, detection sites in 2020 included the juvenile bypass systems at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dam, as well as the Bonneville corner collector. Detection data from all of these sites have been used in previous years.

The Columbia River estuary trawl was a second key component of field work typically done for this study but cancelled in 2020 due to the COVID-19 pandemic. The trawl is usually the primary source of PIT-tag detection data for juvenile fish downstream of Bonneville Dam.

In the absence of detection data from the estuary trawl, we identified four alternative sources of data downstream from Bonneville Dam in 2020:

1) Recoveries of tags from multiple avian nesting and roosting areas in the Columbia River estuary
2) Detections by a PIT-tag monitoring system installed on a pile dike at river kilometer 70 in the Columbia River estuary

3) Detections by an autonomous barge located 3.5 km downstream from Bonneville Dam

4) Detections of precocious juvenile fish as they ascended the adult fish ladder at Bonneville Dam

All four data sources were used for survival estimation in this study for the first time in 2020. We will continue to use these data sources in future study years and are partway through retrospective analyses of survival using them in past years.

Primary research objectives in 2020 were:

1) Estimate reach survival and travel time throughout the migration period of yearling Chinook salmon and steelhead.

2) Evaluate relationships between survival estimates and migration conditions.

3) Evaluate survival estimation models under prevailing conditions.

In 2020, we estimated reach survival and travel time for yearling Chinook salmon and steelhead of both wild and hatchery origin, and also for sockeye *O. nerka* and coho salmon *O. kisutch* of hatchery origin. Survival estimates were calculated using a statistical model for mark-recapture data from single-release groups.

During most of the migration season, detections of yearling Chinook and steelhead were sufficient to estimate survival and detection probabilities for weekly groups leaving Lower Granite Dam. However, due to unprecedented low detection rates at McNary Dam, no survival estimates were possible for any pooled groups of fish detected passing McNary (daily, weekly, or biweekly). Instead, for survival estimation between McNary and Bonneville Dam, we used the same weekly groups from Lower Granite Dam as were used for estimates in the reaches from Lower Granite to McNary. This was a a significant change from methods used in previous years.

Hatchery and wild fish were combined in some analyses. Among PIT-tagged fish detected at Lower Granite Dam, 91% of yearling Chinook and 94% of steelhead were of hatchery origin. In the overall runs, both tagged and untagged, our corresponding estimates of the hatchery-origin component were 88.5% of yearling Chinook and 94% 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 2020. Standard errors in parentheses.

| | Yearling Chinook salmon | Steelhead |
|---|---|---|
| Snake River Trap to Lower Granite Dam | 0.848 (0.058) | 0.914 (0.041) |
| Lower Granite to Little Goose Dam | 0.811 (0.039) | 0.991 (0.049) |
| Little Goose to Lower Monumental Dam | 1.171 (0.128) | 1.025 (0.109) |
| Lower Monumental to McNary Dam[a] | 0.847 (0.095) | 0.834 (0.092) |
| Lower Monumental to Ice Harbor Dam | 0.928 (0.094) | 1.069 (0.077) |
| Ice Harbor to McNary Dam | 0.922 (0.033) | 0.789 (0.040) |
| McNary to John Day Dam | 0.862 (0.039) | 0.985 (0.090) |
| John Day to Bonneville Dam[b] | 0.865 (0.060) | 0.762 (0.057) |
| Snake River Trap to Bonneville Dam[c] | 0.477 (0.046) | 0.544 (0.035) |

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

We also estimated average survival through the entire hydropower system from the Snake River Smolt Trap at the head of Lower Granite reservoir to the tailrace of Bonneville Dam (Table E1). These estimates were the product of average survival estimates through the following three reaches: Snake River Smolt Trap to Lower Granite Dam, Lower Granite to McNary Dam, and McNary to Bonneville Dam. For combined wild and hatchery Snake River fish, average estimated survival through the entire hydropower system was 0.477 (95% CI 0.386-0.569) for yearling Chinook and 0.544 (0.476-0.612) 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 0.668 (SE 0.139) for Entiat Hatchery fish released from the hatchery to 0.157 (0.052) for Methow Hatchery fish released to Goatwall Pond. For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.938 (0.392) for Wells Hatchery fish released from Methow Hatchery—a notably imprecise estimate—to 0.149 (0.028) for Chiwawa Hatchery fish released to the Chiwawa River.

Of the smolt run at large that arrived at Lower Granite Dam, we estimated that 15.7% of yearling Chinook (mean of wild and hatchery estimates) and 16.1% of steelhead were transported from a Snake River collector dam. These estimates were the second lowest on record; only in 2015 were lower proportions transported.

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 2020, proportions of fish collected during transport operations were far below average. For wild and hatchery populations respectively, we estimated that only 24.0 and 15.7% of Chinook and 22.7 and 17.2% of steelhead were collected. These low collection rates were the primary cause of the substantially below-average proportions transported.

In addition to estimates of survival for yearling Chinook salmon and steelhead, we calculated travel time over individual reaches between dams and over combined reaches between Lower Granite and Bonneville Dam (461 km). In early April 2020, median travel times between Lower Granite and Bonneville Dam were longer than in other recent years for both species. After mid-April, when flow approached the average level, travel time for both species was shortened substantially. In late April and May, median travel times for both species were among the shortest on record. These short travel times were coincident with historically high spill percentages during the 2020 migration season.

At dams where PIT-tag detection was possible only in the juvenile bypass system, detection probabilities were especially low in 2020. This lowered the quality of survival estimates in 2020. Survival estimates have suffered from low detection probabilities in other recent years, but the issue was especially acute in 2020. With the exception of Lower Granite and Bonneville, each of which had an additional monitored passage route, every dam had a detection rate less than half of the 2007-2019 average. These extremely low detection rates resulted in highly imprecise survival estimates for most single-project component reaches.

In recent years, spill levels have been increased in an attempt to boost juvenile salmonid survival through the hydropower system. Unfortunately, a side effect of increased spill since 2006 has been a drop in smolt detection rates at Snake and Columbia River dams. This loss of detection has degraded both the quantity and quality of data available for survival estimates. Spill rates were increased further in 2018 and 2019, with a corresponding decrease in detection rates, and the exceptionally high spill in 2020 resulted in exceptionally low detection rates.

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

Specifically, we recommend that the region place high priority on development and installation of PIT-monitoring systems for conventional spillways, as well as for surface-passage structures.

The new spillway detection system at Lower Granite Dam was highly successful; without it, survival estimation for Snake River fish might have been impossible in 2020. When detection was possible only in the juvenile bypass system, the overall mean estimated annual percentage detected from 2007 to 2019 was 26.1% for tagged yearling Chinook passing Lower Granite Dam. In 2020, the estimated overall percentage detected was 31.8%, with only 6.3% 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.

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

At present, there is no other tagging method that allows direct comparison of smolt-to-adult return ratios between groups. Therefore, it is critical that we take the necessary steps to maximize the quantity and quality of information already offered by the PIT tag at existing levels of tagging.

# Contents

# Introduction

Accurate and precise estimates of survival are critical for recovery of depressed stocks of Pacific salmon *Oncorhynchus* spp. that migrate through 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 2020, the National Marine Fisheries Service (NMFS) has estimated survival for Pacific salmon stocks as they pass Snake and Columbia River dams and reservoirs (Iwamoto et al. 1994; Muir et al. 1995, 1996, 2001a,b, 2003; Smith et al. 1998, 2000a,b, 2003, 2005, 2006; Hockersmith et al. 1999; Zabel et al. 2001, 2002; Faulkner et al. 2007-2017, Widener et al. 2018-2020). 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 2020, the 28th year of the study. Research objectives in 2020 were:

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

# Survival from Release to Bonneville Dam

## Methods

### Experimental Design

To estimate survival and detection probability for groups of PIT-tagged Pacific salmon smolts *Oncorhynchus* spp., we used the Cormack-Jolly-Seber (CJS) mark-recapture model for single-release groups, otherwise known as the single-release model (Cormack 1964; Jolly 1965; Seber 1965; Skalski 1998; Skalski et al. 1998; Muir et al. 2001a). In our application of the model, detection of a PIT tagged fish is equivalent to "recapture." Further background information and underlying statistical theory pertaining to the single-release model is detailed by Iwamoto et al. (1994).

During the 2020 migration season, survival estimates were based on detections of fish released 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. 2020).

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 new spillway detection system (inaugurated in 2020) and Bonneville, which has a detection system located in the corner collector of Powerhouse 2 (active since 2006). In 2020, the following eleven sites were equipped with automated monitoring facilities or were monitored by hand (Figure 1; 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>

- Autonomous barge system (~rkm 230.5)
- Pile dike detection system (rkm 70)
- Astoria-Megler Bridge (rkm 12)
- Avian colonies (rkm 8-32)

[1] River kilometer

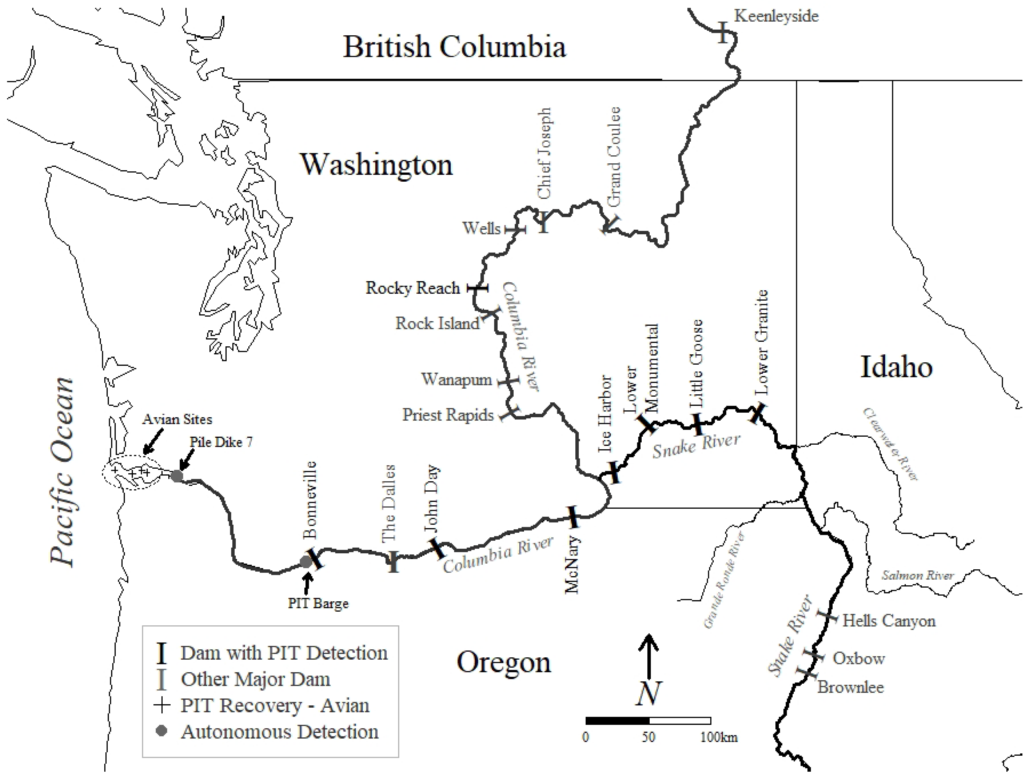


Figure 1. Study area showing PIT-tag detection sites in the Columbia River Basin, 2020. Dams with detection capability are marked with black bars, and those without are marked with gray bars. Other detection sites are marked with gray dots, while sites of recovery from avian nesting and roosting areas are marked with crosses.

The detection sites farthest downstream were in the Columbia River estuary, where we used four sources of detection data in 2020. Besides the autonomous barge detection system, located ~3.5 km downstream of Bonneville Dam, and the detection system at Pile Dike 7[2] at rkm 70, we used recoveries of PIT tags deposited by predaceous birds on several avian colonies in the Columbia River estuary and on the Astoria-Megler Bridge. We also used detections of precocious juveniles (known as “mini-jacks”) migrating upstream through the fish ladders at Bonneville Dam. This behavior is far more common in juvenile Chinook than in other species. The pair-trawl system was not operated in 2020, so these sources comprised all available PIT-tag information after smolts passed Bonneville Dam heading downstream in 2020.

[2] In the PTAGIS database, Pile Dike 7 is designated as site PD7

We grouped detections from all four data sources below Bonneville to form a composite "final detection site." Using the single-release model, survival can be estimated separately from detection probability only to the second-to-last detection site. Thus, to estimate survival to Bonneville Dam requires data from a final site downstream from the dam. In 2020, detection probabilities were low for both Bonneville Dam and the composite final detection site. Though data were sufficient to estimate survival from John Day to Bonneville for most stocks, the resulting estimates were often imprecise.

At Snake and Columbia River dams, most tagged fish were returned to the river after detection, which allowed for the possibility of additional detection at one or more sites downstream (Marsh et al. 1999). Thus, for fish released in the Snake River Basin upstream from Lower Granite Dam, we estimated survival in the following seven reaches, with all estimates between dams spanning the reach from tailrace to tailrace:

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

At Ice Harbor Dam, 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 2020, detections at Ice Harbor were extremely low, and detections at both Lower Monumental and McNary were nearly as low as those at Ice Harbor. These low detection rates resulted in small samples with very poor precision in the resulting survival estimates.

For fish released in the Upper Columbia River, we estimated survival in the following three reaches, with all estimates between dams spanning tailrace to tailrace:

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

### Study Fish

***Releases from Lower Granite Dam*—**During 2020, no smolts were tagged at the Lower Granite Dam juvenile bypass facility due to field-work restrictions stemming from the COVID-19 pandemic. Therefore, for survival estimation in the Snake River, we relied completely on detections of fish tagged and released from Snake River Basin hatcheries and traps by other researchers. We used data from these fish to estimate detection probabilities, survival probabilities, and travel time.

For both yearling Chinook salmon and steelhead, we created virtual daily "release groups" from fish tagged and released upstream from Lower Granite Dam and subsequently detected passing the dam. Virtual release groups included fish detected both in the juvenile bypass system and by the new spillway detection system. Daily groups were formed according to date of detection, and daily groups were then pooled into weekly groups.

We estimated survival for weekly groups in individual reaches between Lower Granite and McNary Dam. We attempted to estimate survival for daily groups as well; however, extremely poor detection rates at every dam downstream from Lower Granite rendered the results unusable. Additionally, for fish released early and late in the season, some weekly groups were too small for reliable estimates of either survival or travel time. These fish were excluded from analyses of weekly groups.

At Lower Granite Dam, a total of 73,064 yearling Chinook salmon (66,507 hatchery, 6,557 wild) were detected and returned to the tailrace. A total of 68,957 steelhead (65,004 hatchery, 3,953 wild) were also detected and returned to the tailrace.

We estimated that 88.5% of the overall yearling Chinook run was of hatchery origin in 2020. This estimate was based on counts of the run at large (both tagged and non-tagged fish) by the Fish Passage Center and on our own estimates of daily detection probability at Lower Granite Dam (based on tagged fish only, FPC 2020a). We estimated that 94.0% of the overall steelhead run was of hatchery origin in 2020. The estimate for steelhead was based on unpublished data from the Smolt Monitoring Program (Jerry McCann, Fish Passage Center, personal communication), using fin erosion as a marker to distinguish hatchery-origin fish from wild fish.

For combined hatchery and wild groups used to estimate survival, estimated proportions of hatchery fish were 91% for yearling Chinook and 94% for steelhead. These proportions were very similar to the hatchery/wild composition of the overall run.

In years when we have tagged fish at Lower Granite Dam for this study, we have intentionally emphasized tagging of wild fish in order to ensure adequate sample sizes for separate estimates of survival for wild fish. The cancellation of the tagging program at Lower Granite Dam in 2020 reduced the sample size of both wild Chinook and wild steelhead for survival estimation.

For example, the total number of wild Chinook in Lower Granite daily groups was 9,962 in 2019 and 6,557 in 2020. For wild steelhead, the numbers were 17,254 in 2019 but only 3,953 in 2020. The sample size of wild Chinook in 2020 was barely sufficient for separate estimates of downstream survival, but the estimates had poor precision. For steelhead, no separate survival estimates of wild fish were possible for any reach between Lower Granite and Bonneville Dam. This was due both to the insufficient number of wild steelhead in Lower Granite groups and to extremely low detection probabilities of steelhead downstream from Lower Granite Dam.

***Releases from McNary Dam*—**To estimate survival downstream of McNary Dam for yearling Chinook and steelhead released from locations throughout the Snake River Basin, our standard methodology in previous years has been to create virtual daily "release groups" at McNary. Virtual groups were formed according to day of detection at McNary. However, in 2020 detection rates at McNary were too low to generate sample sizes sufficient for survival estimation using this method.

In total, only 9,125 yearling Chinook and 2,348 steelhead of Snake River origin were detected passing McNary Dam in 2020, compared to 11,414 Chinook and 7,843 steelhead in 2019. Combined with below-average detection rates at Bonneville Dam and extremely low detection rates at John Day Dam in 2020, these sample sizes were insufficient.

Therefore, for 2020 we needed an alternative method for survival estimation of Snake River Basin fish between McNary Dam and Bonneville Dam. We considered several approaches, and ultimately settled on using virtual release groups based on day of detection at Lower Granite Dam. In past years, virtual release groups from Lower Granite Dam were used only for survival estimation between Lower Granite and McNary Dam, but in 2020 these groups were used for survival estimation from Lower Granite all the way to Bonneville Dam.

A drawback of this method is that while fish that compose a virtual release group all passed Lower Granite Dam on the same day, they tend to disperse as they migrate downstream. Such dispersion results in downstream passage timing that overlaps with the timing of adjacent virtual release groups. 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 changing river conditions across the season.

Additionally, dispersal of virtual groups results in variation among individuals in survival and detection probabilities at each reach and detection site, with variation presumably increasing as fish move downstream. This variation violates the assumption of homogeneous survival and detection probabilities across individuals within a release group. If of sufficient magnitude, this violation can potentially bias survival estimates (Appendix A). However, among the available approaches, this method was the most stable, producing estimates of acceptable quality for comparison with estimates from the method used in previous years.

We created release groups of tagged yearling Chinook and steelhead 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 created overall groups by pooling all fish of a given species into a single group for the entire year, and used these overall groups for estimates between McNary and Bonneville Dam.

***Releases from Hatcheries and Smolt Traps—***In 2020, most hatcheries in the Snake and Upper Columbia River Basins released PIT-tagged fish as part of research independent of our survival study. We used data from hatchery releases of PIT-tagged yearling Chinook, sockeye *O. nerka*, coho *O. kisutch*, and steelhead to obtain estimates of survival and detection probability. For fish originating in the Snake River Basin, we provided estimates from release to Lower Granite Dam and to points downstream from Lower Granite Dam. For fish originating in the Upper Columbia River Basin, we provided estimates of survival from release to McNary Dam and to points downstream from McNary Dam.

We also estimated survival to Lower Granite Dam and to points downstream for wild and hatchery yearling Chinook salmon and steelhead and wild sockeye PIT tagged at and released from smolt traps throughout the Snake River Basin, including the Salmon (White Bird), Snake, Grand Ronde, and Redfish Lake Creek 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 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%).

Data were first downloaded on 8 August 2020, and we published a memo of preliminary survival estimates on 19 October 2020. However, at the time of publication, data from PIT-tag recoveries on avian colonies throughout the basin were unavailable, and data from the pile dike and autonomous barge detection system were incomplete.

Thus, very little information was available from locations below Bonneville Dam, and we were unable to generate any survival estimates downstream of McNary Dam for inclusion in the memo. Additionally, we discovered after publication of the memo that our preliminary data processing had inadvertently excluded some detections from the new spillway detection system at Lower Granite Dam.

By late November 2020, detection data from the pile dike, autonomous barge, and avian colonies had been uploaded to the PTAGIS database, and we had corrected the inadvertent exclusion of detections from the new spillway system to ensure that all detected fish would be included in the analysis. Accordingly, on 1 December we again downloaded tagging and detection data for the 2020 migration year and processed the data for erroneous or inconsistent records.

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 1 December 2020. It is possible that data in the PTAGIS database may have been updated or corrected after this date. Thus, estimates we may provide in the future, or data used for future analyses, may differ slightly from those presented here.

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

In past study years, some sample sizes have been large enough that these tests had sufficient power to detect small violations of model assumptions. However, in 2020 statistical power was likely low for most tests due to small sample sizes and low detection probabilities. Very small deviations have only marginal effects on survival estimates, but large violations can result in biased parameter estimates. Appendix A contains a detailed discussion of these tests of assumption, the extent of assumption violations, and implications of and possible reasons for these violations.

***Survival Estimates***—All of our survival estimates were calculated from a release point or from the tailrace of 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).

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

When estimates of survival through a particular river section were available for a series of release groups from the same stock, we calculated a weighted average of these estimates over the entire migration season. When a series extended across all or most of the season, we considered this weighted average to be the seasonal average for the year. For each survival estimate in such a series, the weight applied was proportional to the inverse of its estimated relative variance (coefficient of variation squared).

We used the inverse of estimated *relative* variance rather than *absolute* variance because the variance of a survival probability estimate from the single-release model is a function of the estimate itself. Consequently, lower survival estimates tend to have smaller estimated variance. Use of the inverse relative variance prevented the weighted mean from being biased toward the lower estimates.

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

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

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

# Results

## Snake River Yearling Chinook Salmon

***Survival Probabilities***—For weekly groups of yearling Chinook salmon, we estimated survival probability from Lower Granite downstream through multiple Snake River dams over eight consecutive weeks during 30 March-24 May (Table 1). Mean estimated survival was 0.811 (SE 0.039) from Lower Granite to Little Goose, 1.171 (0.128) from Little Goose to Lower Monumental, and 0.847 (0.095) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.766 (0.018).

Table 1. Survival probability estimates from Lower Granite Dam to McNary Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly 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 |
| 30 Mar–5 Apr | 1,170 | 0.622 (0.129) | 0.786 (0.344) | 1.824 (0.901) | 0.891 (0.278) |
| 6–12 Apr | 9,525 | 0.856 (0.102) | 1.404 (0.486) | 0.613 (0.211) | 0.736 (0.079) |
| 13–19 Apr | 6,417 | 1.198 (0.313) | 1.033 (0.474) | 0.599 (0.241) | 0.741 (0.103) |
| 20–26 Apr | 12,138 | 0.794 (0.141) | 2.534 (1.283) | 0.420 (0.203) | 0.845 (0.076) |
| 27 Apr–3 May | 13,467 | 0.770 (0.079) | 0.958 (0.173) | 1.026 (0.175) | 0.757 (0.063) |
| 4 –10 May | 9,511 | 0.625 (0.086) | 1.630 (0.486) | 0.743 (0.223) | 0.758 (0.106) |
| 11–17 May | 15,837 | 0.857 (0.066) | 1.046 (0.155) | 0.801 (0.129) | 0.718 (0.071) |
| 18–24 May | 3,080 | 0.849 (0.107) | 1.441 (0.475) | 0.608 (0.219) | 0.744 (0.140) |
| **Weighted mean** | | **0.811 (0.039)** | **1.171 (0.128)** | **0.847 (0.095)** | **0.766 (0.018)** |

In 2020, 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 weekly groups formed from fish detected at Lower Granite Dam; the same groups that were used for Snake River reaches (Table 2).

While these virtual groups are identified by date of passage at Lower Granite Dam, their dates of passage at McNary were later. Detection probabilities were extremely low at McNary and John Day Dam. Consequently, survival estimates were generally imprecise (Table 2). Mean estimated survival was 0.862 (SE 0.039) from McNary to John Day, 0.865 (0.060) from John Day to Bonneville, and 0.733 (0.045) for the combined reach from McNary to Bonneville Dam.

Table 2. Survival probability estimates from McNary to Bonneville Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly 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 |
| 30 Mar–5 Apr | 1,170 | 0.789 (0.348) | 1.219 (0.628) | 0.962 (0.497) |
| 6–12 Apr | 9,525 | 0.861 (0.139) | 1.103 (0.262) | 0.950 (0.220) |
| 13–19 Apr | 6,417 | 0.811 (0.159) | 0.718 (0.161) | 0.583 (0.131) |
| 20–26 Apr | 12,138 | 0.831 (0.124) | 0.833 (0.165) | 0.692 (0.125) |
| 27 Apr–3 May | 13,467 | 0.778 (0.097) | 0.881 (0.197) | 0.686 (0.151) |
| 4 –10 May | 9,511 | 0.801 (0.142) | 1.035 (0.344) | 0.829 (0.285) |
| 11–17 May | 15,837 | 1.062 (0.141) | 0.664 (0.152) | 0.705 (0.165) |
| 18–24 May | 3,080 | 0.796 (0.214) | 0.898 (0.503) | 0.714 (0.399) |
| **Weighted mean** | | **0.862 (0.039)** | **0.865 (0.060)** | **0.733 (0.045)** |

We calculated the product of weekly estimates from Lower Granite to McNary and from McNary to Bonneville Dam and calculated the weighted mean to provide an overall survival estimate of 0.563 (0.039) from Lower Granite to Bonneville Dam. For wild and hatchery yearling Chinook salmon released from the Snake River trap, estimated survival to Lower Granite Dam was 0.848 (0.058). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River yearling Chinook salmon was 0.477 (0.046).

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for weekly groups of hatchery vs. wild yearling Chinook (Table 3). Survival from Lower Granite to McNary was higher for hatchery than for wild fish for most weekly groups. Weighted mean estimated survival across the season was higher for hatchery than for wild Chinook salmon, but the difference was not significant ($P = 0.20$).

Table 3. Survival probability estimates from Lower Granite to McNary Dam for Snake River yearling Chinook salmon in 2020. Separate daily groups of hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

| Date at Lower Granite Dam | Number released | Lower Granite to Little Goose Dam | Little Goose to Lower Monumental Dam | Lower Monumental to McNary Dam | Lower Granite to McNary Dam |
|---|---|---|---|---|---|
| | | **Estimated survival of weekly groups from Lower Granite Dam (SE)** | | | |
| | | **Hatchery yearling Chinook** | | | |
| 30 Mar–5 Apr | 1,094 | 0.648 (0.148) | 0.741 (0.332) | 1.793 (0.909) | 0.861 (0.287) |
| 6–12 Apr | 9,348 | 0.849 (0.103) | 1.389 (0.481) | 0.603 (0.207) | 0.711 (0.076) |
| 13–19 Apr | 5,842 | 1.516 (0.497) | 0.777 (0.408) | 0.686 (0.302) | 0.808 (0.127) |
| 20–26 Apr | 10,066 | 0.729 (0.163) | 3.444 (2.461) | 0.335 (0.230) | 0.842 (0.084) |
| 27 Apr–3 May | 12,290 | 0.735 (0.084) | 0.967 (0.195) | 1.044 (0.197) | 0.742 (0.065) |
| 4–10 May | 8,951 | 0.644 (0.096) | 1.545 (0.504) | 0.820 (0.270) | 0.816 (0.127) |
| 11–17 May | 15,055 | 0.859 (0.071) | 1.111 (0.179) | 0.762 (0.132) | 0.727 (0.075) |
| 18–24 May | 2,683 | 0.884 (0.141) | 1.712 (0.765) | 0.548 (0.261) | 0.829 (0.186) |
| **Weighted mean** | | **0.813 (0.051)** | **1.187 (0.154)** | **0.856 (0.098)** | **0.770 (0.019)** |
| | | **Wild yearling Chinook** | | | |
| 13–19 Apr | 575 | 0.557 (0.218) | 2.692 (2.734) | 0.302 (0.296) | 0.453 (0.129) |
| 20–26 Apr | 2,072 | 0.907 (0.259) | 1.630 (1.165) | 0.551 (0.380) | 0.815 (0.160) |
| 27 Apr–3 May | 1,177 | 1.029 (0.238) | 0.880 (0.353) | 0.940 (0.386) | 0.851 (0.208) |
| 4–10 May | 560 | 0.569 (0.182) | 2.381 (1.709) | 0.382 (0.274) | 0.518 (0.157) |
| 11–17 May | 782 | 0.915 (0.192) | 0.675 (0.239) | 0.921 (0.433) | 0.569 (0.212) |
| 18–24 May | 397 | 0.883 (0.174) | 1.079 (0.514) | 0.550 (0.297) | 0.524 (0.170) |
| **Weighted mean** | | **0.868 (0.066)** | **1.110 (0.260)** | **0.729 (0.104)** | **0.674 (0.073)** |

We were unable to estimate survival probabilities for daily groups of yearling Chinook salmon in 2020. Even for pooled weekly groups, the precision of nearly all survival estimates was extremely poor (Table 1). Consequently, it was impossible to assess any potential within-season trends in survival during 2020.

***Detection Probabilities*—**Detection probability estimates in 2020 were extremely low at almost every dam downstream of Lower Granite Dam (Tables 4-6). In marked contrast, because of the new 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 higher for wild than for hatchery Chinook salmon released during the same week (Table 6).

Table 4. Detection probability estimates at Little Goose, Lower Monumental, and McNary Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. 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 |
| 30 Mar–5 Apr | 1,170 | 0.092 (0.022) | 0.024 (0.011) | 0.046 (0.016) |
| 6–12 Apr | 9,525 | 0.046 (0.006) | 0.012 (0.004) | 0.052 (0.006) |
| 13–19 Apr | 6,417 | 0.019 (0.005) | 0.013 (0.005) | 0.045 (0.007) |
| 20–26 Apr | 12,138 | 0.023 (0.004) | 0.005 (0.002) | 0.053 (0.005) |
| 27 Apr–3 May | 13,467 | 0.056 (0.006) | 0.033 (0.005) | 0.069 (0.006) |
| 4 –10 May | 9,511 | 0.054 (0.008) | 0.019 (0.005) | 0.035 (0.005) |
| 11–17 May | 15,837 | 0.082 (0.007) | 0.044 (0.006) | 0.038 (0.004) |
| 18–24 May | 3,080 | 0.119 (0.016) | 0.035 (0.011) | 0.059 (0.012) |

Table 5. Detection probability estimates at John Day and Bonneville Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. 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 |
| 30 Mar–5 Apr | 1,170 | 0.054 (0.019) | 0.111 (0.047) |
| 6–12 Apr | 9,525 | 0.051 (0.007) | 0.144 (0.030) |
| 13–19 Apr | 6,417 | 0.054 (0.008) | 0.254 (0.046) |
| 20–26 Apr | 12,138 | 0.034 (0.004) | 0.216 (0.034) |
| 27 Apr–3 May | 13,467 | 0.082 (0.008) | 0.151 (0.031) |
| 4 –10 May | 9,511 | 0.104 (0.012) | 0.099 (0.031) |
| 11–17 May | 15,837 | 0.094 (0.009) | 0.133 (0.028) |
| 18–24 May | 3,080 | 0.081 (0.017) | 0.159 (0.084) |

Table 6. Detection probability estimates at Little Goose, Lower Monumental, and McNary Dam for Snake River yearling Chinook salmon in 2020. Separate daily groups of hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. 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** | | |
| 30 Mar–5 Apr | 1,094 | 0.083 (0.022) | 0.025 (0.012) | 0.042 (0.015) |
| 6–12 Apr | 9,348 | 0.046 (0.006) | 0.012 (0.004) | 0.053 (0.006) |
| 13–19 Apr | 5,842 | 0.014 (0.005) | 0.013 (0.006) | 0.039 (0.007) |
| 20–26 Apr | 10,066 | 0.020 (0.005) | 0.003 (0.002) | 0.049 (0.005) |
| 27 Apr–3 May | 12,290 | 0.055 (0.007) | 0.031 (0.005) | 0.067 (0.006) |
| 4–10 May | 8,951 | 0.051 (0.008) | 0.017 (0.005) | 0.032 (0.005) |
| 11–17 May | 15,055 | 0.079 (0.007) | 0.040 (0.006) | 0.038 (0.004) |
| 18–24 May | 2,683 | 0.100 (0.017) | 0.026 (0.011) | 0.051 (0.012) |
| | | **Wild yearling Chinook** | | |
| 13–19 Apr | 575 | 0.062 (0.028) | 0.014 (0.014) | 0.115 (0.038) |
| 20–26 Apr | 2,072 | 0.038 (0.012) | 0.015 (0.010) | 0.077 (0.016) |
| 27 Apr–3 May | 1,177 | 0.075 (0.019) | 0.054 (0.019) | 0.097 (0.025) |
| 4–10 May | 560 | 0.088 (0.032) | 0.038 (0.025) | 0.081 (0.029) |
| 11–17 May | 782 | 0.136 (0.031) | 0.110 (0.034) | 0.045 (0.020) |
| 18–24 May | 397 | 0.205 (0.046) | 0.062 (0.030) | 0.098 (0.038) |

## Snake River Steelhead

***Survival Probabilities*****—**For weekly groups of steelhead, we estimated survival probabilities from Lower Granite Dam downstream through multiple dams for nine consecutive weeks during 30 March-31 May (Table 7). Mean estimated survival was 0.991 (SE 0.049) from Lower Granite to Little Goose, 1.025 (0.109) from Little Goose to Lower Monumental, and 0.834 (0.092) from Lower Monumental to McNary Dam. For the combined reach from Lower Granite to McNary Dam, estimated survival averaged 0.807 (0.043).

Table 7. Survival probability estimates from Lower Granite to McNary Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly 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 |
| 30 Mar–5 Apr | 2,509 | 1.225 (0.241) | 1.240 (0.711) | 0.595 (0.345) | 0.903 (0.195) |
| 6–12 Apr | 3,072 | 0.947 (0.092) | 0.944 (0.290) | 1.024 (0.368) | 0.915 (0.191) |
| 13–19 Apr | 16,331 | 0.933 (0.043) | 1.497 (0.264) | 0.508 (0.099) | 0.710 (0.065) |
| 20–26 Apr | 14,913 | 1.051 (0.096) | 0.914 (0.156) | 0.900 (0.177) | 0.865 (0.116) |
| 27 Apr–3 May | 12,062 | 1.164 (0.117) | 0.820 (0.164) | 1.012 (0.242) | 0.966 (0.160) |
| 4–10 May | 6,517 | 0.684 (0.088) | 1.508 (0.401) | 0.680 (0.194) | 0.701 (0.115) |
| 11–17 May | 7,324 | 1.053 (0.136) | 0.779 (0.181) | 1.318 (0.401) | 1.081 (0.253) |
| 18–24 May | 3,520 | 1.341 (0.185) | 0.715 (0.168) | 0.677 (0.194) | 0.649 (0.139) |
| 25–31 May | 1,448 | 0.878 (0.187) | 0.723 (0.245) | 1.386 (0.799) | 0.880 (0.448) |
| **Weighted mean** | | **0.991 (0.049)** | **1.025 (0.109)** | **0.834 (0.092)** | **0.807 (0.043)** |

In 2020, 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 weekly groups formed from fish detected at Lower Granite Dam—the same groups used for estimates in Snake River reaches (Table 8).

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 McNary and John Day Dam. Consequently, survival estimates were generally imprecise (Table 8). Mean estimated survival was 0.985 (SE 0.090) from McNary to John Day, 0.762 (0.057) from John Day to Bonneville, and 0.738 (0.052) for the entire reach from McNary to Bonneville Dam (Table 8).

Table 8. Survival probability estimates from McNary to Bonneville Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly 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 |
| 30 Mar–5 Apr | 2,509 | 0.595 (0.177) | 0.934 (0.300) | 0.556 (0.183) |
| 6–12 Apr | 3,072 | 0.440 (0.112) | 1.335 (0.390) | 0.588 (0.194) |
| 13–19 Apr | 16,331 | 1.220 (0.142) | 0.730 (0.094) | 0.890 (0.126) |
| 20–26 Apr | 14,913 | 1.157 (0.186) | 0.677 (0.095) | 0.783 (0.136) |
| 27 Apr–3 May | 12,062 | 0.704 (0.130) | 0.816 (0.133) | 0.574 (0.124) |
| 4–10 May | 6,517 | 0.871 (0.177) | 0.791 (0.212) | 0.689 (0.201) |
| 11–17 May | 7,324 | 0.829 (0.215) | 0.531 (0.114) | 0.440 (0.131) |
| 18–24 May | 3,520 | 1.110 (0.275) | 0.752 (0.189) | 0.835 (0.255) |
| 25–31 May | 1,448 | 0.984 (0.560) | 0.921 (0.480) | 0.907 (0.618) |
| **Weighted mean** | | **0.985 (0.090)** | **0.762 (0.057)** | **0.738 (0.052)** |

For each weekly group we calculated the product of estimates from Lower Granite to McNary and from McNary to Bonneville Dam. The weighted mean of these weekly product estimates provided an overall survival estimate of 0.595 (SE 0.027) from Lower Granite to Bonneville Dam. For wild and hatchery steelhead released from the Snake River trap, estimated survival probability to Lower Granite Dam tailrace was 0.914 (0.041). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.544 (0.035).

For weekly groups of hatchery steelhead, we estimated survival and detection probabilities through individual and combined reaches (Table 9). However, for wild steelhead, the numbers detected passing Lower Granite Dam were so low that separate estimates for these fish were impossible in 2020.

For daily groups of steehead in 2020, we were unable to estimate survival probabilities. Even for pooled weekly groups, the precision of nearly all survival estimates was extremely poor (Table 7). Consequently, it was impossible to assess any potential trends in survival within the 2020 migration season.

Table 9. Survival probability estimates from Lower Granite to McNary Dam for Snake River juvenile steelhead in 2020. Daily groups of hatchery fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly groups. Standard errors in parentheses. Data for wild steelhead were insufficient for separate estimates.

| | | **Estimated survival for groups from Lower Granite Dam (SE)** | | | |
|---|---|---|---|---|---|
| Date at Lower Granite Dam | Number released | Lower Granite to Little Goose Dam | Little Goose to Lower Monumental Dam | Lower Monumental to McNary Dam | Lower Granite to McNary Dam |
| | | **Hatchery steelhead** | | | |
| 30 Mar–5 Apr | 2,491 | 1.226 (0.241) | 1.239 (0.710) | 0.590 (0.342) | 0.896 (0.193) |
| 6–12 Apr | 3,048 | 0.938 (0.091) | 0.934 (0.286) | 1.099 (0.398) | 0.963 (0.208) |
| 13–19 Apr | 16,046 | 0.937 (0.044) | 1.561 (0.286) | 0.469 (0.094) | 0.687 (0.063) |
| 20–26 Apr | 14,440 | 1.032 (0.094) | 0.941 (0.162) | 0.843 (0.166) | 0.819 (0.109) |
| 27 Apr–3 May | 11,076 | 1.164 (0.122) | 0.779 (0.158) | 1.067 (0.260) | 0.967 (0.165) |
| 4–10 May | 6,111 | 0.680 (0.088) | 1.442 (0.383) | 0.651 (0.184) | 0.638 (0.103) |
| 11–17 May | 6,400 | 0.998 (0.138) | 1.118 (0.340) | 0.828 (0.295) | 0.924 (0.212) |
| 18–24 May | 2,913 | 1.138 (0.154) | 0.853 (0.222) | 0.647 (0.206) | 0.628 (0.142) |
| 25–31 May | 1,322 | 0.909 (0.202) | 0.705 (0.252) | 1.767 (1.244) | 1.132 (0.728) |
| **Weighted mean** | | **0.976 (0.040)** | **1.083 (0.107)** | **0.780 (0.090)** | **0.777 (0.044)** |

***Detection Probabilities***—For weekly groups of steelhead, detection probability estimates were very low in 2020 at Little Goose, Lower Monumental, McNary, and John Day Dam (Tables 10-12). Detection probability estimates for steelhead were slightly above average at Bonneville Dam, where fish are detected in the corner collector, and well above average at Lower Granite Dam, with its new spillway detection system (Appendix Tables B5, B8, B10).

Table 10. Detection probability estimates at Little Goose Dam, Lower Monumental Dam, and McNary Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. 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 |
| 30 Mar–5 Apr | 2,509 | 0.057 (0.012) | 0.008 (0.005) | 0.046 (0.011) |
| 6–12 Apr | 3,072 | 0.146 (0.016) | 0.021 (0.007) | 0.038 (0.009) |
| 13–19 Apr | 16,331 | 0.109 (0.006) | 0.016 (0.003) | 0.022 (0.002) |
| 20–26 Apr | 14,913 | 0.054 (0.005) | 0.027 (0.004) | 0.011 (0.002) |
| 27 Apr–3 May | 12,062 | 0.066 (0.007) | 0.030 (0.005) | 0.013 (0.002) |
| 4–10 May | 6,517 | 0.076 (0.011) | 0.033 (0.008) | 0.029 (0.005) |
| 11–17 May | 7,324 | 0.060 (0.008) | 0.036 (0.007) | 0.012 (0.003) |
| 18–24 May | 3,520 | 0.087 (0.013) | 0.063 (0.012) | 0.024 (0.006) |
| 25–31 May | 1,448 | 0.086 (0.020) | 0.100 (0.027) | 0.012 (0.007) |

Table 11. Detection probability estimates at John Day Dam and Bonneville Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. 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 |
| 30 Mar–5 Apr | 2,509 | 0.052 (0.012) | 0.236 (0.060) |
| 6–12 Apr | 3,072 | 0.065 (0.012) | 0.262 (0.068) |
| 13–19 Apr | 16,331 | 0.046 (0.004) | 0.307 (0.033) |
| 20–26 Apr | 14,913 | 0.030 (0.003) | 0.322 (0.035) |
| 27 Apr–3 May | 12,062 | 0.054 (0.005) | 0.284 (0.040) |
| 4–10 May | 6,517 | 0.071 (0.009) | 0.237 (0.057) |
| 11–17 May | 7,324 | 0.078 (0.009) | 0.234 (0.044) |
| 18–24 May | 3,520 | 0.109 (0.015) | 0.206 (0.046) |
| 25–31 May | 1,448 | 0.066 (0.018) | 0.155 (0.071) |

Table 12. Detection probability estimates at Little Goose Dam, Lower Monumental Dam, and McNary Dam for Snake River juvenile steelhead in 2020. Daily groups of hatchery fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Standard errors in parentheses. Data for wild steelhead were insufficient for separate estimates.

| Detection probability estimates for groups from Lower Granite Dam | | | | |
|---|---|---|---|---|
| Date at Lower Granite Dam | Number released | Little Goose Dam | Lower Monumental Dam | McNary Dam |
| | Hatchery steelhead | | | |
| 30 Mar–5 Apr | 2,491 | 0.057 (0.012) | 0.008 (0.005) | 0.047 (0.011) |
| 6–12 Apr | 3,048 | 0.147 (0.016) | 0.021 (0.007) | 0.036 (0.008) |
| 13–19 Apr | 16,046 | 0.109 (0.006) | 0.015 (0.003) | 0.022 (0.002) |
| 20–26 Apr | 14,440 | 0.056 (0.005) | 0.026 (0.004) | 0.012 (0.002) |
| 27 Apr–3 May | 11,076 | 0.066 (0.007) | 0.031 (0.006) | 0.013 (0.003) |
| 4–10 May | 6,111 | 0.078 (0.011) | 0.033 (0.008) | 0.031 (0.006) |
| 11–17 May | 6,400 | 0.061 (0.009) | 0.024 (0.007) | 0.014 (0.003) |
| 18–24 May | 2,913 | 0.100 (0.015) | 0.057 (0.013) | 0.024 (0.007) |
| 25–31 May | 1,322 | 0.087 (0.021) | 0.099 (0.029) | 0.009 (0.006) |

## 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 to estimate survival from Lower Monumental to Ice Harbor and from Ice Harbor to McNary Dam. In 2020, detections at Ice Harbor Dam were especially poor and lower than in most recent years (Table 13), and detection probabilities were equally low at Lower Monumental and McNary Dam.

For yearling Chinook salmon in 2020, mean estimated survival was 0.928 (SE 0.094) from Lower Monumental to Ice Harbor Dam and 0.922 (0.033) from Ice Harbor to McNary Dam. For steelhead, mean estimated survival through these reaches was 1.069 (0.077) and 0.789 (0.040), respectively (Table 13).

Table 13. Survival and detection probability estimates from Lower Monumental Dam to McNary Dam, including Ice Harbor Dam, for Snake River yearling Chinook salmon and juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly estimates. Weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

| | Estimated survival probability | | | |
|---|---|---|---|---|
| Date at Lower Granite Dam | Number released | Lower Monumental to Ice Harbor Dam | Ice Harbor to McNary Dam | Detection Probability at Ice Harbor Dam |
| | **Hatchery and wild yearling Chinook salmon** | | | |
| 30 Mar–5 Apr | 1,170 | 1.459 (0.696) | 1.109 (0.468) | 0.041 (0.013) |
| 6–12 Apr | 9,525 | 0.684 (0.228) | 0.920 (0.159) | 0.026 (0.004) |
| 13–19 Apr | 6,417 | 0.699 (0.266) | 0.907 (0.192) | 0.028 (0.005) |
| 20–26 Apr | 12,138 | 0.399 (0.195) | 0.965 (0.140) | 0.025 (0.003) |
| 27 Apr–3 May | 13,467 | 1.097 (0.223) | 0.961 (0.162) | 0.016 (0.003) |
| 4–10 May | 9,511 | 1.264 (0.479) | 0.601 (0.189) | 0.008 (0.002) |
| 11–17 May | 15,837 | 0.942 (0.166) | 0.865 (0.141) | 0.020 (0.003) |
| 18–24 May | 3,080 | 0.569 (0.190) | 0.999 (0.252) | 0.054 (0.010) |
| **Weighted mean** | | **0.928 (0.094)** | **0.922 (0.033)** | |
| | **Hatchery and wild steelhead** | | | |
| 30 Mar–5 Apr | 2,509 | 1.012 (0.595) | 0.732 (0.316) | 0.013 (0.005) |
| 6–12 Apr | 3,072 | 1.218 (0.487) | 0.766 (0.263) | 0.019 (0.006) |
| 13–19 Apr | 16,331 | 0.747 (0.141) | 0.738 (0.103) | 0.018 (0.002) |
| 20–26 Apr | 14,913 | 1.296 (0.281) | 0.693 (0.147) | 0.008 (0.002) |
| 27 Apr–3 May | 12,062 | 1.105 (0.246) | 0.967 (0.218) | 0.014 (0.002) |
| 4–10 May | 6,517 | 0.874 (0.265) | 0.707 (0.178) | 0.021 (0.004) |
| 11–17 May | 7,324 | 1.342 (0.282) | 0.996 (0.263) | 0.040 (0.005) |
| 18–24 May | 3,520 | 0.938 (0.212) | 0.739 (0.192) | 0.049 (0.008) |
| 25–31 May | 1,448 | 1.197 (0.384) | 1.044 (0.570) | 0.071 (0.016) |
| **Weighted mean** | | **1.069 (0.077)** | **0.789 (0.040)** | |

## Survival and Detection from Hatcheries and Smolt Traps

***Snake River Hatchery Release Groups*—**Survival estimates varied among stocks and among release sites for fish of the same hatchery stock (Appendix Tables B1-B3), as did estimated detection probabilities among detection sites (Appendix Tables B4-B6).

For yearling Chinook salmon, estimated survival to Lower Granite Dam ranged from 0.929 (SE 0.034) for Clearwater Hatchery fish released to Clear Creek in the Middle Fork Clearwater Basin to 0.443 (0.044) for Sawtooth Hatchery fish released to the Yankee Fork of the Salmon River (Appendix Table B1).

For steelhead, estimated survival to Lower Granite ranged from 0.866 (0.026) for Magic Valley Hatchery fish released to the Little Salmon River to 0.581 (0.052) for Dworshak Hatchery fish released to Lolo Creek on the Clearwater River (Appendix Table B2).

For sockeye salmon, only one group of hatchery-reared fish was released in 2020. Estimated survival to Lower Granite Dam was 0.640 (0.014) for Springfield Hatchery fish released in early May at Redfish Lake Creek Trap (Appendix Table B3).

***Snake River Smolt Trap Release Groups*—**For tagged wild and hatchery juvenile salmonids released from Snake River Basin smolt traps, estimated survival probability to Lower Granite Dam was generally inversely related to distance between the respective traps and the dam (Appendix Table B7). Estimated detection probabilities at dams other than Lower Granite Dam were substantially below average but were similar among release groups of the same species and rearing type from different traps (Appendix Table B8).

In most cases, estimated detection probabilities at Snake River dams were higher for wild Chinook salmon than for hatchery conspecifics released from the same location (e.g., Grande Ronde and Salmon River traps). Estimated detection probabilities were also higher for wild than hatchery steelhead at Lower Granite Dam, except for fish tagged at the Grande Ronde trap. These differences in detection probability could have been due to fish size (Zabel et al. 2005; Faulkner et al. 2019) but could also have been partly due to differences in migration timing. Detection rates at Little Goose, Lower Monumental, and McNary Dam were generally low for Chinook and steelhead of both rearing types.

***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 0.668 (SE 0.139) for Entiat Hatchery fish released from the hatchery to 0.157 (0.052) for Methow Hatchery fish released to Goatwall Pond.

For Upper Columbia River steelhead, estimated survival from release to Bonneville Dam ranged from 0.938 (0.392) for Wells Hatchery fish released from Methow Hatchery to 0.149 (0.028) for Chiwawa Hatchery fish released to the Chiwawa River.

For coho salmon, estimated survival from release to Bonneville Dam ranged from 0.578 (0.272) for Willard Hatchery fish released from Leavenworth National Fish Hatchery to 0.159 (0.045) for Yakima Hatchery fish released from Prosser 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 arrive 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 was calculated as length of the reach of interest (km) divided by travel time (d) and included the potential delays noted above. We calculated the 20th percentile, median, and 80th percentile travel time and migration rate for each group.

The true complete set of travel times for tagged fish within a release group would include travel time for both detected and non-detected fish. However, travel time cannot be determined for fish that traverse a reach of river without being detected at both ends. Therefore, travel time statistics were computed only for detected fish, which represent a subsample of the complete tagged release group.

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 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 14-19). For both yearling Chinook and steelhead, estimated migration rates were generally highest in the lower river sections. During early April 2020, travel times for both species were longer than in many recent years, though still about equal to the overall average for this period.

After mid-April, travel times for both Chinook and steelhead decreased substantially (Figure 2). In late April and May 2020, travel time for steelhead was very short, even compared to years with much higher flows during the same time of year. Travel time for Chinook during late April and all of May was shorter than in any other year on record.

For both species, the observed decrease in late April travel time appeared to coincide with increasing flow (Figure 3, Appendix Figure C1). Particularly short travel times for both species in late April and throughout May may be related to high levels of spill in 2020 (Appendix Figure C2) or to changes in spill patterns across spill bays. For both species, general decreases in travel time as the season progressed were also presumably related to increased levels of smolt readiness.

Table 14. Travel time statistics from Lower Granite Dam to Bonneville Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly statistics.

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

| Date at Lower Granite Dam | Lower Granite to Little Goose Dam | | | | Little Goose to Lower Monumental | | | | Lower Monumental to McNary Dam | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | 20% | Median | 80% | N | 20% | Median | 80% | N | 20% | Median | 80% |
| 30 Mar–5 Apr | 67 | 6.2 | 8.9 | 13.7 | 4 | 2.6 | 5.8 | 8.3 | 1 | 4.0 | 4.0 | 4.0 |
| 6–12 Apr | 379 | 7.0 | 10.2 | 13.2 | 3 | 4.9 | 6.1 | 6.4 | 2 | 4.1 | 4.2 | 4.4 |
| 13–19 Apr | 145 | 4.3 | 7.1 | 11.1 | 3 | 2.5 | 3.0 | 3.2 | 3 | 3.3 | 3.4 | 3.8 |
| 20–26 Apr | 220 | 2.2 | 3.1 | 4.9 | 1 | 1.6 | 1.6 | 1.6 | 0 | NA | NA | NA |
| 27 Apr–3 May | 585 | 2.1 | 3.0 | 4.4 | 13 | 1.4 | 1.7 | 2.2 | 14 | 3.1 | 3.7 | 4.0 |
| 4–10 May | 323 | 2.2 | 3.2 | 4.4 | 2 | 1.2 | 1.3 | 1.3 | 1 | 2.7 | 2.7 | 2.7 |
| 11–17 May | 1,113 | 1.5 | 2.2 | 3.1 | 31 | 1.2 | 1.6 | 1.9 | 8 | 2.5 | 2.9 | 3.1 |
| 18–24 May | 310 | 1.9 | 2.7 | 3.5 | 7 | 1.1 | 1.4 | 1.6 | 4 | 2.6 | 3.3 | 3.9 |
| 25–31 May | 55 | 0.9 | 1.9 | 3.0 | 2 | 1.0 | 1.0 | 1.0 | 0 | NA | NA | NA |

| 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 | 46 | 14.6 | 19.0 | 27.4 | 107 | 22.2 | 27.1 | 31.1 |
| 6–12 Apr | 358 | 14.7 | 20.4 | 25.3 | 937 | 21.8 | 24.9 | 28.2 |
| 13–19 Apr | 209 | 10.5 | 14.5 | 19.0 | 690 | 15.3 | 18.4 | 22.0 |
| 20–26 Apr | 536 | 6.7 | 8.3 | 10.5 | 1,508 | 10.3 | 11.8 | 14.2 |
| 27 Apr–3 May | 672 | 6.5 | 8.2 | 9.6 | 1,003 | 10.0 | 11.3 | 13.1 |
| 4–10 May | 245 | 6.4 | 7.5 | 9.4 | 568 | 8.7 | 10.1 | 11.9 |
| 11–17 May | 405 | 5.2 | 5.9 | 7.5 | 994 | 7.8 | 8.8 | 10.3 |
| 18–24 May | 125 | 6.7 | 7.6 | 9.3 | 242 | 9.4 | 10.5 | 11.8 |
| 25–31 May | 14 | 4.7 | 6.6 | 7.8 | 71 | 6.3 | 7.5 | 9.5 |

Table 15. Migration rate statistics from Lower Granite Dam to Bonneville Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly statistics.

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

| Date at Lower Granite Dam | Lower Granite to Little Goose Dam | | | | Little Goose to Lower Monumental | | | | Lower Monumental to McNary Dam | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | 20% | Median | 80% | N | 20% | Median | 80% | N | 20% | Median | 80% |
| 30 Mar–5 Apr | 67 | 4.4 | 6.8 | 9.7 | 4 | 5.5 | 8.0 | 17.6 | 1 | 30.0 | 30.0 | 30.0 |
| 6–12 Apr | 379 | 4.6 | 5.9 | 8.6 | 3 | 7.2 | 7.6 | 9.5 | 2 | 27.3 | 28.3 | 29.2 |
| 13–19 Apr | 145 | 5.4 | 8.4 | 13.8 | 3 | 14.2 | 15.3 | 18.6 | 3 | 31.0 | 35.4 | 36.3 |
| 20–26 Apr | 220 | 12.3 | 19.6 | 27.4 | 1 | 28.0 | 28.0 | 28.0 | 0 | NA | NA | NA |
| 27 Apr–3 May | 585 | 13.6 | 20.2 | 28.2 | 13 | 20.4 | 26.4 | 33.6 | 14 | 29.5 | 31.9 | 38.0 |
| 4–10 May | 323 | 13.6 | 18.9 | 27.5 | 2 | 35.9 | 36.5 | 37.4 | 1 | 43.4 | 43.4 | 43.4 |
| 11–17 May | 1,113 | 19.0 | 27.4 | 40.8 | 31 | 24.0 | 28.2 | 38.7 | 8 | 38.1 | 41.2 | 47.6 |
| 18–24 May | 310 | 17.3 | 22.3 | 31.2 | 7 | 28.0 | 33.1 | 41.4 | 4 | 30.4 | 36.0 | 44.9 |
| 25–31 May | 55 | 20.1 | 32.1 | 65.2 | 2 | 44.7 | 45.1 | 45.5 | 0 | NA | NA | NA |

| Date at Lower Granite Dam | Lower Granite to McNary Dam | | | | Lower Granite to Bonneville Dam | | | |
|---|---|---|---|---|---|---|---|---|
| | N | 20% | Median | 80% | N | 20% | Median | 80% |
| 23–29 Mar | 46 | 8.2 | 11.8 | 15.4 | 107 | 14.8 | 17.0 | 20.8 |
| 30 Mar–5 Apr | 358 | 8.9 | 11.0 | 15.3 | 937 | 16.3 | 18.5 | 21.2 |
| 6–12 Apr | 209 | 11.8 | 15.5 | 21.3 | 690 | 21.0 | 25.0 | 30.2 |
| 13–19 Apr | 536 | 21.4 | 27.0 | 33.4 | 1,508 | 32.4 | 39.2 | 44.8 |
| 20–26 Apr | 672 | 23.5 | 27.4 | 34.6 | 1,003 | 35.2 | 40.9 | 46.0 |
| 27 Apr–3 May | 245 | 23.9 | 30.0 | 35.2 | 568 | 38.8 | 45.5 | 52.7 |
| 4–10 May | 405 | 30.1 | 38.0 | 43.4 | 994 | 44.7 | 52.3 | 59.0 |
| 11–17 May | 125 | 24.2 | 29.5 | 33.7 | 242 | 39.0 | 44.0 | 49.1 |
| 18–24 May | 14 | 28.8 | 34.1 | 48.0 | 71 | 48.5 | 61.5 | 73.4 |
| 25–31 May | 46 | 8.2 | 11.8 | 15.4 | 107 | 14.8 | 17.0 | 20.8 |

Table 16. Travel time and migration statistics from McNary Dam to Bonneville Dam for Snake River yearling Chinook salmon in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly statistics.

| Date at Lower Granite Dam | Hatchery and wild yearling Chinook salmon from Lower Granite Dam | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | McNary to John Day Dam | | | | John Day to Bonneville Dam | | | | McNary to Bonneville Dam | | | |
| | N | 20% | Median | 80% | N | 20% | Median | 80% | N | 20% | Median | 80% |
| | **Travel time (d)** | | | | | | | | | | | |
| 30 Mar–5 Apr | 1 | 3.3 | 3.3 | 3.3 | 6 | 1.7 | 1.8 | 2.1 | 5 | 6.0 | 6.2 | 6.8 |
| 6–12 Apr | 13 | 2.5 | 3.2 | 4.2 | 48 | 1.7 | 1.9 | 2.2 | 48 | 4.4 | 4.8 | 5.5 |
| 13–19 Apr | 13 | 2.8 | 3.3 | 4.0 | 36 | 1.5 | 1.8 | 1.9 | 29 | 4.2 | 4.6 | 5.3 |
| 20–26 Apr | 20 | 2.7 | 3.1 | 3.5 | 51 | 1.6 | 1.7 | 2.1 | 77 | 4.0 | 4.3 | 5.0 |
| 27 Apr–3 May | 40 | 2.5 | 2.9 | 3.2 | 85 | 1.5 | 1.7 | 1.9 | 67 | 3.6 | 4.0 | 4.8 |
| 4–10 May | 21 | 2.0 | 2.4 | 2.8 | 62 | 1.4 | 1.5 | 1.8 | 19 | 3.3 | 3.6 | 3.9 |
| 11–17 May | 43 | 1.8 | 2.0 | 2.3 | 93 | 1.2 | 1.4 | 1.6 | 39 | 3.1 | 3.2 | 3.6 |
| 18–24 May | 9 | 1.8 | 2.0 | 2.3 | 21 | 1.1 | 1.3 | 1.6 | 14 | 2.9 | 3.2 | 3.4 |
| 25–31 May | 1 | 2.1 | 2.1 | 2.1 | 2 | 1.2 | 1.2 | 1.2 | 0 | NA | NA | NA |
| | **Migration rate (km/d)** | | | | | | | | | | | |
| 30 Mar–5 Apr | 1 | 37.5 | 37.5 | 37.5 | 6 | 52.6 | 63.5 | 66.1 | 5 | 35.0 | 37.9 | 39.0 |
| 6–12 Apr | 13 | 29.4 | 37.8 | 50.0 | 48 | 52.1 | 58.5 | 66.5 | 48 | 42.7 | 48.7 | 53.8 |
| 13–19 Apr | 13 | 31.0 | 37.4 | 43.2 | 36 | 58.2 | 63.8 | 75.3 | 29 | 44.4 | 51.5 | 56.3 |
| 20–26 Apr | 20 | 35.1 | 39.2 | 46.2 | 51 | 53.6 | 66.9 | 72.4 | 77 | 47.5 | 54.9 | 59.0 |
| 27 Apr–3 May | 40 | 38.1 | 42.1 | 49.8 | 85 | 59.2 | 65.7 | 75.8 | 67 | 49.7 | 59.0 | 65.2 |
| 4–10 May | 21 | 44.1 | 50.4 | 61.2 | 62 | 63.8 | 73.4 | 79.6 | 19 | 61.1 | 64.8 | 71.1 |
| 11–17 May | 43 | 53.7 | 60.0 | 69.9 | 93 | 68.5 | 80.7 | 92.6 | 39 | 65.9 | 74.0 | 77.1 |
| 18–24 May | 9 | 53.2 | 60.6 | 68.0 | 21 | 69.8 | 84.3 | 101.8 | 14 | 69.8 | 74.2 | 82.2 |
| 25–31 May | 1 | 57.2 | 57.2 | 57.2 | 2 | 91.1 | 91.1 | 91.1 | 0 | NA | NA | NA |

Table 17. Travel time statistics from Lower Granite Dam to Bonneville Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly statistics.

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

| Date at Lower Granite Dam | Lower Granite to Little Goose Dam | | | | Little Goose to Lower Monumental | | | | Lower Monumental to McNary Dam | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | 20% | Median | 80% | N | 20% | Median | 80% | N | 20% | Median | 80% |
| 30 Mar–5 Apr | 175 | 3.0 | 4.0 | 5.5 | 0 | NA | NA | NA | 1 | 5.2 | 5.2 | 5.2 |
| 6–12 Apr | 425 | 2.1 | 3.0 | 4.5 | 4 | 5.0 | 6.3 | 16.6 | 1 | 5.9 | 5.9 | 5.9 |
| 13–19 Apr | 1,656 | 2.2 | 3.2 | 4.2 | 26 | 2.2 | 2.9 | 4.8 | 4 | 3.7 | 4.3 | 5.2 |
| 20–26 Apr | 846 | 1.4 | 2.3 | 3.4 | 10 | 2.1 | 3.0 | 3.7 | 1 | 2.6 | 2.6 | 2.6 |
| 27 Apr–3 May | 920 | 1.0 | 1.2 | 1.8 | 7 | 1.7 | 2.0 | 2.5 | 4 | 2.9 | 3.6 | 4.3 |
| 4–10 May | 340 | 1.2 | 1.3 | 2.1 | 9 | 1.5 | 1.6 | 1.8 | 2 | 3.0 | 3.4 | 3.9 |
| 11–17 May | 464 | 0.9 | 1.2 | 1.4 | 6 | 1.0 | 1.5 | 2.0 | 1 | 1.9 | 1.9 | 1.9 |
| 18–24 May | 409 | 0.9 | 1.1 | 1.4 | 5 | 1.3 | 1.5 | 2.1 | 3 | 1.8 | 2.0 | 2.3 |
| 25–31 May | 109 | 0.8 | 0.9 | 1.2 | 4 | 2.1 | 2.8 | 2.9 | 0 | NA | NA | NA |
| 1–7 Jun | 83 | 0.8 | 0.9 | 1.2 | 1 | 1.9 | 1.9 | 1.9 | 0 | NA | NA | NA |

| | Lower Granite to McNary Dam | | | | Lower Granite to Bonneville Dam | | | |
|---|---|---|---|---|---|---|---|---|
| | N | 20% | Median | 80% | N | 20% | Median | 80% |
| 30 Mar–5 Apr | 103 | 9.6 | 11.8 | 14.5 | 291 | 15.6 | 17.5 | 20.5 |
| 6–12 Apr | 101 | 10.3 | 12.2 | 14.5 | 413 | 14.6 | 16.5 | 19.6 |
| 13–19 Apr | 241 | 7.9 | 9.3 | 10.9 | 3,003 | 11.6 | 12.9 | 15.2 |
| 20–26 Apr | 139 | 6.4 | 7.7 | 10.2 | 3,086 | 9.7 | 10.8 | 12.6 |
| 27 Apr–3 May | 146 | 5.2 | 6.0 | 7.4 | 1,790 | 8.7 | 9.5 | 10.6 |
| 4–10 May | 126 | 4.9 | 5.6 | 6.5 | 697 | 7.8 | 8.7 | 9.7 |
| 11–17 May | 90 | 4.0 | 4.4 | 5.3 | 771 | 7.0 | 7.7 | 8.7 |
| 18–24 May | 50 | 3.9 | 4.6 | 5.6 | 362 | 6.8 | 7.5 | 8.5 |
| 25–31 May | 14 | 3.5 | 4.0 | 4.2 | 159 | 5.6 | 6.4 | 6.8 |
| 1–7 Jun | 7 | 3.5 | 4.2 | 5.2 | 54 | 6.3 | 6.8 | 8.4 |

Table 18. Migration rate statistics from Lower Granite Dam to Bonneville Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly statistics.

**Migration rate of juvenile steelhead from Lower Granite Dam (km/d)**

| Date at Lower Granite Dam | Lower Granite to Little Goose Dam | | | | Little Goose to Lower Monumental | | | | Lower Monumental to McNary Dam | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | 20% | Median | 80% | N | 20% | Median | 80% | N | 20% | Median | 80% |
| 30 Mar–5 Apr | 175 | 10.8 | 14.9 | 20.1 | 0 | NA | NA | NA | 1 | 22.8 | 22.8 | 22.8 |
| 6–12 Apr | 425 | 13.2 | 19.7 | 28.8 | 4 | 2.8 | 7.3 | 9.3 | 1 | 20.3 | 20.3 | 20.3 |
| 13–19 Apr | 1,656 | 14.3 | 19.0 | 27.1 | 26 | 9.6 | 15.9 | 20.7 | 4 | 23.0 | 27.4 | 32.2 |
| 20–26 Apr | 846 | 17.7 | 26.3 | 43.2 | 10 | 12.4 | 15.5 | 21.5 | 1 | 45.8 | 45.8 | 45.8 |
| 27 Apr–3 May | 920 | 33.1 | 50.4 | 61.2 | 7 | 18.5 | 22.5 | 26.4 | 4 | 27.5 | 33.1 | 40.9 |
| 4–10 May | 340 | 28.2 | 47.6 | 51.7 | 9 | 26.0 | 28.2 | 30.5 | 2 | 30.5 | 34.6 | 40.1 |
| 11–17 May | 464 | 42.9 | 51.7 | 63.8 | 6 | 22.5 | 31.3 | 44.2 | 1 | 63.6 | 63.6 | 63.6 |
| 18–24 May | 409 | 42.3 | 55.6 | 67.4 | 5 | 21.8 | 30.5 | 35.9 | 3 | 52.2 | 58.9 | 65.7 |
| 25–31 May | 109 | 49.2 | 63.8 | 70.6 | 4 | 16.0 | 16.4 | 21.8 | 0 | NA | NA | NA |
| 1–7 Jun | 83 | 50.8 | 66.7 | 74.1 | 1 | 24.7 | 24.7 | 24.7 | 0 | NA | NA | NA |

| 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 | 103 | 15.5 | 19.1 | 23.5 | 291 | 22.5 | 26.3 | 29.6 |
| 6–12 Apr | 101 | 15.5 | 18.4 | 21.8 | 413 | 23.5 | 27.9 | 31.6 |
| 13–19 Apr | 241 | 20.5 | 24.2 | 28.6 | 3,003 | 30.3 | 35.8 | 39.6 |
| 20–26 Apr | 139 | 22.1 | 29.1 | 35.1 | 3,086 | 36.5 | 42.6 | 47.7 |
| 27 Apr–3 May | 146 | 30.3 | 37.6 | 43.2 | 1,790 | 43.5 | 48.6 | 53.0 |
| 4–10 May | 126 | 34.7 | 40.2 | 45.7 | 697 | 47.4 | 53.0 | 59.1 |
| 11–17 May | 90 | 42.6 | 50.8 | 56.8 | 771 | 53.3 | 59.8 | 65.4 |
| 18–24 May | 50 | 40.1 | 49.0 | 58.0 | 362 | 54.4 | 61.2 | 67.8 |
| 25–31 May | 14 | 53.3 | 56.4 | 65.2 | 159 | 67.4 | 71.9 | 82.9 |
| 1–7 Jun | 7 | 42.9 | 53.1 | 63.7 | 54 | 54.6 | 67.7 | 72.9 |

Table 19. Travel time and migration statistics from McNary Dam to Bonneville Dam for Snake River juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly statistics.

| | Hatchery and wild juvenile steelhead from Lower Granite Dam | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date at Lower Granite Dam | McNary to John Day Dam | | | | John Day to Bonneville Dam | | | | McNary to Bonneville Dam | | | |
| | N | 20% | Median | 80% | N | 20% | Median | 80% | N | 20% | Median | 80% |
| | **Travel time (d)** | | | | | | | | | | | |
| 30 Mar–5 Apr | 4 | 3.6 | 3.9 | 4.3 | 16 | 1.8 | 2.1 | 2.1 | 13 | 5.2 | 5.8 | 6.1 |
| 6–12 Apr | 1 | 4.8 | 4.8 | 4.8 | 27 | 1.7 | 1.9 | 2.1 | 16 | 4.2 | 4.7 | 5.4 |
| 13–19 Apr | 17 | 2.9 | 3.1 | 3.2 | 133 | 1.5 | 1.6 | 1.9 | 63 | 4.0 | 4.3 | 4.7 |
| 20–26 Apr | 8 | 2.6 | 3.0 | 5.0 | 92 | 1.4 | 1.6 | 1.8 | 31 | 3.8 | 4.0 | 4.5 |
| 27 Apr–3 May | 7 | 2.3 | 2.4 | 2.8 | 99 | 1.3 | 1.5 | 1.8 | 23 | 3.6 | 4.0 | 4.5 |
| 4–10 May | 7 | 2.2 | 2.3 | 2.8 | 47 | 1.2 | 1.4 | 1.5 | 22 | 3.2 | 3.4 | 3.7 |
| 11–17 May | 7 | 2.1 | 2.2 | 2.4 | 57 | 1.2 | 1.3 | 1.5 | 8 | 2.9 | 3.0 | 3.1 |
| 18–24 May | 10 | 1.9 | 1.9 | 2.4 | 39 | 1.2 | 1.3 | 1.4 | 9 | 3.2 | 3.4 | 3.5 |
| 25–31 May | 2 | 1.8 | 2.2 | 2.6 | 10 | 1.1 | 1.2 | 1.2 | 2 | 2.7 | 2.7 | 2.8 |
| | **Migration rate (km/d)** | | | | | | | | | | | |
| 30 Mar–5 Apr | 4 | 28.4 | 31.2 | 33.9 | 16 | 53.3 | 54.9 | 64.2 | 13 | 38.5 | 41.0 | 45.8 |
| 6–12 Apr | 1 | 25.4 | 25.4 | 25.4 | 27 | 53.3 | 60.4 | 66.5 | 16 | 43.9 | 50.4 | 55.9 |
| 13–19 Apr | 17 | 38.8 | 40.1 | 43.0 | 133 | 60.1 | 68.5 | 77.4 | 63 | 49.8 | 54.5 | 59.4 |
| 20–26 Apr | 8 | 24.5 | 40.3 | 47.7 | 92 | 62.4 | 71.1 | 80.7 | 31 | 52.8 | 58.9 | 62.1 |
| 27 Apr–3 May | 7 | 43.9 | 51.0 | 54.2 | 99 | 62.1 | 75.3 | 85.0 | 23 | 53.0 | 59.4 | 64.7 |
| 4–10 May | 7 | 43.6 | 53.0 | 56.2 | 47 | 73.4 | 81.3 | 90.4 | 22 | 63.6 | 69.2 | 74.7 |
| 11–17 May | 7 | 51.7 | 55.2 | 58.3 | 57 | 73.4 | 86.3 | 95.8 | 8 | 74.9 | 78.1 | 82.5 |
| 18–24 May | 10 | 52.3 | 64.7 | 66.1 | 39 | 82.5 | 89.0 | 95.8 | 9 | 66.7 | 69.4 | 74.4 |
| 25–31 May | 2 | 46.8 | 55.4 | 68.3 | 10 | 91.1 | 96.6 | 103.7 | 2 | 85.2 | 87.1 | 88.7 |

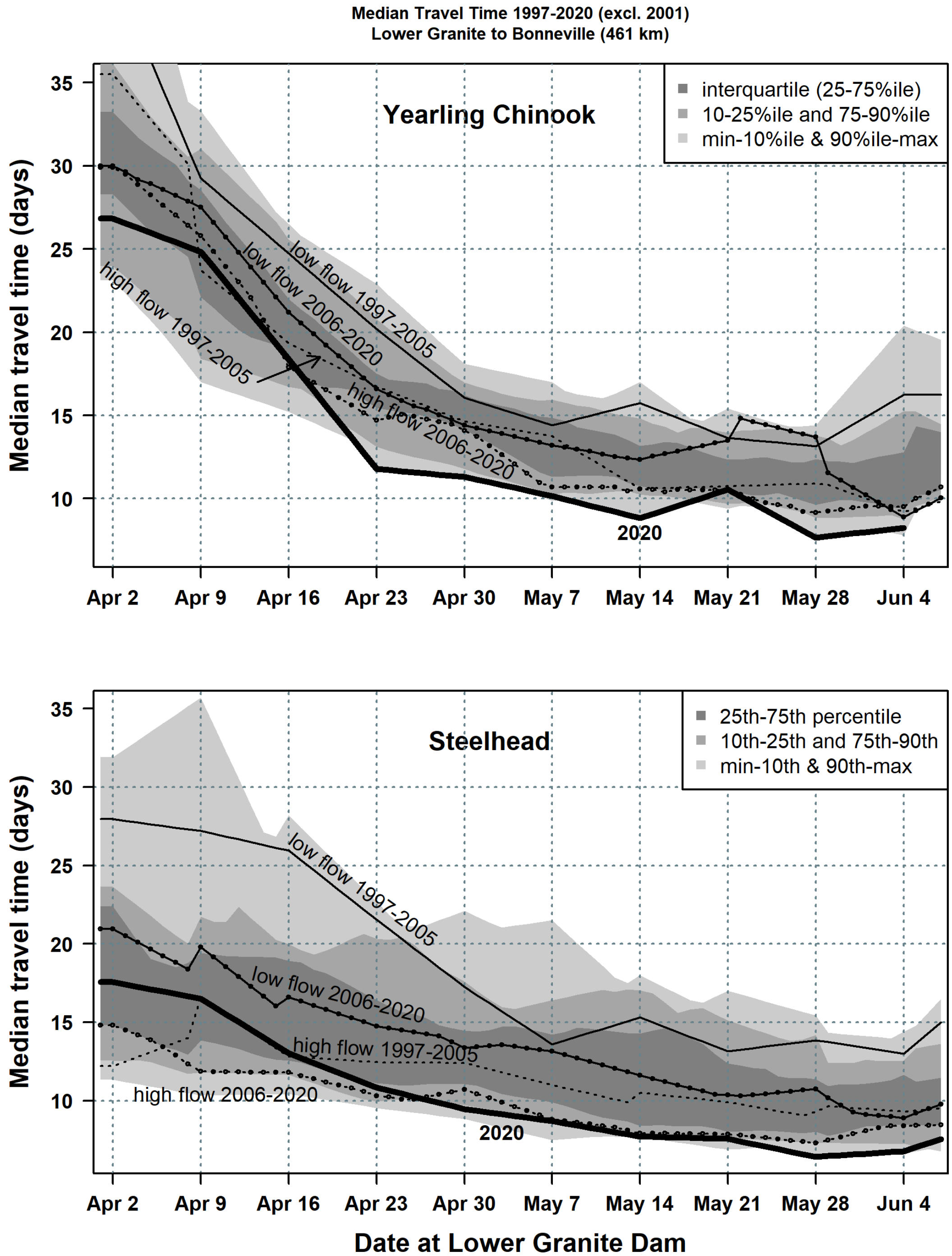


Figure 2. Median travel time (d) from Lower Granite to Bonneville Dam (461 km) vs. date passing Lower Granite Dam for yearling Chinook salmon and juvenile steelhead. Shaded regions show daily quantiles during 1997-2020 (excluding 2001). Lines show daily medians from selected subsets of years: low-flow years during the former (2004-2005) and present spill regimes (2007, 2010, 2013, and 2015); high-flow years during the former (1997 and 2006) and present spill regimes (2011, 2012, 2017, 2018, and 2019).

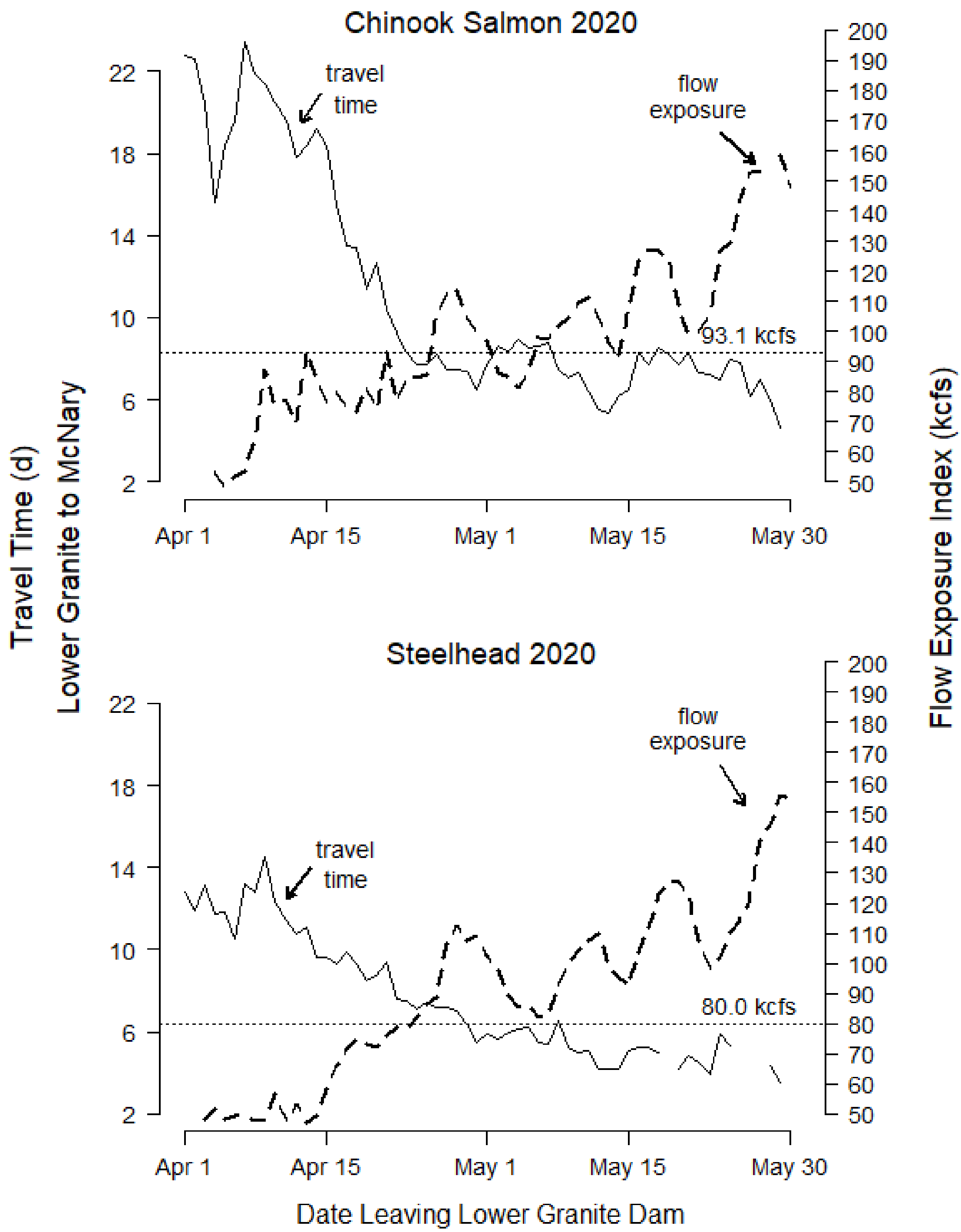


Figure 3. Median travel time (d) from Lower Granite to McNary Dam and index of flow exposure at Lower Monumental Dam (kcfs) for daily groups of PIT-tagged yearling Chinook salmon and juvenile steelhead during 2020. Dashed horizontal lines represent the mean flow exposure index for the year weighted by the number of PIT-tagged fish in each daily group.

# Proportion Transported of Spring Migrants

## Methods

To estimate the proportion of non-tagged fish that were transported, we incorporated three estimates:

1. The total number of non-tagged fish passing Lower Granite Dam each day
2. Travel time distributions to and probabilities of entering juvenile bypass systems at Little Goose and Lower Monumental Dam
3. Proportions of fish collected each day that were transported from each of the three dams

The process for estimating the proportion transported for a particular stock is detailed step-by-step below, including data sources, calculations, and elaboration regarding assumptions and other key underlying concepts.

1. Acquire Lower Granite Dam smolt report from the Smolt Monitoring Program (FPC 2020a). Extract daily "collection counts," which estimate the number of fish, tagged and untagged, that entered the juvenile bypass system each day.

2. Acquire smolt transportation reports for Lower Granite, Little Goose, and Lower Monumental Dams from the Smolt Monitoring Program (FPC 2020b). For each day at each dam, calculate the proportion of collected smolts that were transported.

3. Use PIT-tag 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).

   At Lower Granite Dam, two passage routes are now monitored for PIT-tagged fish: the juvenile bypass system and the spillway detection system.[3] These calculations use only juvenile bypass system detections. Because detection efficiency in the juvenile bypass system is nearly 100% (i.e., almost every tagged fish that enters is detected at least once in the system), we assume that the estimated daily detection probability estimates are equivalent to the probability of entering the system.

4. For each day, divide the collection count (step 1) by the estimated probability of entering the juvenile bypass system (step 3) to get an estimate of the total number of fish (tagged and untagged) that passed Lower Granite Dam on that day. Subtracting

[3] In the PTAGIS database, the juvenile bypass system is designated as site GRJ and the spillway detection system is site GRS.

the collection count from the estimated total number passing gives an estimate of the number of fish that passed via routes other than the juvenile bypass system, and thus were not subject to transportation.

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

    5a. For each daily group of PIT-tagged fish detected in the juvenile bypass system at Lower Granite Dam and directed to the tailrace to continue in-river migration, tabulate the number that were next detected at Little Goose Dam (i.e. next entered a juvenile bypass system) and the number that passed Little Goose undetected and next entered a juvenile bypass at Lower Monumental Dam.

    5b. Translate these counts into Lower Granite *equivalents*. An equivalent is a count at a downstream dam that is adjusted upward to account for mortality that occurred between release and that downstream site (i.e., the number of fish that had to have left Lower Granite Dam in order to realize the downstream counts at Little Goose and Lower Monumental Dam).

    5c. Assume that for the group of untagged fish arriving at Lower Granite Dam on a given day, the proportion of Lower Granite equivalents first collected at Lower Granite, Little Goose, and Lower Monumental is the same as that of the group of PIT-tagged fish that arrived at Lower Granite on that day. (The number of tagged fish that arrived at Lower Granite but were not detected in the juvenile bypass system is estimated using detection counts and the probability estimates from step 3.)

6. 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 at each dam is almost always nearly 100% (see step 2). 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 of the group that arrive at each downstream dam after transportation has started there. Travel-time distributions change throughout the season. For example, fish that arrive earlier at Lower Granite Dam tend to take longer to get to the downstream dams.

To estimate downstream arrival distributions for a daily group of untagged 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.

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

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

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

## Results

In 2020, collection for transportation began on 24 April at Lower Granite and Little Goose Dams and on 23 April at Lower Monumental Dam. At each of these dams, the first barge departed on 24 April. Before these dates, smolts collected at Snake River dams were bypassed to the tailrace of the dam.

Estimated percentages of non-tagged yearling Chinook salmon transported during the entire 2020 season were 18.8% for wild and 12.5% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 20.5% for wild and 11.7% for hatchery smolts.

These estimates represent 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 2020 was far lower than in 2018 or 2019, despite a similar start date for transportation in all 3 years (Figure 4; Table 20).

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

Starting in 2014, transportation has begun simultaneously at all three collector dams. This schedule was followed in 2020, with the exception that some fish were collected for transportation at Lower Monumental Dam one day before the other dams started collection.

The run in 2020 was not particularly early; only a modest proportion of smolts had passed the collector dams before transportation began. We estimate that 25.5% of wild and 22.1% of hatchery Chinook salmon, and 10.6% of wild and 37.3% of hatchery steelhead passed prior to the start of transportation on 24 April. These numbers are lower than in either 2018 or 2019, indicating that run timing was not a cause of the low transportation rate in 2020.

Of fish arriving at Lower Granite Dam during general transportation operations, we estimated that for yearling Chinook, approximately 24.0% of wild and 15.7% of hatchery smolts were transported. For steelhead, these estimates were 22.7% of wild and 17.2% of hatchery smolts. These estimates accounted for fish transported either from Lower Granite or from a downstream collector dam. The difference in proportion of transported fish between rear-types resulted from a difference in the probability of entering the collection system.

Collection rates in 2020 were less than one-half of those in 2018 or 2019. These low collection rates were a result of extremely high spill at collector dams during the 2020 migration season. The low overall transportation rate in 2020 was driven by these very low collection rates.

Our survival estimates are based largely on PIT-tagged fish that migrated in the river. These fish were either detected in juvenile bypass systems and returned to the river or they passed dams via turbines or spillways (including surface-passage structures). Detections of fish that were ultimately transported were used for survival information only to the point where they were removed from the river.

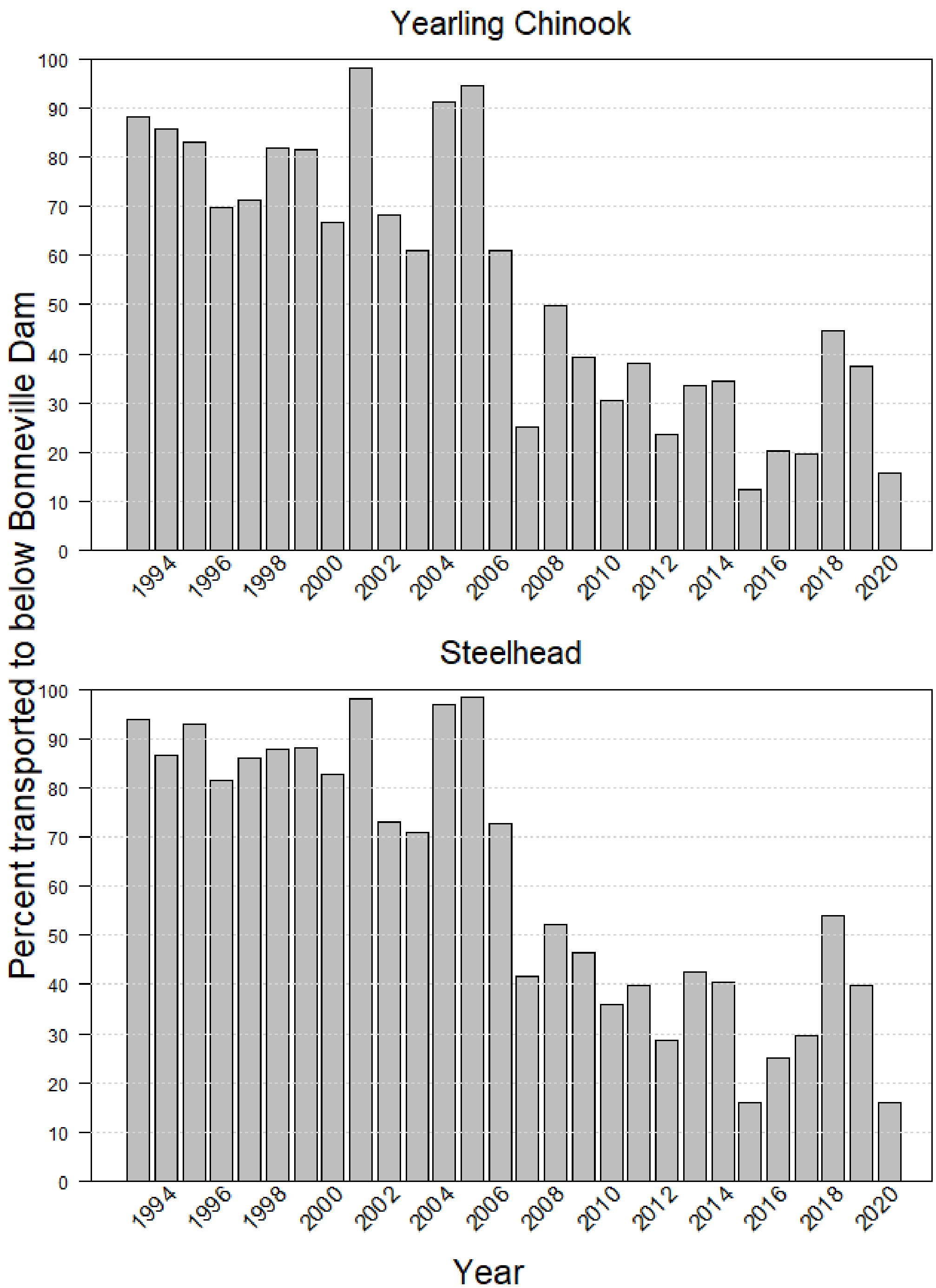


Figure 4. Annual estimated percentages of fish arriving at Lower Granite Dam that were transported and released downstream of Bonneville Dam, for Snake River yearling Chinook salmon and juvenile steelhead (mean of estimates for hatchery and wild), 1993-2020.

Table 20. Annual estimated percentages of fish arriving at Lower Granite Dam that were transported and released downstream of Bonneville Dam, for Snake River yearling Chinook salmon and juvenile steelhead (hatchery, wild, and mean), 1993-2020. Simple arithmetic means across all years, and for periods with similar transportation schedules (1993-2006 and 2007-2020), are given.

| | **Estimated percentages of fish transported, 1993-2020 (%)** | | | | | |
|---|---|---|---|---|---|---|
| | **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 |
| **Mean** | | | | | | |
| **1993-2020** | **53.1** | **56.0** | **54.6** | **58.8** | **63.8** | **61.3** |
| **1993-2006** | **76.7** | **80.9** | **78.8** | **86.0** | **86.7** | **86.4** |
| **2007-2020** | **29.6** | **31.1** | **30.3** | **31.6** | **40.9** | **36.3** |

# Comparisons Among Annual Estimates

## Comparison Among Years

We made two types of comparisons among annual survival estimates from 2020 and those from the previous 27 study years. First, for Snake River hatchery yearling Chinook salmon, we compared estimated survival to Lower Granite Dam with distance of the respective hatcheries from the dam.

Second, for Snake and Columbia River yearling Chinook, steelhead, and sockeye, we compared estimates of overall seasonal survival through specific reaches during 2020 with estimates of overall survival through those same reaches in all previous study years for which these data were available.

We also made comparisons of detection probability estimates in 2020 to those from previous study years. For all yearling Chinook salmon released upstream from Lower Granite Dam in 2020, we calculated annual mean detection probability at three major Snake River dams and three major lower Columbia River dams. We compared these detection estimates to annual mean detection estimates for the same stock at the same dams in the years 2000-2019.

### Snake River Stocks

***Yearling Chinook Salmon***—For yearling Chinook salmon, estimated survival to Lower Granite Dam in 2020 was above average for fish from most hatcheries, with below-average survival estimated only for fish from Lookingglass and Rapid River Hatchery (Table 21). Sawtooth Hatchery fish had the highest survival on record.

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 for hatchery yearling Chinook salmon, using mean estimated survival across years, in Figure 5 ($R^2 = 0.809$, $P = 0.006$).

For combined wild and hatchery yearling Chinook salmon in 2020, mean estimated survival was 0.766 (95% CI 0.731-0.801) from Lower Granite to McNary Dam and 0.733 (0.645-0.821) from McNary to Bonneville Dam (Tables 22-23; Figures 6-7).

Table 21. Survival probability estimates from release to Lower Granite Dam for groups of yearling Chinook salmon released from selected Snake River Basin hatcheries, 1993-2020. Distance to Lower Granite Dam is shown for each release site (km). Standard errors in parentheses. Simple arithmetic means across all years are given.

| | **Estimated survival of hatchery yearling Chinook salmon (SE)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Dworshak (116 km) | Kooskia (176 km) | Lookingglass* (209 km) | Rapid River (283 km) | McCall (457 km) | Pahsimeroi (630 km) | Sawtooth (747 km) | Mean |
| 1993 | 0.647 (0.028) | 0.689 (0.047) | 0.660 (0.025) | 0.670 (0.017) | 0.498 (0.017) | 0.456 (0.032) | 0.255 (0.023) | 0.554 (0.060) |
| 1994 | 0.778 (0.020) | 0.752 (0.053) | 0.685 (0.021) | 0.526 (0.024) | 0.554 (0.022) | 0.324 (0.028) | 0.209 (0.014) | 0.547 (0.081) |
| 1995 | 0.838 (0.034) | 0.786 (0.024) | 0.617 (0.015) | 0.726 (0.017) | 0.522 (0.011) | 0.316 (0.033) | 0.230 (0.015) | 0.576 (0.088) |
| 1996 | 0.776 (0.017) | 0.744 (0.010) | 0.567 (0.014) | 0.588 (0.007) | 0.531 (0.007) | NA | 0.121 (0.017) | 0.555 (0.096) |
| 1997 | 0.576 (0.017) | 0.449 (0.034) | 0.616 (0.017) | 0.382 (0.008) | 0.424 (0.008) | 0.500 (0.008) | 0.508 (0.037) | 0.494 (0.031) |
| 1998 | 0.836 (0.006) | 0.652 (0.024) | 0.682 (0.006) | 0.660 (0.004) | 0.585 (0.004) | 0.428 (0.021) | 0.601 (0.033) | 0.635 (0.046) |
| 1999 | 0.834 (0.011) | 0.653 (0.031) | 0.668 (0.009) | 0.746 (0.006) | 0.649 (0.008) | 0.584 (0.035) | 0.452 (0.019) | 0.655 (0.045) |
| 2000 | 0.841 (0.009) | 0.734 (0.027) | 0.688 (0.011) | 0.748 (0.007) | 0.689 (0.010) | 0.631 (0.062) | 0.546 (0.030) | 0.697 (0.035) |
| 2001 | 0.747 (0.002) | 0.577 (0.019) | 0.747 (0.003) | 0.689 (0.002) | 0.666 (0.002) | 0.621 (0.016) | 0.524 (0.023) | 0.653 (0.032) |
| 2002 | 0.819 (0.011) | 0.787 (0.036) | 0.667 (0.012) | 0.755 (0.003) | 0.592 (0.006) | 0.678 (0.053) | 0.387 (0.025) | 0.669 (0.055) |
| 2003 | 0.720 (0.008) | 0.560 (0.043) | 0.715 (0.012) | 0.691 (0.007) | 0.573 (0.006) | 0.721 (0.230) | 0.595 (0.149) | 0.654 (0.028) |
| 2004 | 0.821 (0.003) | 0.769 (0.017) | 0.613 (0.004) | 0.694 (0.003) | 0.561 (0.002) | 0.528 (0.017) | 0.547 (0.018) | 0.648 (0.044) |
| 2005 | 0.823 (0.003) | 0.702 (0.021) | 0.534 (0.004) | 0.735 (0.002) | 0.603 (0.003) | 0.218 (0.020) | 0.220 (0.020) | 0.548 (0.092) |
| 2006 | 0.853 (0.007) | 0.716 (0.041) | 0.639 (0.014) | 0.764 (0.004) | 0.634 (0.006) | 0.262 (0.024) | 0.651 (0.046) | 0.646 (0.071) |
| 2007 | 0.817 (0.007) | 0.654 (0.015) | 0.682 (0.010) | 0.748 (0.004) | 0.554 (0.007) | 0.530 (0.038) | 0.581 (0.015) | 0.652 (0.040) |
| 2008 | 0.737 (0.011) | 0.631 (0.015) | 0.694 (0.008) | 0.801 (0.004) | 0.578 (0.007) | 0.447 (0.011) | 0.336 (0.012) | 0.603 (0.062) |
| 2009 | 0.696 (0.007) | 0.633 (0.012) | 0.699 (0.009) | 0.728 (0.005) | 0.513 (0.005) | 0.510 (0.006) | 0.367 (0.007) | 0.592 (0.050) |
| 2010 | 0.898 (0.017) | 0.744 (0.030) | 0.682 (0.025) | 0.786 (0.019) | 0.566 (0.014) | 0.384 (0.023) | 0.427 (0.018) | 0.641 (0.072) |
| 2011 | 0.722 (0.006) | 0.729 (0.014) | 0.572 (0.009) | 0.766 (0.006) | 0.631 (0.007) | 0.498 (0.005) | 0.521 (0.007) | 0.634 (0.041) |
| 2012 | 0.743 (0.008) | 0.652 (0.013) | 0.689 (0.009) | 0.718 (0.014) | 0.571 (0.006) | 0.581 (0.006) | 0.473 (0.008) | 0.632 (0.036) |
| 2013 | 0.794 (0.015) | 0.609 (0.026) | 0.703 (0.019) | 0.735 (0.011) | 0.656 (0.011) | 0.606 (0.016) | 0.564 (0.011) | 0.667 (0.031) |

Table 21. Continued.

| | Estimated survival of hatchery yearling Chinook salmon (SE) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Dworshak (116 km) | Kooskia (176 km) | Lookingglass* (209 km) | Rapid River (283 km) | McCall (457 km) | Pahsimeroi (630 km) | Sawtooth (747 km) | Mean |
| 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) |
| **Mean** | **0.770 (0.013)** | **0.662 (0.016)** | **0.655 (0.009)** | **0.693 (0.019)** | **0.607 (0.014)** | **0.533 (0.032)** | **0.481 (0.030)** | **0.629 (0.011)** |

* Released at Imnaha River Weir.

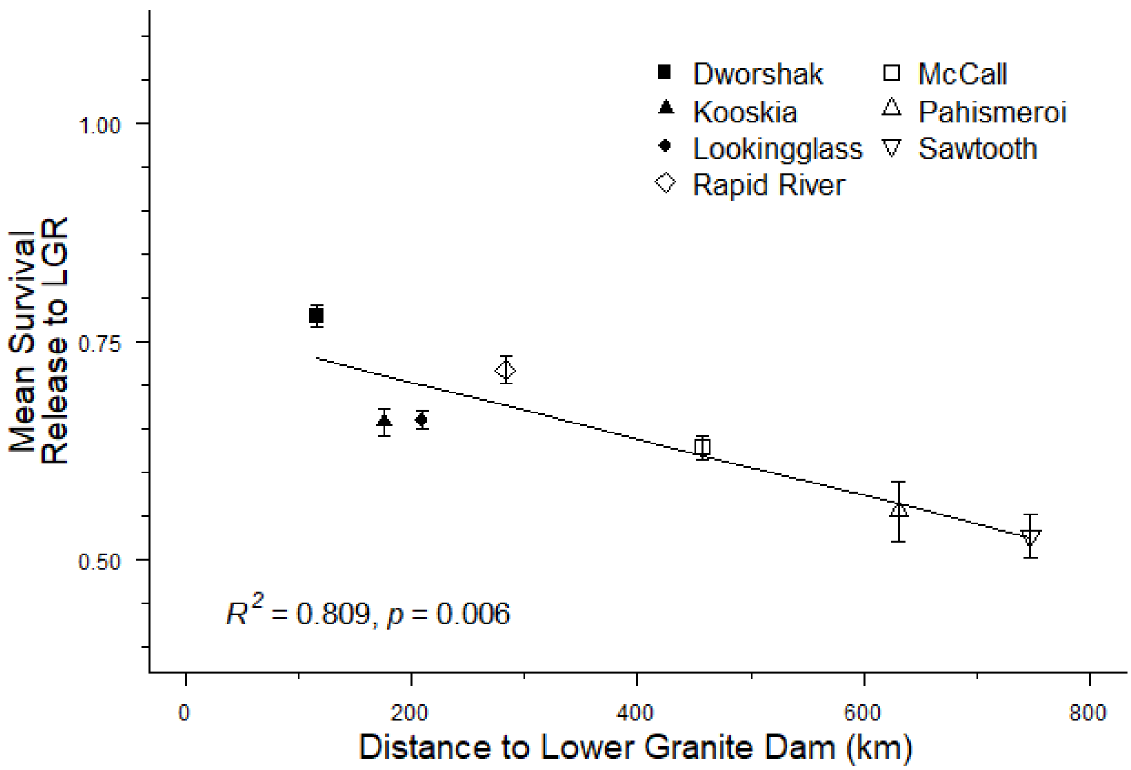


Figure 5. Mean estimated survival probability from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2020, vs. distance (km) to Lower Granite Dam. The coefficient of determination between survival and migration distance is also shown, along with the *P*-value for a test of the null hypothesis of zero correlation. Whiskers extend one standard error above and below point estimates.

Table 22. Annual survival probability estimates from the Snake River trap to Bonneville Dam for Snake River yearling Chinook salmon (combined hatchery and wild fish), 1993-2020. 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 22. 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* |
| **Mean** | **0.921 (0.010)** | **0.922 (0.007)** | **0.932 (0.012)** | **0.860 (0.011)** | **0.927 (0.006)** | **0.867 (0.018)** | **0.808 (0.022)** | **0.897 (0.012)** |

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

Table 23. 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), 1993–2020. 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) |
| 2013 | 0.845 (0.031) | 0.781 (0.016) | 0.796 (0.064) | 0.622 (0.052) | 0.525 (0.048) |

Table 23. 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 |
| 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) |
| **Mean** | **0.921 (0.010)** | **0.735 (0.012)** | **0.702 (0.019)** | **0.523 (0.018)** | **0.485 (0.018)** |

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

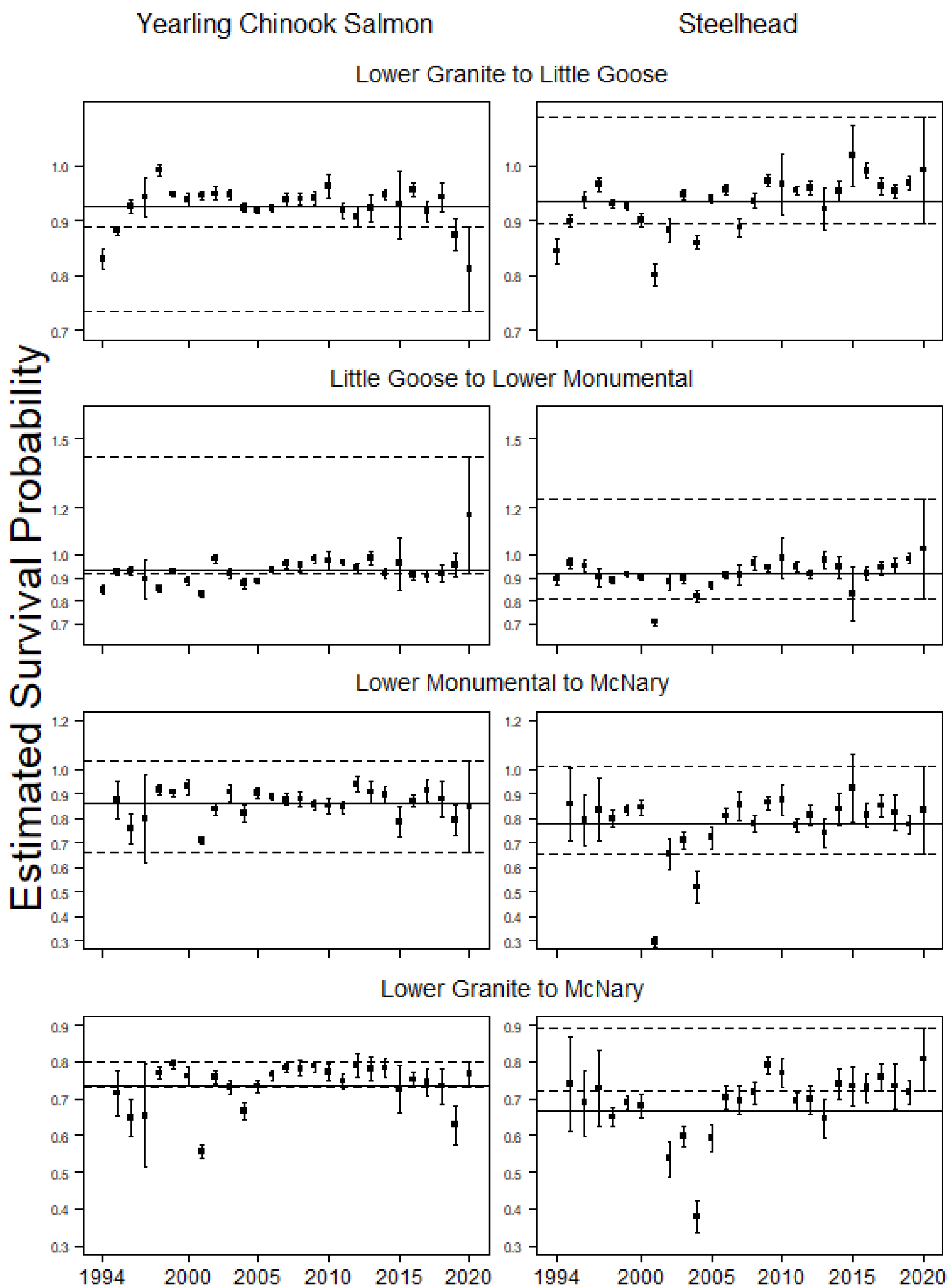


Figure 6. Annual survival probability estimates through Snake River reaches for Snake River yearling Chinook salmon and juvenile steelhead (combined hatchery and wild fish), 1993-2020. Whiskers represent 95% CIs. Dashed horizontal lines indicate 95% CI endpoints for 2020 estimates; solid horizontal lines indicate long-term means (1993-2020).

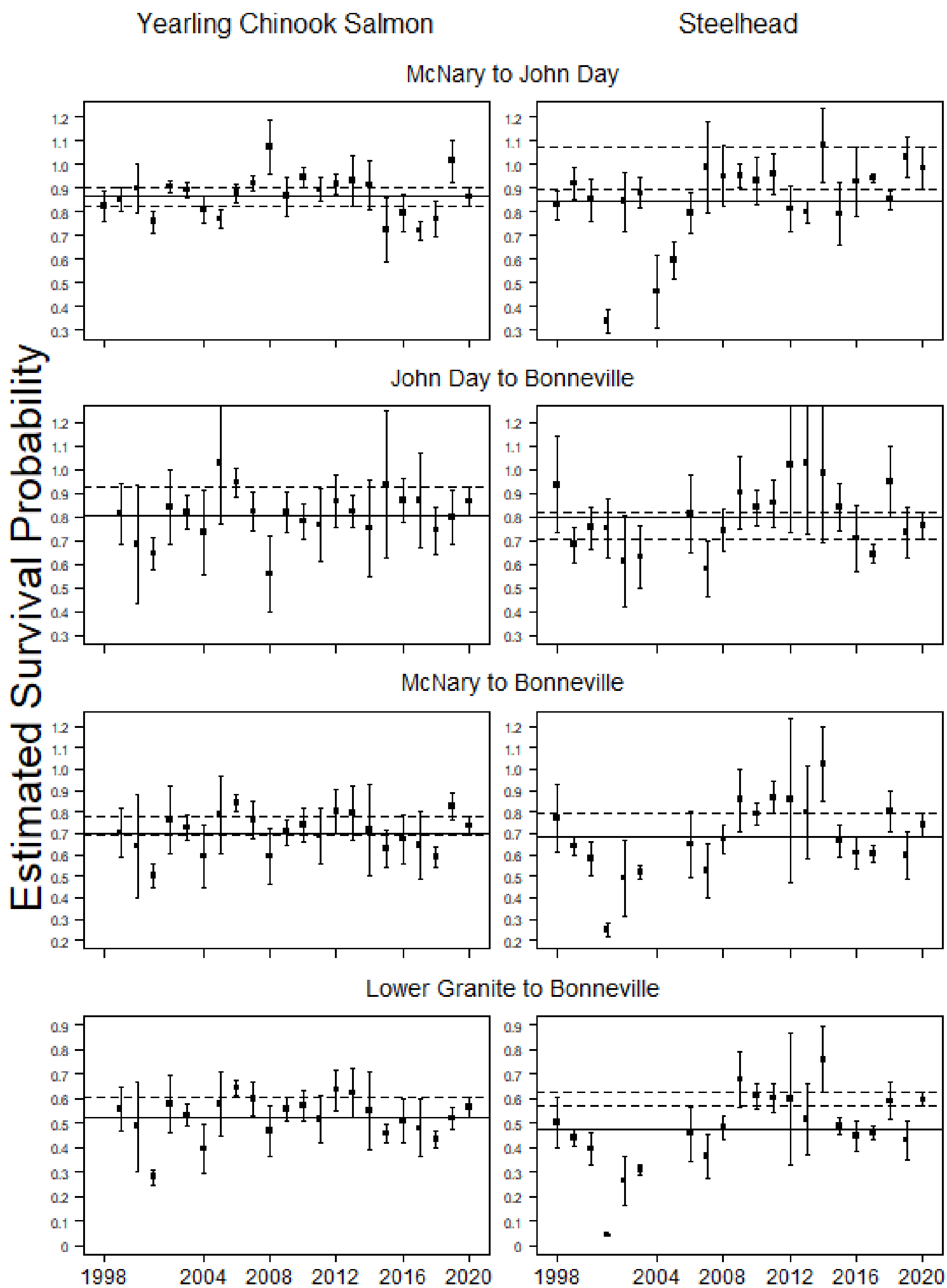


Figure 7. Annual survival probability estimates through Columbia River reaches and from Lower Granite to Bonneville Dam for Snake River yearling Chinook and juvenile steelhead (combined hatchery and wild fish), 1993-2020. Whiskers represent 95% CIs. Dashed horizontal lines indicate 95% CI endpoints for 2020 estimates; solid horizontal lines indicate long-term means (1993-2020).

The estimate from Lower Granite to McNary Dam was above the long-term mean of 0.735, but the difference was not statistically significant (*P* = 0.15). The estimate from McNary to Bonneville was also above the long-term mean of 0.702, but again, the difference was not significant (*P* = 0.53). The overall estimate from Lower Granite to Bonneville Dam was 0.563, which was above, but not significantly different from the long-term mean of 0.523 (*P* = 0.35).

For combined wild and hatchery yearling Chinook salmon from the Snake River trap to the tailrace of Bonneville Dam, mean estimated survival was 0.477 (95% CI 0.386-0.569; Table 23) in 2020. This estimate was close to the 24-year mean of 0.485, and the highest estimate since 2014. However, the difference between the estimate of 0.477 in 2020 and the estimate of 0.407 from 2019 was not significant (*P* = 0.23).

For wild yearling Chinook salmon in 2020, mean estimated survival was 0.674 (95% CI 0.531-0.817) from Lower Granite to McNary Dam. This estimate was below, but not significantly different from, the long-term average of 0.720 (Table 24; *P* = 0.54).

Due to the low number of wild Chinook smolts detected passing Lower Granite Dam, we did not have sufficient data to estimate survival for weekly groups from McNary to Bonneville Dam. Instead, we used a single pooled group of all wild fish released upstream from McNary Dam. Using this method, estimated survival from McNary to Bonneville Dam was 0.463 (0.179-0.747), which was well below the long-term average of 0.654 (Table 24). However, due to the uncertainty in this estimate, the difference was not significant (*P* = 0.20).

Estimated survival for wild Chinook from the Snake River trap to Bonneville Dam was 0.219 (0.062-0.378), far below and significantly different from the long-term average of 0.439 (*P* = 0.01). However, in 2020 many survival estimates for wild Snake River Chinook were less precise than those in previous years. Moreover, the estimate from the Snake River trap to Lower Granite Dam was based on a very small sample size which may not be representative of survival for the population as a whole.

Table 24. Annual survival probability estimates through the entire hydropower system, and through component river reaches for Snake River yearling Chinook salmon (wild fish only), 1993–2020. 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) |
| 2013 | 0.791 (0.045) | 0.778 (0.018) | 0.685 (0.092) | 0.553 (0.073) | 0.422 (0.062) |

Table 24. 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 |
| 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)* | 0.674 (0.073) | 0.463 (0.145) | 0.312 (0.103) | 0.219 (0.081) |
| **Mean** | **0.907 (0.013)** | **0.720 (0.013)** | **0.654 (0.032)** | **0.478 (0.026)** | **0.439 (0.026)** |

* Based on a sample size of just 69 tagged fish released.

***Steelhead***—For combined wild and hatchery steelhead, mean estimated survival from Lower Granite to McNary Dam was 0.807 (95% CI 0.723-0.891) in 2020, which was higher than the 2019 estimate of 0.713 with a moderately significant difference ($P$ = 0.052; Tables 25-26; Figures 6-7). This estimate was also higher than and significantly different from the long-term average of 0.668 ($P$ = 0.006).

Mean estimated survival from McNary to Bonneville Dam for Snake River steelhead was 0.738 (0.636-0.840) in 2020, which was higher than, but not significantly different from the estimate of 0.595 in 2019 ($P$ = 0.24). The 2020 estimate was also higher than the long-term average of 0.679, but again the difference was not significant ($P$ = 0.35).

Estimated survival from the Snake River trap to Bonneville Dam for combined wild and hatchery steelhead was 0.544 (0.476-0.612; Table 26), which was higher than both the estimate of 0.412 from 2019 and the long-term average of 0.461. However, the differences between these estimates were not significant, either for 2019 vs. 2020 ($P$ = 0.12) or for 2020 vs. the long-term average ($P$ = 0.09).

Due to the very low number of wild steelhead detected passing Lower Granite Dam in 2020, we were unable to estimate survival for these fish in any downstream reach. For wild steelhead released from the Snake River trap, survival from the trap to Lower Granite Dam was 0.802 (95% CI 0.588-1.016; Table 27). This estimate was the lowest on record for this reach, but very imprecise. Moreover, the estimate was based on a very small sample size that may not be representative of the population.

Table 25. Annual survival probability estimates from Snake River Trap to Bonneville Dam for Snake River juvenile steelhead (combined hatchery and wild fish), 1993–2020. 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 25. 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) | 0.643 (0.040) | 0.802 |
| 2018 | 0.983 (0.025) | 0.953 (0.007) | 0.950 (0.016) | 0.823 (0.036) | 0.907 | 0.851 (0.039) | 0.946 (0.150) | 0.973 |
| 2019 | 0.965 (0.027) | 0.968 (0.006) | 0.981 (0.011) | 0.774 (0.019) | 0.880 | 1.029 (0.084) | 0.734 (0.110) | 0.857 |
| 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* |
| **Mean** | **0.951 (0.010)** | **0.934 (0.009)** | **0.916 (0.012)** | **0.777 (0.025)** | **0.878 (0.016)** | **0.849 (0.036)** | **0.798 (0.029)** | **0.890 (0.016)** |

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

Table 26. Annual survival probability estimates through the entire hydropower system, and through component river reaches for Snake River juvenile steelhead (combined hatchery and wild fish), 1993–2020. Standard errors in parentheses. Simple arithmetic means across all available years are given.

| | Annual survival estimates for hatchery and wild steelhead | | | | |
|---|---|---|---|---|---|
| Year | Snake River Trap to Lower Granite Dam | Lower Granite to McNary Dam | McNary to Bonneville Dam | Lower Granite to Bonneville Dam | Trap to Bonneville Dam |
| 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) |
| 2013 | 0.973 (0.032) | 0.645 (0.026) | 0.798 (0.112) | 0.515 (0.075) | 0.501 (0.075) |

Table 26. Continued.

| Annual survival estimates for hatchery and wild steelhead | | | | | |
|---|---|---|---|---|---|
| Year | Snake River Trap to Lower Granite Dam | Lower Granite to McNary Dam | McNary to Bonneville Dam | Lower Granite to Bonneville Dam | Trap to Bonneville Dam |
| 2014 | 1.018 (0.028) | 0.740 (0.021) | 1.023 (0.088) | 0.757 (0.069) | 0.771 (0.073) |
| 2015 | 0.874 (0.046) | 0.733 (0.027) | 0.663 (0.039) | 0.486 (0.034) | 0.425 (0.037) |
| 2016 | 0.998 (0.016) | 0.730 (0.020) | 0.608 (0.040) | 0.444 (0.032) | 0.443 (0.032) |
| 2017 | NA | 0.759 (0.019) | 0.605 (0.037) | 0.459 (0.030) | NA |
| 2018 | 0.983 (0.025) | 0.733 (0.031) | 0.802 (0.098) | 0.588 (0.076) | 0.578 (0.076) |
| 2019 | 0.965 (0.027) | 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 [a] (0.052) | 0.595 (0.027) | 0.544 (0.035) |
| **Mean** | **0.951 (0.010)** | **0.668 (0.026)** | **0.679 (0.035)** | **0.476 (0.032)** | **0.461 (0.035)** |

a. The estimate for 2020 for the reach 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 (wild fish only), 1993–2020. Standard errors in parentheses. Simple arithmetic means across all available years are given.

| **Annual survival estimates for wild steelhead** | | | | | |
|---|---|---|---|---|---|
| Year | Snake River Trap to Lower Granite Dam | Lower Granite to McNary Dam | McNary to Bonneville Dam | Lower Granite to Bonneville Dam | Trap to Bonneville Dam |
| 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 |
| 2013 | 0.921 (0.057) | 0.621 (0.055) | 0.671 (0.142) | 0.417 (0.096) | 0.384 (0.091) |

Table 27. 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 |
| 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 [a] (0.109) | NA | NA | NA | NA |
| **Mean** | **0.945 (0.012)** | **0.657 (0.030)** | **0.624 (0.044)** | **0.432 (0.035)** | **0.418 (0.036)** |

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

***Sockeye Salmon***—For pooled groups of wild and hatchery Snake River sockeye salmon, estimated survival from Lower Granite to McNary Dam was 0.803 in 2020 (95% CI 0.613-1.052; Table 28). This estimate was slightly lower than the 2019 estimate of 0.836 but substantially higher than the long-term average of 0.644 (1996-2020). For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.439 (0.278-0.694) in 2020. This estimate was slightly above the long-term average of 0.409.

Table 28. Annual survival probability estimates for juvenile sockeye salmon (combined hatchery and wild fish) from Lower Granite Dam to Bonneville Dam for Snake River fish and from Rock Island Dam to Bonneville Dam for Columbia River fish, 1996-2020. 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) |
| **Mean** | **0.644 (0.033)** | **0.563 (0.063)** | **0.409 (0.047)** |

Table 28. Continued.

| | Annual survival estimates for upper Columbia River sockeye | | |
|---|---|---|---|
| | Rock Island to McNary Dam[a] | McNary to Bonneville Dam[b] | Rock Island to Bonneville Dam[a] |
| 1996 | NA | NA | NA |
| 1997 | 0.397 (0.119) | NA | NA |
| 1998 | 0.624 (0.058) | 1.655 (1.617) | 1.033 (1.003) |
| 1999 | 0.559 (0.029) | 0.683 (0.177) | 0.382 (0.097) |
| 2000 | 0.487 (0.114) | 0.894 (0.867) | 0.435 (0.410) |
| 2001 | 0.657 (0.117) | NA | NA |
| 2002 | 0.531 (0.044) | 0.286 (0.110) | 0.152 (0.057) |
| 2003 | NA | NA | NA |
| 2004 | 0.648 (0.114) | 1.246 (1.218) | 0.808 (0.777) |
| 2005 | 0.720 (0.140) | 0.226 (0.209) | 0.163 (0.147) |
| 2006 | 0.793 (0.062) | 0.767 (0.243) | 0.608 (0.187) |
| 2007 | 0.625 (0.046) | 0.642 (0.296) | 0.401 (0.183) |
| 2008 | 0.644 (0.094) | 0.679 (0.363) | 0.437 (0.225) |
| 2009 | 0.853 (0.076) | 0.958 (0.405) | 0.817 (0.338) |
| 2010 | 0.778 (0.063) | 0.627 (0.152) | 0.488 (0.111) |
| 2011 | 0.742 (0.088) | 0.691 (0.676) | 0.513 (0.498) |
| 2012 | 0.945 (0.085) | 0.840 (0.405) | 0.794 (0.376) |
| 2013 | 0.741 (0.068) | 0.658 (0.217) | 0.487 (0.155) |
| 2014 | 0.428 (0.056) | 0.565 (0.269) | 0.242 (0.111) |
| 2015 | 0.763 (0.182) | 0.446 (0.200) | 0.340 (0.130) |
| 2016 | 0.807 (0.082) | 0.545 (0.126) | 0.448 (0.144) |
| 2017 | 0.719 (0.113) | 0.611 (0.181) | 0.500 (0.332) |
| 2018 | 0.927 (0.118) | 0.560 (0.112) | 0.344 (0.124) |
| 2019 | 0.941 (0.125) | 0.701 (0.120) | 0.737 (0.191) |
| 2020 | 0.910 (0.218) | 0.288 (0.154) | 0.352 (0.325) |
| **Mean** | **0.706 (0.033)** | **0.694 (0.070)** | **0.499 (0.050)** |

[a] Estimates in these columns use all fish tagged at Rock Island Dam.

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

## Upper Columbia River Stocks

***Sockeye Salmon***—For Upper Columbia River sockeye salmon captured, tagged, and released to the tailrace of Rock Island Dam in 2020, estimated survival to McNary Dam was 0.910 (95% CI 0.573-1.446; Table 28). This (highly imprecise) estimate was higher than the long-term average of 0.706 and similar to the 2019 estimate of 0.941. Estimated survival of sockeye from Rock Island to Bonneville Dam in 2020 was 0.352 (0.076-1.640) This estimate was lower than both the long-term average of 0.499 and the 2019 estimate of 0.737. However, this estimate was also extremely imprecise.

***Yearling Chinook Salmon***—For pooled groups of yearling Chinook from Upper Columbia River hatcheries, estimated survival in 2020 from McNary to Bonneville Dam was 0.800 (95% CI 0.653-0.980), very close to the 1999-2020 average of 0.811 (Table 29).

***Steelhead***—For pooled groups of hatchery steelhead from Upper Columbia hatcheries, estimated survival from McNary to Bonneville Dam in 2020 was 0.756 (95% CI 0.596-0.959). This estimate was nearly equal to the long-term average of 0.763 (Table 29).

Table 29. Annual survival probability estimates from release to Bonneville Dam for upper Columbia River yearling Chinook salmon and juvenile steelhead (hatchery-origin only), 1999-2020. Multiple release sites were used in each year and were not the same in all years. Standard errors in parentheses. Simple arithmetic means across all available years are given.

| Annual survival estimates upper Columbia River | | | | |
|---|---|---|---|---|
| Year | Release site to McNary Dam | McNary to John Day Dam | John Day to Bonneville Dam | McNary to Bonneville Dam |
| | **Hatchery yearling Chinook salmon** | | | |
| 1999 | 0.572 (0.014) | 0.896 (0.044) | 0.795 (0.129) | 0.712 (0.113) |
| 2000 | 0.539 (0.025) | 0.781 (0.094) | NA | NA |
| 2001 | 0.428 (0.009) | 0.881 (0.062) | NA | NA |
| 2002 | 0.555 (0.003) | 0.870 (0.011) | 0.940 (0.048) | 0.817 (0.041) |
| 2003 | 0.625 (0.003) | 0.900 (0.008) | 0.977 (0.035) | 0.879 (0.031) |
| 2004 | 0.507 (0.005) | 0.812 (0.019) | 0.761 (0.049) | 0.618 (0.038) |
| 2005 | 0.545 (0.012) | 0.751 (0.042) | NA | NA |
| 2006 | 0.520 (0.011) | 0.954 (0.051) | 0.914 (0.211) | 0.871 (0.198) |
| 2007 | 0.584 (0.009) | 0.895 (0.028) | 0.816 (0.091) | 0.730 (0.080) |
| 2008 | 0.582 (0.019) | 1.200 (0.085) | 0.522 (0.114) | 0.626 (0.133) |
| 2009 | 0.523 (0.013) | 0.847 (0.044) | 1.056 (0.143) | 0.895 (0.116) |
| 2010 | 0.660 (0.014) | 0.924 (0.040) | 0.796 (0.046) | 0.735 (0.037) |
| 2011 | 0.534 (0.010) | 1.042 (0.047) | 0.612 (0.077) | 0.637 (0.077) |
| 2012 | 0.576 (0.012) | 0.836 (0.035) | 1.140 (0.142) | 0.953 (0.115) |
| 2013 | 0.555 (0.013) | 0.965 (0.050) | 1.095 (0.129) | 1.056 (0.117) |
| 2014 | 0.571 (0.013) | 0.974 (0.047) | 0.958 (0.122) | 0.933 (0.114) |
| 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) |
| **Mean** | **0.560 (0.011)** | **0.896 (0.020)** | **0.901 (0.037)** | **0.811 (0.028)** |
| | **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) |
| **Mean** | **0.414 (0.013)** | **0.891 (0.026)** | **0.863 (0.051)** | **0.763 (0.045)** |

## *Detection Probabilities*

Based on our estimates, the probability of detecting passing PIT-tagged juvenile Chinook salmon in 2020 was extremely low at most dams on the Snake and Columbia Rivers (Figure 8). Detection probability plummeted at Little Goose and Lower Monumental Dam in 2020 compared to the previous 4 years, reaching record lows at those dams.

Detection probabilities were also notably lower at McNary and John Day Dam in 2020, continuing a trend of declining detection over the past few years (Figure 8). Detection probability in 2020 was the lowest ever at McNary and the second lowest ever at John Day. Detection probability at Bonneville Dam has not trended in any consistent direction and in 2020 was near average. The stability of detection probability at Bonneville Dam was 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 the other dams, detection probability increased at Lower Granite Dam in 2020 relative to the past 3 years (Figure 8). This increase resulted from implementation of the new spillway detection system at that site. Detection in the bypass system at Lower Granite Dam was less than 10% in 2020. Had the bypass system been the only detection site at the dam, as in all previous years, this detection probability estimate would have been the lowest on record.

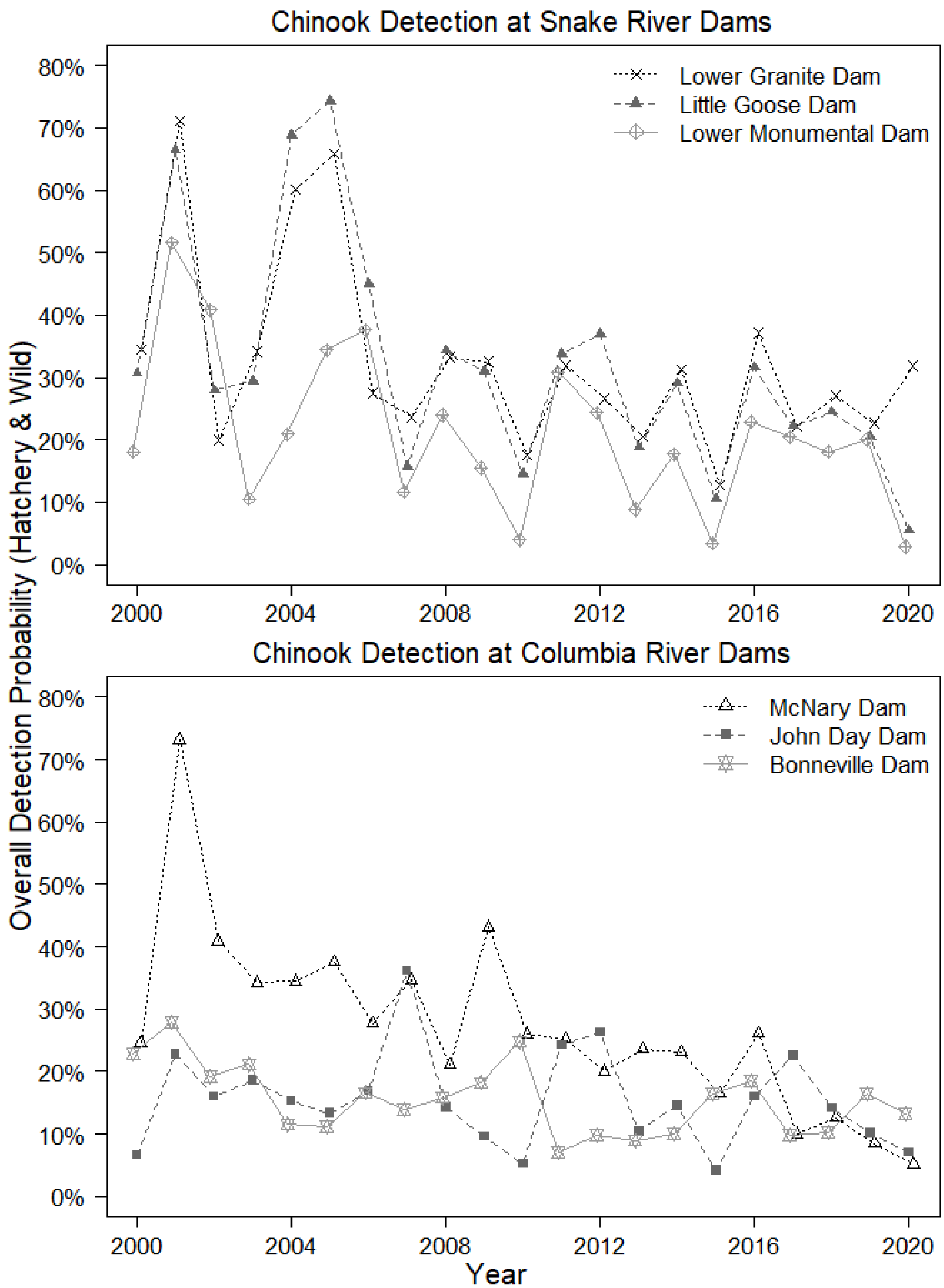


Figure 8. Annual mean detection probability across the migration season for Snake River yearling Chinook salmon at six major dams on the Snake and Columbia Rivers, 2000-2020. Ice Harbor Dam is excluded because of persistent very low juvenile detection probabilities.

## Comparison Between Snake and Columbia River Stocks

In 2020, estimated survival from McNary to Bonneville Dam was slightly lower for hatchery and wild yearling Chinook originating in the Snake River (0.733; 95% CI 0.645-0.821; Table 30) than for those originating in the Upper Columbia River Basin (0.779; 0.701-0.857), but the difference was not statistically significant ($P = 0.44$).

For hatchery and wild steelhead migrating between McNary and Bonneville during 2020, estimated survival for Snake River fish was 0.738 (0.636-0.840; Table 30). This was slightly below the survival estimate for Upper Columbia River fish (0.761; 0.596-0.926), but the difference was not statistically significant ($P = 0.82$).

For hatchery and wild sockeye, estimated survival from McNary to Bonneville was much higher for stocks originating in the Snake (0.546; 0.323-0.923; Table 28) than in the Upper Columbia River Basin (0.288; 0.108-0.770; Table 30). However, due to the very poor precision of both estimates, the difference was not statistically significant ($P = 0.26$).

Table 30. Annual survival probability estimates from McNary Dam to Bonneville Dam for various spring-migrating salmonid stocks (hatchery and wild combined) in 2020. In shaded rows, the annual estimates are weighted means of estimates for weekly groups. In all other rows, all release cohorts were pooled into a single group for the annual estimate. Release numbers for pooled cohorts are from points upstream 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 | 71,145 | 0.862 (0.039) | 0.865 (0.060) | 0.733 (0.045) |
| Upper Columbia Chinook | Upper Columbia sites[a] | 311,561 | 0.908 (0.035) | 0.858 (0.043) | 0.779 (0.040) |
| Upper Columbia Chinook | Yakima River sites[b] | 56,415 | 0.858 (0.090) | 0.867 (0.157) | 0.744 (0.134) |
| Upper Columbia Coho | Upper Columbia sites[a] | 54,714 | 0.876 (0.079) | 0.852 (0.113) | 0.746 (0.109) |
| Upper Columbia Coho | Yakima River sites[b] | 16,401 | 0.684 (0.100) | 1.098 (0.218) | 0.751 (0.158) |
| Snake River Sockeye | Snake River sites[c] | 50,573 | 0.830 (0.150) | 0.657 (0.174) | 0.546 (0.149) |
| Upper Columbia Sockeye | Upper Columbia sites[a] | 8,242 | 0.614 (0.149) | 0.470 (0.254) | 0.288 (0.154) |
| Snake River Steelhead | Lower Granite Dam tailrace | 67,696 | 0.985 (0.090) | 0.762 (0.057) | 0.738 (0.052) |
| Upper Columbia Steelhead | Upper Columbia sites[a] | 107,525 | 0.922 (0.078) | 0.825 (0.075) | 0.761 (0.084) |

[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

The work of NOAA Fisheries and other agencies was hampered in 2020 by restrictions related to the COVID-19 pandemic. Because of these restrictions, a number of field projects planned for the 2020 migration season were not carried out. Among these were the tagging program at Lower Granite Dam and operation of the Columbia River estuary trawl. Both of these projects are important components of our annual study, providing vital data for objectives of the smolt survival project. In the absence of data from these projects, we used alternative methods and data sources where feasible.

At Lower Granite Dam, data impacts from cancellation of the tagging program were somewhat ameliorated by the new spillway detection system in the ogee of the spill bay that houses the removable spillway weir. This system was installed during winter 2019-2020 and operated for the first time during the 2020 spring migration.

Inauguration of the new spillway detection system coincided with a year with record levels of planned spill. Increased spill levels in 2020 had the predictable result of sharply decreasing the proportion of fish passing via the juvenile bypass system, which prior to 2020 was the only possible detection point at the dam. Only 16,401 Chinook salmon and 11,060 steelhead were detected there during the 2020 spring migration season (Table 31). Because nearly 100% of PIT-tagged fish that enter the bypass system are detected, the number of detections is equivalent to the number passing via the bpass system.

Fortunately, the new spillway detection system was very successful. Systematic testing has not yet been done to quantify efficiency of the system under normal operating conditions. However, it is known that the velocity at which tagged fish pass in the spillway results in lower detection efficiency relative to the juvenile bypass system. Nonetheless, totals of 65,634 yearling Chinook and 63,532 steelhead were detected by the spillway system during the 2020 migration season.

The total sample of fish available for survival estimation beginning at Lower Granite Dam is the combination of those collected and tagged at the dam and those tagged upstream and then detected passing the dam. The sharp decrease in the number of fish using the juvenile bypass system, combined with the absence of tagging at the dam, had the potential to massively reduce our sample sizes for survival estimation in 2020. However, the addition of detections by the spillway detection system substantially increased the number of tagged fish available for survival estimation. For hatchery fish, the sample was actually slightly larger in 2020 than in many previous years (Table 31).

Table 31. Total number of PIT-tagged hatchery and wild yearling Chinook salmon and juvenile steelhead used for survival probability estimates for weekly groups of fish at Lower Granite Dam, 2010-2020. Categories are fish tagged upstream from the dam and detected in spillway or bypass system and fish collected and tagged in the bypass system. 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 |
| 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 |

However, the spillway detection system did not compensate for all data losses at Lower Granite Dam in 2020. The tagging program at the dam is specifically designed to bolster the number of tagged wild smolts available. Additional detections in the spillway did not make up for the cancellation of this component of the study. The shortage of tagged wild smolts severely impacted the quality of survival estimates for wild Chinook, and we were unable generate any satisfactory estimates at all for wild steelhead.

A second major component of the survival study cancelled in 2020 because of COVID-19 restrictions was the towed PIT-tag detection array operated in the Columbia River estuary. Using the single-release-model, detection information downstream of Bonneville Dam is required to estimate survival to Bonneville, and since the first year of its operation in 1998, the towed array has been our sole source for such information. Therefore, alternate sources of data downstream from Bonneville were needed in 2020.

We identified four sources of PIT-tag detection data from below Bonneville Dam in 2020:

1) Tags deposited by avian predators on colonies in the Columbia River estuary, on the Astoria-Megler Bridge, and at other miscellaneous locations in the estuary
2) An autonomous stationary detection system installed on a pile dike in the estuary at rkm 70 (referred to as Pile Dike 7)
3) An experimental autonomous barge detection system located approximately 3.5 km downstream from Bonneville Dam
4) Detections of juvenile fish 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 2020; however, the number of smolts detected at each individual site was quite low (Table 32). Therefore, we combined all detections at these four sites below Bonneville Dam into a single synthetic "final detection site" for survival estimation using the single-release model.

Table 32. Number of PIT tags detected or recovered at various locations downstream from Bonneville Dam, 2020. Only tags that contributed to one or more of the survival estimates in this report are included in this table. That is, these counts do not include tags from stocks for which we do not report survival or tags recovered from avian sites that were from previous smolt migration years.

| | Number of PIT tags detected or recovered | | | |
|---|---|---|---|---|
| Site | Yearling Chinook | Steelhead | Coho | Sockeye |
| Columbia River estuary[a] | 39 | 21 | 3 | 5 |
| East Sand Island[b] | 944 | 2,417 | 153 | 63 |
| Rice Island[b] | 41 | 163 | 6 | 6 |
| Miller Sands Island[b] | 1 | 2 | 0 | 0 |
| Astoria-Megler Bridge[b] | 469 | 244 | 55 | 28 |
| Pile dike 7 | 393 | 58 | 34 | 3 |
| PIT-detection barge | 110 | 45 | 22 | 9 |
| Bonneville Dam adult ladders | 9,037 | 42 | 422 | 1 |
| **Total** | **11,034** | **2,992** | **695** | **115** |

a A catch-all site for PIT tags recovered in the Columbia River estuary that do not fit any of the other sites; referred to as site "COLR1" in the PTAGIS database.
b An avian nesting, loafing, and/or roosting site.

Low detection probabilities resulting from high spill also required us to use an alternative method to estimate survival downstream from McNary Dam. Rather than regrouping 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 necessary use of a combination of alternative methods and data sources introduced a new variable when comparing 2020 results with the time series of previous smolt migration years. We are conducting a reanalysis of historical data, applying the new approaches used in 2020 where possible, but the analysis is not yet complete. We are also investigating consequences of shifting the primary data source at Lower Granite Dam from fish passing via the juvenile bypass system to fish passing 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 appreciably changed or biased estimates. We have found that for the majority 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.

Despite pandemic-related challenges in 2020, we were able to estimate smolt survival through the hydropower system for most stocks, with the exception of wild steelhead. However, as noted, the differences between methods and data sources in 2020 vs. previous years do add a caveat when comparing estimates between years. Additionally, many estimates produced in 2020 suffered from very poor precision, which decreased their utility as a monitoring tool.

For combined hatchery and wild stocks of both yearling Chinook and steelhead, survival estimates through the hydrosystem in 2020 were about average or above average (Tables 24 and 26). However, for wild Chinook alone, estimated survival was far below average: among all study years, only 2001 had a lower estimate. Even given its relative imprecision, this estimate was far enough below average for the difference to be statistically significant. Survival estimates for wild Chinook were below average in both the Snake and lower Columbia Rivers, and especially far below the mean in the reach from McNary to Bonneville Dam.

In 2019, we observed unusually low estimated survival for a number of hatchery yearling Chinook stocks in reaches upstream from Lower Granite Dam. This was not repeated in 2020; instead, most hatchery stocks had above-average survival to Lower Granite Dam. Additionally, survival to Lower Granite was near or above average for both hatchery and wild fish tagged at most smolt traps, such as the Grande Ronde and Salmon River traps (Figure 9).

However, in the reach from the Snake River trap to Lower Granite Dam, estimated survival in 2020 was substantially below average for hatchery and wild fish of both species. Sample sizes for separate estimates of wild fish survival in this reach were so small in 2020 that we question whether those estimates truly reflected the wild population as a whole. Sample sizes for combined hatchery and wild fish were sufficient for estimates with a higher degree of confidence, and those estimates were not as far below the mean (Figure 9).

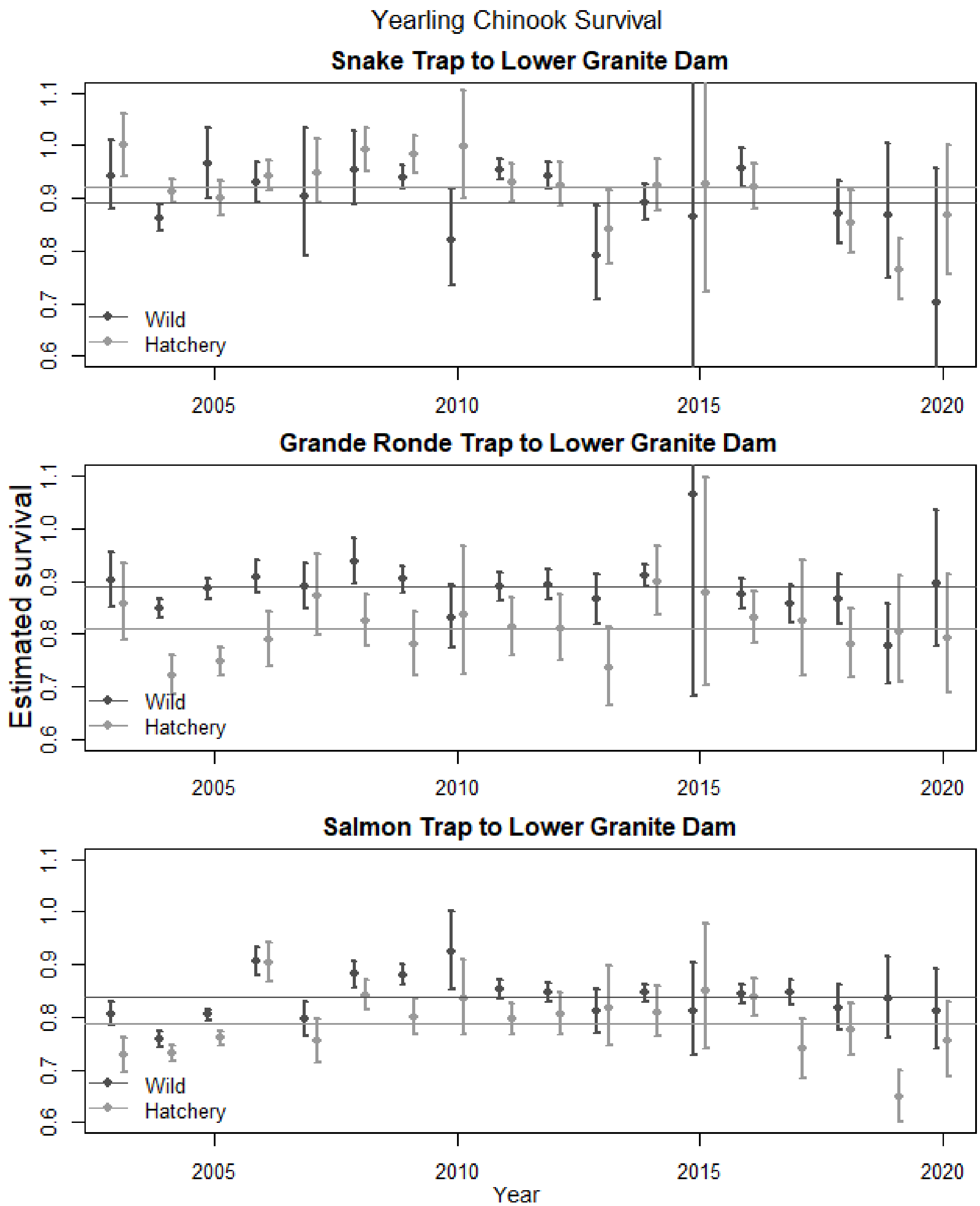


Figure 9. Survival probability estimates from release location to Lower Granite Dam for Snake River yearling Chinook salmon tagged and released at traps in the Snake River basin, 2003-2020. Whiskers represent 95% confidence intervals. Horizontal lines indicate long-term means (2003-2020) for each rear type.

Survival estimates in this reach have been below average in each of the past 3 years, but uncertainty in these estimates precludes any firm conclusion about systematic decreases in survival at the present time. If this pattern of decreased survival continues, managers may need to consider investigating causes of low survival for fish tagged at the Snake River trap.

Environmental conditions and management actions in 2020 resulted in a year with overall water temperatures that were average but with relatively high variability from day to day. Juvenile migrants also experienced lower-than-average flow and extremely high spill proportions for most of the 2020 migration season (Appendix Figures C1-C2). Mean flow in the Snake River was below average for essentially all of April, but a number of pulses in flow during May resulted in daily flow values that fluctuated above and below the mean. Daily water temperature values also fluctuated rapidly in May, though changes in water temperature were not well correlated with changes in flow.

Spill discharge levels and percentages were extremely high for the entire migration season; 2020 was the highest spill year on record by a wide margin. These high spill proportions were the result of a management program titled the *Flexible Spill Operation*. This operation used 16 h of high spill each day, which was intended to decrease travel time and increase survival of smolts during their downstream migration. These 16 h were combined with two, 4-h periods of reduced spill, which were intended to aid adult upstream passage and allow increased power generation.

To accommodate the new spill program, the total dissolved gas (TDG) limit 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 during hours of peak spill, which was typically 60-90% of total flow at the dams. During hours of reduced spill, typical spill proportions were 25-45%.

Increased spill resulted in above-average levels of TDG in 2020. Daily average values of TDG were generally below 125% at Snake River dams for most of the migration season (Appendix Figure C3). However, hourly TDG levels were often much higher. Hourly TDG varied widely due to the *Flexible Spill Operations* program, and the 125% gas cap was reached or approached within a few percentage points for part of the day at most dams on most days in May and June.

During the juvenile salmonid migration period, TDG levels were at or above 120% for 28-65% of the time, depending on the dam, and were at or above 125% as much as 17% of the time (Table 33). On some days the limit was exceeded significantly for short periods. For example, in the McNary tailrace, TDG levels were sustained at 130-131% for 23 h on 8-9 June and at 155% for 9 h on 10 June.

Exposure of fish to high levels of TDG can cause gas bubble trauma (GBT, 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 predation due to impaired senses and reduced swimming ability or through increased susceptibility to pathogens. Severity of gas bubble trauma depends on absolute TDG levels and on duration of exposure, temperature, depth, and fish size.

Table 33. Summary of total dissolved gas (TDG) levels from monitors below dams in 2020. Measurments 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 and are less than the maximum TDG produced in the immediate tailraces of the dams. Distance (km) downstream from the respective dam tailrace is given for each monitor.

| | Distance from tailrace | Total dissolved gas (%) | | Proportion of hours (%) | |
|---|---|---|---|---|---|
| Dam | (km) | Mean | Max | TDG ≥ 120% | TDG ≥ 125% |
| Lower Granite | 1.3 | 118.6 | 127.6 | 48.3 | 11.1 |
| Little Goose | 1.1 | 120.1 | 127.0 | 50.4 | 9.7 |
| Lower Monumental | 1.6 | 120.4 | 126.1 | 65.2 | 2.8 |
| Ice Harbor | 5.8 | 118.0 | 127.4 | 28.0 | 4.6 |
| McNary | 2.1 | 120.4 | 155.5 | 49.5 | 17.4 |
| John Day | 1.3 | 118.4 | 125.5 | 32.6 | 0.5 |
| The Dalles | 4.0 | 119.5 | 129.2 | 48.9 | 1.1 |
| Bonneville* | 0.4 | 120.3 | 124.9 | 55.6 | 0.0 |

* Monitor at Cascade Island. Data were missing for 13% of hours when measurements were not taken. Missing data were due to high flow; therefore, the periods of highest TDG were not measured.

Levels of TDG decrease with increasing depth in the water column, so fish can reduce their 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). They found that exposure to 120% TDG for 1.5 d resulted in over 50% mortality, and mortality was 100% within 3 d.

Dawley et al. (1976) performed a similar experiment with subyearling Chinook and juvenile steelhead exposed to a range of TDG levels from 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 subyearling Chinook having approximately 12% mortality and steelhead having 25% mortality 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 high levels of TDG affected fish survival in 2020. We can only speculate that exposure to excessive TDG contributed to below-average estimated survival for wild Chinook. Fish may have used swim depth to compensate for higher TDG. It is also possible that reduced gas levels during periods of lower spill each day were enough to alleviate symptoms of gas bubble trauma and limit associated mortality.

Another possible explanation for poor survival estimates of wild Chinook salmon is predation by piscivorous fish. 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 northern pikeminnow abundance and consumption of juvenile salmon have decreased (Porter 2012; Storch et al. 2014). We have no evidence that this pattern changed in 2020. 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.

The population of smallmouth bass in Snake River reservoirs does not appear to have changed in a consistent direction in recent years (Table 34, Erhardt et al. 2018), and collection counts at Snake River dams were about average in 2020. Erhardt et al. (2018) noted that Chinook yearlings are less vulnerable to smallmouth bass predation than subyearlings because yearlings are larger and migrate when the river is cooler.

However, Erhardt et al. also found that yearling Chinook were the most common prey item in the stomachs of large smallmouth bass in April. Storch et al. (2014) estimated that spring indices of smallmouth bass predation on salmonids generally increased over the period 1991-2013. Walleye density and predation rates on juvenile salmon have not been estimated with confidence in the Snake River (Storch et al. 2014), but collection counts of walleye have increased since 2013 (Table 34).

These sources suggest the possibility that juvenile salmonids have faced increased predation from smallmouth bass and walleye in Snake River reservoirs in recent years, but 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.

Wild smolts are smaller than their hatchery counterparts, which increases their vulnerability to gape-limited predators such as piscivorous fish. However, wild yearling Chinook 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). Predation by piscivorous fish may have been a factor in the below-average survival of wild Chinook salmon in 2020, but without current data on piscivorous predator populations in the Columbia River we cannot be certain.

Table 34. Collection counts of notable incidental species at the fish bypass facilities of Snake River dams. The collection counts in this Table are the counts 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.

| Year | Smallmouth Bass | Walleye | Siberian Prawn |
|---|---|---|---|
| | | Lower Granite Dam | |
| 2010 | 1,024 | 0 | 11,711 |
| 2011 | 682 | 1 | 3,400 |
| 2012 | 620 | 1 | 3,831 |
| 2013 | 445 | 0 | 6,634 |
| 2014 | 2,037 | 0 | 9,839 |
| 2015 | 2,160 | 1 | 20,979 |
| 2016 | 4,819 | 3 | 25,848 |
| 2017 | 1,604 | 1 | 4,148 |
| 2018 | 3,625 | 5 | 43,434 |
| 2019 | 7,781 | 13 | 71,565 |
| 2020 | 3,037 | 5 | 145,030 |
| | | Little Goose Dam | |
| 2008 | 15,503 | 32 | 5,213 |
| 2009 | 5,092 | 19 | 6,327 |
| 2010 | 4,150 | 20 | 38,676 |
| 2011 | 3,691 | 8 | 15,743 |
| 2012 | 2,442 | 7 | 23,183 |
| 2013 | 1,279 | 9 | 45,015 |
| 2014 | 3,528 | 14 | 81,310 |
| 2015 | 2,102 | 27 | 464,586 |
| 2016 | 2,992 | 65 | 51,518 |
| 2017 | 8,977 | 110 | 31,668 |
| 2018 | 2,939 | 170 | 11,159 |
| 2019 | 4,896 | 101 | 36,217 |
| 2020 | 1,922 | 137 | 87,409 |
| | | Lower Monumental Dam | |
| 2010 | 12,171 | 10 | 8,599 |
| 2011 | 393 | 19 | 2,818 |
| 2012 | 10,984 | 8 | 2,219 |
| 2013 | 428 | 9 | 12,969 |
| 2014 | 1,457 | 92 | 18,388 |
| 2015 | 779 | 337 | 48,243 |
| 2016 | 848 | 608 | 10,527 |
| 2017 | 1,764 | 733 | 9,020 |
| 2018 | 1,046 | 352 | 1,557 |
| 2019 | 1,053 | 656 | 2,182 |

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

In Lake Wallula (McNary Dam reservoir), Crescent Island recently harbored the second largest Caspian tern *Hydroprogne caspia* colony in North America, with an annual average of about 500 breeding pairs from 2000 through 2014. The Island also had large populations of gulls *Larus* spp. Other avian piscivores in this area include the American white pelican *Pelecanus erythrorhynchos,* double-crested cormorant *Phalacrocorax auritus*, great egret *Ardea alba*, and herons *A. herodias* and *Nycticorax nycticorax.*

Starting in 2015 and continuing through 2020, passive and active dissuasion measures were employed on the Crescent Island Caspian tern colony. These efforts resulted in elimination of nesting at that location since 2015. However, terns displaced from this colony have attempted to relocate or join other colonies within the mid-Columbia Basin.

Relocation of terns to the Blalock Islands colony in Lake Umatilla (John Day Dam reservoir) has increased the number of predators in that reach (Collis et al. 2020). Numbers are not yet available for 2020, but in 2019 the Blalock Islands tern colony was only slightly smaller than the original colony on Crescent Island (Collis et al. 2020). Additionally, several other large colonies of gulls were seen in the mid-Columbia region in 2019 on Island 20, Badger Island, and Miller Rocks Island. These colonies were all estimated to have preyed substantially on juvenile steelhead and sockeye salmon in 2019 (Collis et al. 2020).

These mid-Columbia River avian predators likely did not contribute much to lower-than-average survival of wild Chinook salmon in Snake River reaches. Evans et al. (2016) found that avian predators from mid-Columbia River colonies take most of their prey within 50 miles of their nesting sites and take very few prey further than 100 miles away. Thus, we would expect the majority of mortality stemming from mid-Columbia avian colonies to occur in Lakes Wallula and Umatilla, where the colonies are located. Wild Chinook salmon did have unusually low survival in the lower Columbia River in 2020, which prompts the question of whether avian predators were responsible.

However, avian predation rates on yearling Chinook salmon smolts are considerably lower than on steelhead (Evans et al. 2012, Hostetter et al. 2012). Many mid-Columbia bird colonies in 2019 were found to have consumption rates of 3% or more on Snake River steelhead, but lower consumption rates (0.8% or less) on Snake River yearling Chinook (Collis et al. 2020). Also, hatchery smolts tend to be more vulnerable to avian predators than wild smolts (Flagg et al. 2000). However, steelhead and hatchery Chinook salmon did not show a similar pattern of below-average survival in the Columbia River. Therefore, avian predation was likely not a significant factor in the poor survival of wild Chinook observed in Columbia reaches during 2020.

An exploding population of invasive Siberian prawn *Palaemon modestus* also potentially influenced survival of juvenile salmon in Snake River reservoirs in 2020 and other recent years. This prawn may compete with salmonid smolts, and was first documented in the Snake River in 1998 (Haskell et al. 2006). Collection counts of Siberian prawn were low in the 2000s but have increased significantly, reaching a peak of 464,586 at Little Goose Dam in 2015 (Table 34, Erhardt and Tiffan 2016). Siberian prawn consume the same types of prey as juvenile salmon, and competition with this prawn may depress growth rates of juvenile salmon in Snake River reservoirs (Tiffan et al. 2014; Tiffan and Hurst 2016).

Collection counts of Siberian prawn have also rapidly increased at Lower Granite Dam, although counts at other dams have generally declined since 2015 (Table 34). This suggests the possibility that salmonids continue to face increased competition from Siberian prawn, at least in Lower Granite reservoir. However, it is not clear whether Siberian prawn were a factor in the low survival of wild Chinook observed in 2020.

It seems doubtful that competition with Siberian prawn would impact wild Chinook but not other stocks, and estimated survival for both hatchery Chinook and hatchery steelhead was average or above-average in 2020. Furthermore, few Siberian prawn are observed at lower Columbia River dams, the reaches where wild Chinook survival was the lowest.

Since court-ordered spill was instituted in 2006, and with the installation of surface collectors at four additional dams, average travel time between Lower Granite and Bonneville Dam has generally decreased, more so for steelhead than for Chinook smolts. When there is no spill, 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 increased further in the past several years, travel time has generally been very short throughout the season, although the marginal benefits decrease with increasing levels of spill. Despite high spill levels during early to mid-April in 2020, travel times for both Chinook and steelhead were longer than in most recent years.

Longer travel times in early 2020 were possibly related to lower water velocities resulting from below-average flow. After late April 2020, when flow was above or near the mean, travel times were very short, similar to those from other recent years.

High spill volumes in 2020 induced notable eddies in the tailrace at some dams (Blane Bellerud, pers. comm. April 2021). The severity of eddies generated in the tailrace depends on flow and spill conditions, as well as general configuration of the dam (Bellerud 2017, Fredricks 2017). The combination of below-average flow and extreme high spill in early April 2020 may have resulted in more severe eddies 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, increasing exposure to predation.

In 2020, estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams were the second lowest of our time series; only the 2015 migration year was lower. After low transportation rates in 2015-2017, when the general program began around 1 May, the proportion increased in 2018 and 2019 because the start date was changed to 23 April. While 2020 shared the earlier start date, the proportion of fish transported plummeted because the extremely high rates of spill reduced the proportions of fish collected.

Detection probabilities have been lower in general since 2007, when programs were instituted at most dams to encourage spillway passage by increasing spill and using surface-passage structures. These programs have successfully increased spillway passage, and there is evidence that surface spill is disproportionately attractive to fish at lower flow levels. However, higher proportions of spillway passage result in lower proportions of tagged fish entering bypass systems. Extremely high and unprecedented levels of spill in 2020 exacerbated this issue, and detection rates were extremely low at all dams except 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 effectively proportional to the number of detected fish, which depends on both detection probability and total number of migrating PIT-tagged fish. Reduced effective sample sizes have become common in recent years, as reliance on spillway and surface passage has increased. Spill is now the primary management strategy used to increase survival of juvenile fish passing dams within the Federal Columbia River Power System.

At present, the emphasis on spillway passage reduces detection rates by reducing the proportion of fish that enter juvenile bypass systems. At most dams, juvenile bypass systems have been 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 probabilities of PIT-tag detection. The consequences of reduced detection probability include:

1) Reduced certainty in survival estimates: standard errors become larger and confidence intervals wider. Estimates are also more likely to be further from the true survival value and are frequently greater than 100%.
2) Greater negative correlation between survival estimates in consecutive reaches. That is, there is an increased chance that sampling variability will result in estimates that are 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 usually most serious for the furthest downstream reaches within the migration corridor: from McNary to John Day and from John Day to Bonneville Dam.

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

If detection rates remain low, precision in survival estimates can be increased only by releasing larger numbers of tagged fish. This option is not feasible, as it would increase both the cost of monitoring and the burden on an already stressed biological resource. Therefore, assuming the emphasis on spillway passage will continue, the best option for retaining or increasing precision in survival estimates is to increase rates of detection by developing PIT-tag monitoring systems for additional fish-passage routes.

As previously noted, the spillway detection system installed in the ogee at Lower Granite Dam greatly increased overall detection probability during the 2020 migration season. 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. Large within-season variation in detection probability can have negative effects on the accuracy of survival and detection probability estimates from mark-recapture models and can also introduce bias to estimates of travel time.

Detection capability in multiple passage routes will also advance our understanding of passage-route distributions throughout the migration season, producing valuable insight into fish passage behavior. The new 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 the two passage routes.

The success of the new spillway detection system at Lower Granite Dam is very encouraging. Because the present management goal is to pass as many juveniles via spill as possible, the spillway is the ideal location for expanded PIT-tag detection. Increased detection rates will pay dividends on all of the other investments in PIT-tag research within the region, not merely this project.

We believe that the region should prioritize installation of similar spillway systems at other dams on the Snake and Columbia Rivers, particularly at 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 new PIT-tag detection methods will lead to other opportunities for improving detection. For example, autonomous detection barges could allow detection in tailraces of dams. Stationary, removable, or semi-permanent arrays placed downstream of Bonneville Dam could enhance or even supplant data from the towed array in the estuary pair trawl 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. Therefore, actions to improve detection of these fish are critical to protect these valuable natural resources and avoid exposing threatened stocks to further harm which we will no longer be able to measure.

# Conclusions and Recommendations

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

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

2) Pursue development of alternative PIT-detection technologies that could improve detection downstream of Bonneville Dam and potentially at other dams.

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

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

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# References


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

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

BPA (Bonneville Power Administration). 2020. Federal agencies spill record amount of water at dams. BPA News & Us web page. Newsroom article 9 June 2020. Available at: www.bpa.gov/news/newsroom/Pages/Federal%20agencies%20spill%20record%20amount%20of%20water%20at%20dams.aspx

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

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

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

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

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

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

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

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

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

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

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

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

Evans, A. F., N. J. Hostetter, K. Collis, D. D. Roby, and F. J. Loge. 2014. Relationship between juvenile fish condition and survival to adulthood in steelhead. Transactions of the American Fisheries Society 143:899–909.

Evans, A. F., Q. Payton, A. Turecek, B. Cramer, K. Collis, D. D. Roby, P. J. Loschl, L. Sullivan, J. Skalski, M. Weiland and C. Dotson. 2016. Avian predation on juvenile salmonids: spatial and temporal analysis based on acoustic and passive integrated transponder tags. Transactions of the American Fisheries Society 145:860–877.

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

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

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

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

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

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

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

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

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

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

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

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

Flagg, T. A., B. A. Berejikian, J. Colt, W. W. Dickhoff, L. W. Harrell, D. J. Maynard, C. E. Nash, M. S. Strom, R. N. Iwamoto, C. V. Mahnken. 2000. Ecological and behavioral impacts of artificial production strategies on the abundance of wild salmon populations. NOAA Technical Memorandum NMFS-NWFSC-41, 92 p.

FPC (Fish Passage Center). 2020a. Smolt Passage Index: Daily Passage Index by Project. Online interactive database. Available at fpc.org/smolt/smolt_queries/Q_smoltpassageindexquery.php. (August 2021).

FPC (Fish Passage Center). 2020b. Smolt Data: Historic and Real-time Smolt Transportation Data. Online interactive database. Available at fpc.org/smolt/transportation/smolt_transportation_query.html (August 2021).

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

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

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

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

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

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

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

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

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

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

McCann, J., B. Chockley, E. Cooper, G. Scheer, S. Haeseker, B. Lessard, T. Copeland, J. Ebel, A. Storch, and D. Rawding. 2020. Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye: 2020 Annual Report. Report of the Comparative Survival Study Oversight Committee and Fish Passage Center to the Bonneville Power Administration, Portland, Oregon. Available: https://www.fpc.org/documents/CSS/2020-CSS-Report.pdf

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

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

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

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

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

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

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

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

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

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

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

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

Roby, D. D., K. Collis, D. E. Lyons, J. Y. Adkins, P. J. Loschl, Y. Suzuki, T. Marcella, L. Kerr, A. Evans, B. Cramer, N. Hostetter, B P. Sandford, R. D. Ledgerwood, D. R. Kuligowski, and S. Sebring. 2011. Impacts of avian predation on salmonid smolts from the Columbia and Snake Rivers. 2004-2009 Synthesis Report. Report to the U.S. Army Corps of Engineers, Walla Walla, WA.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Ward, B. R., and P. A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Canadian Journal of Fisheries and Aquatic Sciences 45:1110–1122.

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

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

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

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

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

Zabel, R. W., and J. G. Williams. 2002. Selective mortality in Chinook Salmon: what is the role of human disturbance? Ecological Applications 12:173–183.

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

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

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

# Appendix A: Evaluation of Model Assumptions

## Background

Using the Cormack-Jolly-Seber (CJS), or single-release 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 $\chi^2$ tests to identify systematic deviations from what was expected if the assumptions were met. We applied the tests to weekly groups of yearling Chinook salmon and steelhead (hatchery and wild combined) leaving Lower Granite Dam during the migration year (Snake River-origin fish only, i.e., the fish 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 we conducted, we follow the nomenclature of Burnham et al. (1987). For release groups from Lower Granite Dam, we analyzed 6-digit detection histories indicating status at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams, and the final digit for detection anywhere below Bonneville Dam (PIT barge, pile dike, Bonneville adult ladder, or bird island recovery).

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

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

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

If all model assumptions are met, counts of fish detected at Little Goose should be in constant proportion to those of fish not detected (i.e., $n_{11}/n_{21}$, $n_{12}/n_{22}$, $n_{13}/n_{23}$, $n_{14}/n_{24}$, and $n_{15}/n_{25}$ are equal in expectation). Because this table counted only fish detected below Little Goose (i.e., all fish survived passage at Goose), differential *direct* mortality between fish detected and not detected at Little Goose will not cause violations of Test 2.C2 by itself. However, differential *indirect* mortality related to Little Goose passage could cause violations if differences in mortality are expressed below Lower Monumental Dam.

Behavioral response to guidance at Little Goose could also cause violations of Test 2.C2. For example, if fish detected at Little Goose become more likely to be detected downstream, then they will tend to have more first downstream detections at Lower Monumental. Conversely, if fish detected at Little Goose become less likely to be detected downstream, they will have fewer first detections at Lower Monumental. Inherent differences among fish could also cause violations of Test 2.C2, and would be difficult to distinguish from behavioral responses.

There are three additional component tests of Test 2 (Tests 2.C3, 2.C4, and 2.C5), conditioning on detection status at McNary, John Day, and Bonneville Dams, respectively, and taking analogous form 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. Differences in mortality expressed below McNary could cause violations, however, as could behavioral responses (possibly somewhat harder to detect because of the conditioning on detection at Lower Monumental) or inherent differences in detectability or survival between fish detected at Little Goose and those not detected there.

The 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 conditioning on detection at McNary, John Day, and Bonneville analogously to Lower Monumental in Test 3.SR3. Similarly, there are two additional component 3.Sm tests (Sm4 and Sm5), respectively conditioning on detection at McNary and John Day analogously 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 $\chi^2$ distribution does not sufficiently approximate the sampling distribution of the test statistic. For tables with more than two columns, if any column 2 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 2x2 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 $\chi^2$ test were met for all combined tests.

## Results

For release groups in 2020 there were more significant overall tests than expected by chance alone (5%) for yearling Chinook salmon but not for steelhead ($\alpha = 0.05$; Appendix Table A1). There were 8 weekly groups of yearling Chinook salmon, and the overall sum of $\chi^2$ test statistics was significant for one group (12.5%). The overall test was not significant for any of the 9 steelhead groups. Counting all individual component tests (i.e., 2.C2, 3.SR3, etc.), 1 tests out of 83 (1%) was significant for yearling Chinook salmon and 2 out of 93 (2%) were significant for steelhead (Appendix Tables A2-A5). There is a 92% chance of 1 or more tests out of 83 being significant if the true test-wise probability of a "false positive" result is $\alpha = 0.05$, and an 85% chance of 2 or more significant tests out of 93. Thus, the number of observed positive tests for Chinook and steelhead could be simply due to chance. However, due to the very low detection probabilities at most dams, many of the tests were likely under-powered, which means that it would not be likely to 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 weekly groups of yearling Chinook, the one significant component test (Test 2.C2) indicated that fish detected at

Little Goose Dam had more first detections at Lower Monumental Dam than fish not detected at Little Goose Dam.

For steelhead, one of the significant component tests (Test 2.C3) indicated that fish detected at Lower Monumental Dam were more likely to be detected below Bonneville Dam than fish not detected at Lower Monumental Dam. The other significant component test (Test 3.SR5) indicated that among fish detected at John Day Dam, those fish also detected at McNary Dam had fewer detections downstream of John Day Dam than those not detected at McNary Dam.

## Discussion

We believe that inherent differences in detectability (guidability) of fish within a release group are the most likely cause of the patterns we observed in contingency table tests in 2020, as in previous years. Zabel et al. (2002, 2005) and Faulkner et al. (2019) provided evidence of inherent differences related to length of fish at tagging, and similar observations were made in 2020 data.

Fish size probably does not explain all inherent differences, but it appeared to explain some. The relationship between length at tagging and detection probability at Little Goose Dam suggested that the heterogeneity was inherent, and not a behavioral response (Zabel et al. 2005). Probability of detection at Little Goose Dam afforded the best insight into the relationship between fish size and detection, as Little Goose was the first dam encountered after release by fish included in these datasets (all fish included in the dataset were detected at Lower Granite Dam, and Little Goose is the first dam encountered after leaving Lower Granite). However, the fact that fish detected at an upstream site were not consistently more likely to be detected downstream offers evidence against the proposition that size selection is the only mechanism driving these assumption violations.

Another possibility is that changes in spill level among sequential dams were correlated with one another during passage of a cohort, and this resulted in correlated detection probabilities within subsets of the cohort. To illustrate, suppose that spill percentage at both Little Goose and Lower Monumental Dam is high early in the season and low late in the season. The earliest migrating fish from a cohort arrive at Little Goose Dam during high spill, and consequently have low probability of detection. These early fish will also tend to arrive at Lower Monumental during the period of high spill and low detection probability. The opposite will be true for later migrants from the cohort: they will encounter low spill and have higher probability of detection. When the combined data for the cohort are analyzed, fish detected at Little Goose will be more likely to be detected at Lower Monumental than fish not detected at Little Goose Dam.

Although the contingency table tests did well at detecting some violations of CJS model assumptions, there are instances where assumptions could be violated without resulting in significant tests. A specific example is that of acute differential post-detection mortality, where detected and non-detected fish have different rates of mortality between detection at a point of interest and at the subsequent detection point. This mortality would constitute a violation of assumption A3. However, none of the contingency table tests described here would detect this violation because each test relies on data from fish with known fates, either at the site of interest or at sites downstream.

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

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

Appendix Table A1. Number of tests of goodness-of-fit to the single-release model conducted, and number of significant ($\alpha = 0.05$) results for groups of Snake River Chinook salmon and juvenile steelhead in 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly groups for tests.

| | | Species | | |
|---|---|---|---|---|
| Test | | Chinook | Steelhead | Total |
| Test 2.C2 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 1 | 0 | 1 |
| Test 2.C3 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 1 | 1 |
| Test 2.C4 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 2.C5 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 3.SR3 | Tests (n) | 8 | 8 | 16 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 3.Sm3 | Tests (n) | 5 | 6 | 11 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 3.SR4 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 3.Sm4 | Tests (n) | 7 | 7 | 14 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 3.SR5 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 1 | 1 |
| Test 3.Sm5 | Tests (n) | 7 | 9 | 16 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 3.SR6 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 2 sum | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 1 | 0 | 1 |
| Test 3 sum | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 0 | 0 | 0 |
| Test 2 + 3 | Tests (n) | 8 | 9 | 17 |
| | Significant tests (n) | 1 | 0 | 1 |

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 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly groups for tests.

| | Overall (2+3) | | Test 2 (sum) | | Test 2.C2 | |
|---|---|---|---|---|---|---|
| Release | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value |
| 30 Mar–5 Apr | 38.68 | **0.005** | 22.19 | **0.014** | 20.78 | **0.001** |
| 6–12 Apr | 12.58 | 0.764 | 7.45 | 0.682 | 6.13 | 0.156 |
| 13–19 Apr | 20.12 | 0.215 | 15.03 | 0.131 | 5.47 | 0.341 |
| 20–26 Apr | 15.60 | 0.552 | 13.26 | 0.209 | 6.62 | 0.207 |
| 27 Apr–3 May | 27.56 | 0.120 | 15.06 | 0.130 | 8.65 | 0.075 |
| 4 –10 May | 18.64 | 0.350 | 13.12 | 0.217 | 8.83 | 0.059 |
| 11–17 May | 17.65 | 0.546 | 12.92 | 0.228 | 5.53 | 0.282 |
| 18–24 May | 20.83 | 0.234 | 12.73 | 0.239 | 3.77 | 0.376 |
| **Total (df)** | 171.66 (142) | **0.046** | 111.76 (80) | **0.011** | 65.78 (32) | **<0.001** |

| | Test 2.C3 | | Test 2.C4 | | Test 2.C5 | |
|---|---|---|---|---|---|---|
| Release | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value |
| 30 Mar–5 Apr | 0.81 | 1.000 | 0.58 | 0.792 | 0.02 | 1.000 |
| 6–12 Apr | 0.85 | 1.000 | 0.47 | 0.791 | 0.00 | 0.970 |
| 13–19 Apr | 4.46 | 0.316 | 5.05 | 0.075 | 0.05 | 0.775 |
| 20–26 Apr | 1.91 | 0.423 | 4.56 | 0.102 | 0.17 | 1.000 |
| 27 Apr–3 May | 2.94 | 0.387 | 2.11 | 0.347 | 1.36 | 0.244 |
| 4 –10 May | 2.26 | 0.681 | 0.23 | 1.000 | 1.80 | 0.180 |
| 11–17 May | 2.68 | 0.516 | 4.70 | 0.057 | 0.01 | 0.908 |
| 18–24 May | 5.75 | 0.078 | 1.70 | 0.279 | 1.51 | 0.377 |
| **Total (df)** | 21.66 (24) | 0.600 | 19.40 (16) | 0.248 | 4.92 (8) | 0.766 |

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 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly groups for tests.

| Release period | Test 3 (sum) $\chi^2$ | Test 3 (sum) *P*-value | Test 3.SR3 $\chi^2$ | Test 3.SR3 *P*-value | Test 3.Sm3 $\chi^2$ | Test 3.Sm3 *P*-value | Test 3.SR4 $\chi^2$ | Test 3.SR4 *P*-value |
|---|---|---|---|---|---|---|---|---|
| 30 Mar–5 Apr | 16.49 | 0.057 | 0.63 | 0.571 | 4.00 | 0.500 | 4.73 | 0.063 |
| 6–12 Apr | 5.13 | 0.644 | 0.53 | 1.000 | - | - | 0.59 | 0.499 |
| 13–19 Apr | 5.09 | 0.532 | 2.27 | 0.262 | 1.20 | 1.000 | 1.00 | 1.000 |
| 20–26 Apr | 2.34 | 0.939 | 0.11 | 1.000 | - | - | 0.02 | 1.000 |
| 27 Apr–3 May | 12.50 | 0.253 | 0.74 | 0.475 | 7.82 | 0.213 | 0.00 | 0.967 |
| 4 –10 May | 5.52 | 0.597 | 0.35 | 1.000 | - | - | 0.00 | 1.000 |
| 11–17 May | 4.73 | 0.857 | 0.09 | 0.760 | 1.93 | 0.606 | 0.18 | 1.000 |
| 18–24 May | 8.10 | 0.324 | 0.00 | 1.000 | 0.90 | 1.000 | 1.74 | 0.242 |
| **Total (df)** | 59.90 (62) | 0.552 | 4.72 (8) | 0.787 | 15.85 (10) | 0.104 | 8.26 (8) | 0.408 |

| | Test 3.Sm4 $\chi^2$ | Test 3.Sm4 *P*-value | Test 3.SR5 $\chi^2$ | Test 3.SR5 *P*-value | Test 3.Sm5 $\chi^2$ | Test 3.Sm5 *P*-value | Test 3.SR6 $\chi^2$ | Test 3.SR6 *P*-value |
|---|---|---|---|---|---|---|---|---|
| 30 Mar–5 Apr | 0.75 | 1.000 | 0.01 | 1.000 | 3.43 | 0.250 | 2.94 | 0.143 |
| 6–12 Apr | 2.64 | 0.325 | 0.79 | 0.592 | 0.40 | 1.000 | 0.18 | 1.000 |
| 13–19 Apr | - | - | 0.31 | 0.740 | 0.23 | 1.000 | 0.08 | 1.000 |
| 20–26 Apr | 1.09 | 0.404 | 0.64 | 0.585 | 0.19 | 1.000 | 0.29 | 1.000 |
| 27 Apr–3 May | 1.61 | 0.631 | 0.03 | 0.857 | 0.21 | 0.513 | 2.09 | 0.228 |
| 4 –10 May | 1.31 | 0.488 | 1.53 | 0.216 | 0.25 | 1.000 | 2.08 | 0.159 |
| 11–17 May | 0.56 | 0.589 | 0.27 | 0.603 | 1.59 | 0.356 | 0.11 | 1.000 |
| 18–24 May | 4.89 | 0.156 | 0.18 | 0.746 | - | - | 0.39 | 0.473 |
| **Total (df)** | 12.85 (13) | 0.459 | 3.76 (8) | 0.878 | 6.30 (7) | 0.505 | 8.16 (8) | 0.418 |

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 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly groups for tests.

| Release | Overall (2+3) $\chi^2$ | Overall (2+3) *P*-value | Test 2 (sum) $\chi^2$ | Test 2 (sum) *P*-value | Test 2.C2 $\chi^2$ | Test 2.C2 *P*-value |
|---|---|---|---|---|---|---|
| 30 Mar–5 Apr | 13.49 | 0.488 | 5.83 | 0.829 | 3.16 | 0.588 |
| 6–12 Apr | 13.11 | 0.873 | 6.99 | 0.726 | 3.89 | 0.436 |
| 13–19 Apr | 19.18 | 0.510 | 11.17 | 0.344 | 2.17 | 0.704 |
| 20–26 Apr | 20.78 | 0.410 | 14.54 | 0.150 | 2.16 | 0.666 |
| 27 Apr–3 May | 21.10 | 0.222 | 15.73 | 0.108 | 7.61 | 0.169 |
| 4 –10 May | 14.36 | 0.762 | 7.50 | 0.678 | 2.53 | 0.540 |
| 11–17 May | 21.66 | 0.302 | 12.97 | 0.225 | 8.73 | 0.063 |
| 18–24 May | 27.06 | 0.103 | 17.37 | 0.067 | 6.35 | 0.124 |
| 25–31 May | 13.00 | 0.602 | 10.06 | 0.435 | 6.99 | 0.090 |
| **Total (df)** | 163.74 (163) | 0.469 | 102.16 (90) | 0.179 | 43.59 (36) | 0.180 |

| Release | Test 2.C3 $\chi^2$ | Test 2.C3 *P*-value | Test 2.C4 $\chi^2$ | Test 2.C4 *P*-value | Test 2.C5 $\chi^2$ | Test 2.C5 *P*-value |
|---|---|---|---|---|---|---|
| 30 Mar–5 Apr | 1.54 | 0.476 | 0.52 | 0.646 | 0.61 | 0.704 |
| 6–12 Apr | 1.62 | 0.386 | 1.48 | 0.522 | 0.00 | 1.000 |
| 13–19 Apr | 4.88 | 0.100 | 1.41 | 0.489 | 2.71 | 0.099 |
| 20–26 Apr | 9.65 | **0.035** | 2.66 | 0.245 | 0.07 | 0.780 |
| 27 Apr–3 May | 4.99 | 0.230 | 1.24 | 0.340 | 1.89 | 0.232 |
| 4 –10 May | 2.50 | 0.486 | 0.86 | 0.499 | 1.61 | 0.208 |
| 11–17 May | 1.89 | 0.516 | 1.07 | 0.822 | 1.28 | 0.258 |
| 18–24 May | 6.08 | 0.070 | 4.93 | 0.128 | 0.01 | 0.904 |
| 25–31 May | 0.87 | 0.860 | 1.95 | 0.426 | 0.25 | 0.643 |
| **Total (df)** | 34.02 (27) | 0.165 | 16.12 (18) | 0.584 | 8.43 (9) | 0.491 |

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 2020. Daily groups of combined hatchery and wild fish, determined by day of detection at Lower Granite Dam, were pooled for weekly groups for tests.

| Release period | Test 3 (sum) | | Test 3.SR3 | | Test 3.Sm3 | | Test 3.SR4 | |
|---|---|---|---|---|---|---|---|---|
| | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value |
| 30 Mar–5 Apr | 7.66 | 0.105 | - | - | - | - | 1.09 | 0.584 |
| 6–12 Apr | 6.12 | 0.805 | 0.02 | 1.000 | 3.94 | 0.444 | 0.20 | 1.000 |
| 13–19 Apr | 8.01 | 0.628 | 0.52 | 0.440 | 2.17 | 1.000 | 0.00 | 0.951 |
| 20–26 Apr | 6.24 | 0.795 | 0.51 | 0.440 | 2.04 | 0.438 | 2.13 | 0.200 |
| 27 Apr–3 May | 5.37 | 0.615 | 1.71 | 0.340 | - | **-** | 0.04 | 1.000 |
| 4 –10 May | 6.86 | 0.652 | 2.00 | 0.169 | 2.95 | 0.308 | 0.01 | 1.000 |
| 11–17 May | 8.69 | 0.466 | 2.51 | 0.139 | 0.59 | 1.000 | 0.04 | 1.000 |
| 18–24 May | 9.69 | 0.376 | 0.03 | 1.000 | 4.46 | 0.333 | 4.37 | 0.058 |
| 25–31 May | 2.94 | 0.709 | 0.36 | 0.532 | - | - | 0.64 | 1.000 |
| **Total (df)** | 61.58 (73) | 0.827 | 7.66 (8) | 0.467 | 16.15 (17) | 0.513 | 8.52 (9) | 0.483 |

| | Test 3.Sm4 | | Test 3.SR5 | | Test 3.Sm5 | | Test 3.SR6 | |
|---|---|---|---|---|---|---|---|---|
| | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value | $\chi^2$ | *P*-value |
| 30 Mar–5 Apr | - | - | 1.33 | 0.355 | 4.96 | 0.176 | 0.28 | 1.000 |
| 6–12 Apr | 0.13 | 1.000 | 1.53 | 0.304 | 0.16 | 1.000 | 0.14 | 1.000 |
| 13–19 Apr | 4.26 | 0.128 | 0.01 | 0.930 | 1.04 | 0.282 | 0.01 | 0.923 |
| 20–26 Apr | 1.15 | 0.413 | 0.05 | 0.827 | 0.23 | 1.000 | 0.13 | 1.000 |
| 27 Apr–3 May | 3.26 | 0.310 | 0.12 | 1.000 | 0.08 | 1.000 | 0.16 | 1.000 |
| 4 –10 May | 0.49 | 1.000 | 0.76 | 0.367 | 0.59 | 1.000 | 0.06 | 0.683 |
| 11–17 May | 1.22 | 0.467 | 4.05 | **0.044** | 0.14 | 1.000 | 0.14 | 0.727 |
| 18–24 May | 0.17 | 1.000 | 0.65 | 0.416 | 0.01 | 1.000 | 0.00 | 1.000 |
| 25–31 May | - | - | 0.87 | 0.317 | 0.48 | 1.000 | 0.59 | 1.000 |
| **Total (df)** | 10.68 (12) | 0.557 | 9.37 (9) | 0.404 | 7.69 (9) | 0.566 | 1.51 (9) | 0.997 |

# 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 2020. 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 | 9,691 | 0.929 (0.034) | 0.817 (0.207) | 1.412 (0.683) | 0.600 (0.260) | 0.643 (0.081) |
| Powell Pond | 25,364 | 0.592 (0.013) | 0.808 (0.103) | 0.949 (0.227) | 1.091 (0.244) | 0.495 (0.045) |
| Red River Pond | 17,029 | 0.613 (0.023) | 0.770 (0.148) | 0.998 (0.330) | 0.808 (0.241) | 0.380 (0.046) |
| Selway River | 17,054 | 0.600 (0.016) | 0.774 (0.163) | 0.955 (0.341) | 1.283 (0.407) | 0.570 (0.073) |
| N Fork Clearwater R | 17,039 | 0.878 (0.017) | 1.042 (0.159) | 1.442 (0.460) | 0.592 (0.176) | 0.782 (0.076) |
| **Dworshak Hatchery** | | | | | | |
| N Fork Clearwater R | 41,950 | 0.811 (0.011) | 0.912 (0.088) | 1.233 (0.280) | 0.631 (0.136) | 0.576 (0.034) |
| **Kooskia Hatchery** | | | | | | |
| Kooskia | 7,876 | 0.747 (0.029) | 1.011 (0.220) | 0.553 (0.194) | 1.254 (0.387) | 0.524 (0.068) |
| **Lookingglass Hatchery** | | | | | | |
| Catherine Creek Pond | 20,999 | 0.530 (0.015) | 0.774 (0.070) | 1.522 (0.316) | 0.680 (0.150) | 0.425 (0.047) |
| Grande Ronde Pond | 1,997 | 0.468 (0.053) | 0.690 (0.163) | 0.836 (0.339) | 1.483 (0.855) | 0.400 (0.184) |
| Imnaha Weir | 20,997 | 0.629 (0.017) | 0.944 (0.128) | 0.851 (0.188) | 0.891 (0.178) | 0.450 (0.041) |
| Lookingglass Hatchery | 5,004 | 0.609 (0.031) | 0.856 (0.102) | 1.138 (0.258) | 0.798 (0.226) | 0.473 (0.096) |
| Lostine Pond | 5,649 | 0.567 (0.029) | 0.896 (0.112) | 0.910 (0.189) | 1.026 (0.267) | 0.474 (0.092) |
| **McCall Hatchery** | | | | | | |
| Knox Bridge | 51,800 | 0.733 (0.011) | 0.982 (0.067) | 0.750 (0.083) | 0.961 (0.102) | 0.519 (0.030) |
| Johnson Creek | 2,003 | 0.595 (0.056) | 0.877 (0.214) | 1.587 (0.829) | 0.495 (0.325) | 0.410 (0.187) |
| **Pahsimeroi Hatchery** | | | | | | |
| Pahsimeroi Pond | 21,381 | 0.559 (0.018) | 0.876 (0.109) | 1.675 (0.540) | 0.439 (0.145) | 0.360 (0.049) |
| **Rapid River Hatchery** | | | | | | |
| Rapid River Hatchery | 51,758 | 0.567 (0.010) | 0.883 (0.085) | 0.896 (0.148) | 0.888 (0.134) | 0.398 (0.026) |
| **Sawtooth Hatchery** | | | | | | |
| Alturas Lake Creek | 990 | 0.561 (0.057) | 1.155 (0.466) | 0.869 (0.482) | NA | NA |
| Sawtooth Hatchery | 18,743 | 0.681 (0.020) | 1.169 (0.193) | 1.032 (0.334) | 0.575 (0.172) | 0.472 (0.049) |
| Yankee Fork | 2,458 | 0.443 (0.044) | 0.774 (0.366) | 1.200 (0.942) | 0.775 (0.532) | 0.319 (0.088) |

Appendix Table B2. Survival probability estimates for juvenile steelhead released from Snake River Basin hatcheries in 2020. 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 | 10,712 | 0.814 (0.010) | 0.843 (0.067) | 0.985 (0.190) | 1.317 (0.308) | 0.890 (0.136) |
| Newsome Creek | 2,563 | 0.711 (0.029) | 1.434 (0.481) | 0.724 (0.402) | 0.512 (0.261) | 0.378 (0.094) |
| S Fork Clearwater R | 4,674 | 0.835 (0.017) | 0.924 (0.136) | 1.502 (0.656) | 0.432 (0.193) | 0.501 (0.086) |
| **Dworshak Hatchery** | | | | | | |
| S Fork Clearwater R | 8,888 | 0.770 (0.010) | 0.989 (0.073) | 1.030 (0.230) | 0.661 (0.163) | 0.519 (0.064) |
| Dworshak NFH | 15,475 | 0.784 (0.008) | 0.912 (0.058) | 1.230 (0.217) | 0.602 (0.118) | 0.530 (0.055) |
| Lolo Creek | 1,000 | 0.581 (0.052) | NA | NA | NA | NA |
| **Hagerman Hatchery** | | | | | | |
| East Fork Salmon R | 8,570 | 0.640 (0.016) | 1.322 (0.253) | 0.515 (0.150) | 1.024 (0.305) | 0.446 (0.089) |
| Sawtooth Hatchery | 29,795 | 0.607 (0.007) | 1.075 (0.091) | 1.089 (0.204) | 0.814 (0.170) | 0.579 (0.071) |
| **Irrigon Hatchery** | | | | | | |
| Big Canyon Facility | 6,736 | 0.781 (0.019) | 0.879 (0.116) | 1.046 (0.259) | 1.123 (0.396) | 0.807 (0.228) |
| Little Sheep Facility | 14,887 | 0.784 (0.010) | 0.953 (0.068) | 1.247 (0.201) | 0.754 (0.158) | 0.702 (0.105) |
| Wallowa Hatchery | 10,706 | 0.761 (0.014) | 1.414 (0.199) | 0.527 (0.125) | 1.346 (0.382) | 0.764 (0.160) |
| **Lyons Ferry Hatchery** | | | | | | |
| Cottonwood Pond | 5,700 | 0.858 (0.013) | 1.039 (0.101) | 1.091 (0.256) | 0.880 (0.290) | 0.856 (0.212) |

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 | 4,568 | 0.866 (0.026) | 1.025 (0.198) | 0.628 (0.225) | 1.689 (0.765) | 0.942 (0.317) |
| Pahsimeroi R Trap | 11,058 | 0.710 (0.015) | 1.296 (0.201) | 0.982 (0.307) | 0.732 (0.248) | 0.661 (0.132) |
| Sawtooth Hatchery | 5,671 | 0.799 (0.027) | 1.119 (0.253) | 1.282 (0.659) | 0.510 (0.279) | 0.585 (0.169) |
| Yankee Fork | 13,167 | 0.620 (0.014) | 0.838 (0.097) | 1.517 (0.449) | 0.603 (0.194) | 0.475 (0.079) |
| **Niagara Springs Hatchery** | | | | | | |
| Hells Canyon Dam | 8,569 | 0.827 (0.017) | 1.005 (0.108) | 1.224 (0.340) | 0.991 (0.331) | 1.007 (0.213) |
| Little Salmon R | 4,898 | 0.810 (0.028) | 0.984 (0.176) | 0.995 (0.329) | 0.909 (0.336) | 0.721 (0.172) |
| Pahsimeroi R Trap | 8,970 | 0.740 (0.018) | 1.113 (0.176) | 1.567 (0.644) | 0.407 (0.178) | 0.525 (0.110) |

Appendix Table B3. Survival probability estimates for juvenile sockeye and coho salmon released from Snake River Basin hatcheries for migration year 2020. 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 Cr Trap | 5-7 May 2020 | 49,666 | 0.640 (0.014) | 0.947 (0.256) | 1.670 (0.850) | 0.532 (0.242) | 0.842 (0.121) | 0.539 (0.076) |
| | | | | **Coho salmon** | | | | |
| **Eagle Creek Hatchery** | | | | | | | | |
| Kooskia Hatchery | 24 March 2020 | 4,953 | 0.426 (0.026) | 0.643 (0.194) | 0.894 (0.425) | 1.729 (0.842) | 0.995 (0.325) | 0.424 (0.136) |
| N Lapwai Valley Pd | 27 March 2020 | 4,987 | 0.695 (0.025) | NA | NA | NA | NA | NA |
| **Kooskia Hatchery** | | | | | | | | |
| Kooskia Hatchery | 23 March 2020 | 4,983 | 0.410 (0.025) | NA | NA | NA | NA | NA |

Appendix Table B4. Detection probability estimates for yearling Chinook salmon released from Snake River Basin hatcheries in 2020. 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 | 9,691 | 0.279 (0.011) | 0.026 (0.007) | 0.012 (0.005) | 0.042 (0.006) |
| Powell Pond | 25,364 | 0.356 (0.008) | 0.036 (0.005) | 0.021 (0.004) | 0.043 (0.004) |
| Red River Pond | 17,029 | 0.258 (0.011) | 0.040 (0.008) | 0.026 (0.007) | 0.050 (0.007) |
| Selway River | 17,054 | 0.380 (0.011) | 0.022 (0.005) | 0.014 (0.004) | 0.036 (0.005) |
| N F Clearwater R | 17,039 | 0.394 (0.009) | 0.022 (0.004) | 0.010 (0.003) | 0.037 (0.004) |
| **Dworshak Hatchery** | | | | | |
| N F Clearwater R | 41,950 | 0.399 (0.006) | 0.033 (0.003) | 0.011 (0.002) | 0.055 (0.004) |
| **Kooskia Hatchery** | | | | | |
| Kooskia | 7,876 | 0.326 (0.014) | 0.040 (0.009) | 0.037 (0.011) | 0.078 (0.011) |
| **Lookingglass Hatchery** | | | | | |
| Catherine Cr Pond | 20,999 | 0.274 (0.008) | 0.115 (0.010) | 0.040 (0.008) | 0.048 (0.006) |
| Grande Ronde P | 1,997 | 0.243 (0.030) | 0.114 (0.027) | 0.051 (0.020) | 0.043 (0.021) |
| Imnaha Weir | 20,997 | 0.278 (0.008) | 0.063 (0.009) | 0.036 (0.006) | 0.061 (0.006) |
| Lookingglass H | 5,004 | 0.272 (0.016) | 0.093 (0.012) | 0.038 (0.008) | 0.044 (0.010) |
| Lostine Pond | 5,649 | 0.267 (0.015) | 0.085 (0.011) | 0.045 (0.009) | 0.047 (0.010) |
| **McCall Hatchery** | | | | | |
| Knox Bridge | 51,800 | 0.274 (0.005) | 0.067 (0.005) | 0.049 (0.004) | 0.043 (0.003) |
| Johnson Creek | 2,003 | 0.266 (0.028) | 0.082 (0.020) | 0.029 (0.014) | 0.035 (0.017) |
| **Pahsimeroi Hatchery** | | | | | |
| Pahsimeroi Pond | 21,381 | 0.269 (0.010) | 0.085 (0.010) | 0.023 (0.007) | 0.040 (0.006) |
| **Rapid River Hatchery** | | | | | |
| Rapid River Hatch | 51,758 | 0.328 (0.006) | 0.053 (0.005) | 0.031 (0.004) | 0.060 (0.004) |
| **Sawtooth Hatchery** | | | | | |
| Alturas Lake Cr | 990 | 0.346 (0.039) | 0.039 (0.017) | 0.047 (0.020) | 0.012 (0.012) |
| Sawtooth H. | 18,743 | 0.289 (0.009) | 0.043 (0.007) | 0.018 (0.005) | 0.051 (0.006) |
| Yankee Fork | 2,458 | 0.257 (0.028) | 0.071 (0.034) | 0.034 (0.022) | 0.072 (0.022) |

Appendix Table B5. Detection probability estimates for juvenile steelhead released from Snake River Basin hatcheries in 2020. 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 | 10,712 | 0.676 (0.009) | 0.084 (0.007) | 0.024 (0.005) | 0.020 (0.004) |
| Newsome Creek | 2,563 | 0.489 (0.022) | 0.045 (0.016) | 0.031 (0.014) | 0.032 (0.010) |
| S Fork Clearwater R | 4,674 | 0.662 (0.015) | 0.069 (0.011) | 0.013 (0.005) | 0.035 (0.007) |
| **Dworshak Hatchery** | | | | | |
| S Fork Clearwater R | 8,888 | 0.658 (0.010) | 0.122 (0.010) | 0.027 (0.006) | 0.034 (0.005) |
| Dworshak NFH | 15,475 | 0.662 (0.008) | 0.102 (0.007) | 0.028 (0.005) | 0.024 (0.003) |
| Lolo Creek | 1,000 | 0.461 (0.044) | NA | NA | NA |
| **Hagerman Hatchery** | | | | | |
| East Fork Salmon R | 8,570 | 0.458 (0.013) | 0.055 (0.011) | 0.044 (0.010) | 0.019 (0.004) |
| Sawtooth Hatchery | 29,795 | 0.506 (0.007) | 0.060 (0.005) | 0.023 (0.004) | 0.014 (0.002) |
| **Irrigon Hatchery** | | | | | |
| Big Canyon Facility | 6,736 | 0.470 (0.013) | 0.078 (0.011) | 0.039 (0.008) | 0.011 (0.003) |
| Little Sheep Facility | 14,887 | 0.559 (0.008) | 0.077 (0.006) | 0.026 (0.004) | 0.014 (0.002) |
| Wallowa Hatchery | 10,706 | 0.514 (0.011) | 0.045 (0.007) | 0.025 (0.005) | 0.012 (0.003) |
| **Lyons Ferry Hatchery** | | | | | |
| Cottonwood Pond | 5,700 | 0.642 (0.011) | 0.102 (0.011) | 0.041 (0.009) | 0.011 (0.003) |
| **Magic Valley Hatchery** | | | | | |
| Little Salmon R | 4,568 | 0.432 (0.015) | 0.060 (0.012) | 0.029 (0.009) | 0.009 (0.003) |
| Pahsimeroi R Trap | 11,058 | 0.435 (0.011) | 0.047 (0.008) | 0.018 (0.005) | 0.012 (0.003) |
| Sawtooth Hatchery | 5,671 | 0.390 (0.015) | 0.050 (0.012) | 0.018 (0.008) | 0.013 (0.004) |
| Yankee Fork | 13,167 | 0.428 (0.011) | 0.087 (0.010) | 0.025 (0.007) | 0.020 (0.004) |
| **Niagara Springs Hatchery** | | | | | |
| Hells Canyon Dam | 8,569 | 0.458 (0.011) | 0.073 (0.008) | 0.021 (0.006) | 0.013 (0.003) |
| Little Salmon R | 4,898 | 0.392 (0.016) | 0.082 (0.015) | 0.046 (0.013) | 0.026 (0.007) |
| Pahsimeroi Trap | 8,970 | 0.433 (0.012) | 0.052 (0.008) | 0.014 (0.005) | 0.013 (0.003) |

Appendix Table B6. Detection probability estimates for juvenile sockeye and coho salmon released from Snake River Basin hatcheries for migration year 2020. 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 Lk Cr Trap | 5-7 May | 49,666 | 0.353 (0.008) | 0.012 (0.003) | 0.006 (0.002) | 0.016 (0.002) |
| | | | **Coho salmon** | | | |
| **Eagle Creek Hatchery** | | | | | | |
| Kooskia Hatchery | 24 March | 4,953 | 0.338 (0.022) | 0.076 (0.024) | 0.040 (0.016) | 0.028 (0.010) |
| Lapwai Valley Pd | 27 March | 4,987 | 0.409 (0.016) | 0.032 (0.012) | NA | NA |
| **Kooskia Hatchery** | | | | | | |
| Kooskia Hatchery | 23 March | 4,983 | 0.319 (0.022) | 0.015 (0.015) | 0.028 (0.023) | 0.019 (0.008) |

Appendix Table B7. Survival probability estimates for juvenile salmonids released from traps in Snake River Basin in 2020. 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 | 01 Apr-19 May | 52 | 69 | 0.703 (0.111) | NA | NA | NA | NA |
| Grande Ronde | 06 Mar-26 May | 100 | 1,317 | 0.897 (0.066) | 2.715 (1.817) | 0.792 (0.922) | 0.250 (0.250) | 0.483 (0.130) |
| Imnaha | 01 Feb-30 May | 142 | 3,867 | 0.961 (0.050) | 0.845 (0.158) | 0.922 (0.333) | 0.617 (0.213) | 0.462 (0.064) |
| Lolo Creek | 12 Mar-31 May | 159 | 624 | 0.904 (0.150) | NA | NA | NA | NA |
| Salmon | 13 Mar-11 May | 233 | 2,317 | 0.813 (0.038) | 1.322 (0.408) | 0.785 (0.371) | 0.658 (0.261) | 0.556 (0.090) |
| Lookingglass Cr | 02 Feb-15 May | 235 | 155 | 0.406 (0.088) | NA | NA | NA | NA |
| Minam | 07 Mar-20 May | 246 | 896 | 0.509 (0.046) | 1.119 (0.351) | 0.983 (0.579) | 0.989 (0.668) | 0.554 (0.248) |
| Lostine | 01 Feb-28 May | 274 | 927 | 0.545 (0.055) | 1.814 (0.964) | 0.366 (0.245) | 1.343 (0.890) | 0.486 (0.251) |
| Catherine Creek | 24 Feb-18 May | 362 | 320 | 0.402 (0.086) | NA | NA | NA | NA |
| U. Grande Ronde | 11 Mar-15 May | 397 | 718 | 0.421 (0.062) | 0.718 (0.298) | NA | NA | NA |
| S. Fork Salmon | 28 Mar-29 Apr | 408 | 797 | 0.725 (0.071) | 0.965 (0.351) | NA | NA | NA |
| Johnson Creek | 27 Feb-26 May | 436 | 483 | 0.403 (0.072) | 0.608 (0.236) | 1.047 (0.718) | 0.871 (0.733) | 0.224 (0.135) |
| Lower Lemhi R. | 10 Mar-24 May | 553 | 1,551 | 0.719 (0.047) | 1.089 (0.320) | 1.069 (0.631) | 0.619 (0.374) | 0.518 (0.158) |
| Upper Lemhi R. | 27 Mar-30 May | 595 | 506 | 0.880 (0.117) | 0.585 (0.202) | 0.983 (0.533) | 0.981 (0.558) | 0.496 (0.176) |
| Pahsimeroi | 02 Apr-31 May | 621 | 156 | 0.701 (0.214) | NA | NA | NA | NA |
| Marsh Creek | 24 Mar-30 Apr | 630 | 174 | 0.632 (0.147) | NA | NA | NA | NA |
| Sawtooth | 21 Mar-31 May | 747 | 365 | 0.578 (0.096) | 1.229 (0.767) | 0.762 (0.793) | NA | NA |
| **Wild Sockeye Salmon** | | | | | | | | |
| Redfish Lake Cr | 21 Apr-31 May | 748 | 533 | 0.705 (0.122) | 0.699 (0.250) | NA | NA | NA |

Appendix Table B7. Continued.

| Trap | Release dates | Distance to LGR (km) | Number released | Release to Lower Granite | Lower Granite to Little Goose | Little Goose to Lower Monumental | Lower Monumental to McNary Dam | Release to McNary Dam |
|---|---|---|---|---|---|---|---|---|
| **Wild Steelhead** | | | | | | | | |
| Snake | 10 Mar-19 May | 52 | 124 | 0.802 (0.109) | NA | NA | NA | NA |
| Asotin Creek | 01 Feb-31 May | 64 | 3,075 | 0.726 (0.029) | 1.170 (0.288) | 0.676 (0.252) | 1.378 (0.643) | 0.791 (0.293) |
| Grande Ronde | 15 Mar-26 May | 100 | 235 | 1.032 (0.168) | 0.519 (0.250) | 0.615 (0.371) | 1.833 (1.714) | 0.604 (0.516) |
| Imnaha | 05 Feb-30 May | 142 | 4,624 | 0.790 (0.024) | 1.299 (0.230) | 0.696 (0.192) | 1.921 (0.914) | 1.373 (0.583) |
| Lolo Creek | 31 Mar-31 May | 159 | 137 | 0.766 (0.206) | NA | NA | NA | NA |
| Lochsa River | 31 Mar-19 May | 208 | 469 | 0.972 (0.102) | 1.202 (1.071) | 0.600 (0.755) | 0.860 (0.930) | 0.602 (0.375) |
| Salmon | 30 Mar-11 May | 233 | 152 | 0.922 (0.136) | NA | NA | NA | NA |
| Minam | 09 Mar-29 May | 246 | 379 | 0.819 (0.116) | NA | NA | NA | NA |
| Lostine | 05 Feb-21 May | 274 | 141 | 0.545 (0.112) | NA | NA | NA | NA |
| Upper Grande Ronde | 11 Mar-19 May | 397 | 419 | 0.489 (0.087) | 0.810 (0.669) | NA | NA | NA |
| Lower Lemhi R. | 11 Mar-30 May | 553 | 328 | 0.612 (0.105) | NA | NA | NA | NA |
| Hayden Creek | 08 Apr-29 May | 596 | 360 | 0.556 (0.090) | NA | NA | NA | NA |
| **Hatchery Chinook Salmon** | | | | | | | | |
| Snake | 17 Mar-19 May | 52 | 1,561 | 0.869 (0.063) | 0.857 (0.182) | 1.604 (0.736) | 1.158 (0.727) | 1.383 (0.653) |
| Grande Ronde | 25 Mar-27 May | 100 | 1,385 | 0.793 (0.058) | 1.123 (0.229) | 0.877 (0.270) | 0.610 (0.213) | 0.476 (0.120) |
| Salmon | 17 Mar-30 Apr | 233 | 3,999 | 0.755 (0.036) | 1.098 (0.205) | 1.416 (0.510) | 0.597 (0.225) | 0.701 (0.149) |
| **Hatchery Steelhead** | | | | | | | | |
| Snake | 12 Feb-19 May | 52 | 1,722 | 0.924 (0.044) | 1.345 (0.317) | 1.156 (0.550) | 0.388 (0.208) | 0.557 (0.189) |
| Grande Ronde | 30 Mar-27 May | 100 | 1,174 | 0.832 (0.038) | 0.808 (0.137) | 1.106 (0.432) | 1.458 (1.081) | 1.085 (0.706) |
| Salmon | 10 Apr-11 May | 233 | 1,245 | 0.806 (0.041) | 1.149 (0.261) | NA | NA | NA |

Appendix Table B8. Detection probability estimates for juvenile salmonids released from fish traps in Snake River Basin in 2020. 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 | 01 Apr-19 May | 52 | 69 | 0.639 (0.112) | NA | NA | NA |
| Grande Ronde | 06 Mar-26 May | 100 | 1,317 | 0.333 (0.028) | 0.028 (0.019) | 0.020 (0.019) | 0.075 (0.023) |
| Imnaha | 01 Feb-30 May | 142 | 3,867 | 0.286 (0.017) | 0.060 (0.012) | 0.033 (0.011) | 0.100 (0.016) |
| Lolo Creek | 12 Mar-31 May | 159 | 624 | 0.229 (0.042) | NA | NA | NA |
| Salmon | 13 Mar-11 May | 233 | 2,317 | 0.387 (0.021) | 0.053 (0.017) | 0.046 (0.017) | 0.110 (0.020) |
| Lookingglass Cr | 02 Feb-15 May | 235 | 155 | 0.476 (0.111) | NA | NA | NA |
| Minam | 07 Mar-20 May | 246 | 896 | 0.382 (0.039) | 0.116 (0.038) | 0.057 (0.030) | 0.064 (0.031) |
| Lostine | 01 Feb-28 May | 274 | 927 | 0.360 (0.041) | 0.050 (0.027) | 0.084 (0.037) | 0.057 (0.032) |
| Catherine Creek | 24 Feb-18 May | 362 | 320 | 0.350 (0.082) | NA | NA | NA |
| U. Grande Ronde | 11 Mar-15 May | 397 | 718 | 0.351 (0.057) | 0.140 (0.059) | NA | NA |
| S. Fork Salmon | 28 Mar-29 Apr | 408 | 797 | 0.322 (0.036) | 0.128 (0.047) | NA | NA |
| Johnson Creek | 27 Feb-26 May | 436 | 483 | 0.354 (0.069) | 0.135 (0.056) | 0.064 (0.044) | 0.083 (0.056) |
| Lower Lemhi R. | 10 Mar-24 May | 553 | 1,551 | 0.354 (0.027) | 0.101 (0.030) | 0.050 (0.026) | 0.053 (0.018) |
| Upper Lemhi R. | 27 Mar-30 May | 595 | 506 | 0.301 (0.045) | 0.114 (0.041) | 0.078 (0.038) | 0.074 (0.032) |
| Pahsimeroi | 02 Apr-31 May | 621 | 156 | 0.293 (0.098) | NA | NA | NA |
| Marsh Creek | 24 Mar-30 Apr | 630 | 174 | 0.373 (0.096) | NA | NA | NA |
| Sawtooth | 21 Mar-31 May | 747 | 365 | 0.322 (0.061) | 0.070 (0.045) | NA | NA |
| **Wild Sockeye Salmon** | | | | | | | |
| Redfish Lake Cr | 21 Apr-31 May | 748 | 533 | 0.242 (0.047) | 0.115 (0.041) | NA | NA |

Appendix Table B8. Continued.

| Trap | Release dates | Distance to LGR (km) | Number released | Lower Granite Dam | Little Goose Dam | Lower Monumental Dam | McNary Dam |
|---|---|---|---|---|---|---|---|
| | | | **Wild Steelhead** | | | | |
| Snake | 10 Mar-19 May | 52 | 124 | 0.613 (0.092) | NA | NA | NA |
| Asotin Creek | 01 Feb-31 May | 64 | 3,075 | 0.437 (0.020) | 0.072 (0.018) | 0.068 (0.020) | 0.018 (0.007) |
| Grande Ronde | 15 Mar-26 May | 100 | 235 | 0.396 (0.072) | 0.092 (0.049) | 0.083 (0.046) | 0.030 (0.030) |
| Imnaha | 05 Feb-30 May | 142 | 4,624 | 0.472 (0.016) | 0.064 (0.012) | 0.058 (0.013) | 0.010 (0.004) |
| Lolo Creek | 31 Mar-31 May | 159 | 137 | 0.314 (0.095) | NA | NA | NA |
| Lochsa River | 31 Mar-19 May | 208 | 469 | 0.432 (0.051) | 0.051 (0.046) | 0.048 (0.043) | 0.041 (0.028) |
| Salmon | 30 Mar-11 May | 233 | 152 | 0.578 (0.094) | NA | NA | NA |
| Minam | 09 Mar-29 May | 246 | 379 | 0.374 (0.059) | NA | NA | NA |
| Lostine | 05 Feb-21 May | 274 | 141 | 0.469 (0.106) | NA | NA | NA |
| Upper Grande Ronde | 11 Mar-19 May | 397 | 419 | 0.366 (0.071) | 0.085 (0.072) | NA | NA |
| Lower Lemhi R. | 11 Mar-30 May | 553 | 328 | 0.403 (0.075) | NA | NA | NA |
| Hayden Creek | 08 Apr-29 May | 596 | 360 | 0.429 (0.075) | NA | NA | NA |
| | | | **Hatchery Chinook Salmon** | | | | |
| Snake | 17 Mar-19 May | 52 | 1,561 | 0.307 (0.026) | 0.068 (0.016) | 0.022 (0.010) | 0.021 (0.010) |
| Grande Ronde | 25 Mar-27 May | 100 | 1,385 | 0.285 (0.025) | 0.078 (0.017) | 0.067 (0.018) | 0.066 (0.019) |
| Salmon | 17 Mar-30 Apr | 233 | 3,999 | 0.336 (0.018) | 0.042 (0.008) | 0.018 (0.006) | 0.044 (0.010) |
| | | | **Hatchery Steelhead** | | | | |
| Snake | 12 Feb-19 May | 124 | 1,722 | 0.445 (0.024) | 0.045 (0.011) | 0.017 (0.007) | 0.021 (0.008) |
| Grande Ronde | 30 Mar-27 May | 235 | 1,174 | 0.562 (0.030) | 0.118 (0.022) | 0.031 (0.013) | 0.011 (0.008) |
| Salmon | 10 Apr-11 May | 152 | 1,245 | 0.492 (0.029) | 0.066 (0.016) | 0.026 (0.011) | 0.005 (0.005) |

Appendix Table B9. Survival probability estimates for yearling Chinook, steelhead, and coho salmon released from upper-Columbia River hatcheries in 2020. Standard errors in parentheses.

| Hatchery/ Release site | Number released | Release to McNary Dam | McNary to John Day Dam | John Day to Bonneville Dam | McNary to Bonneville Dam | Release to Bonneville Dam |
|---|---|---|---|---|---|---|
| **Yearling Chinook salmon** | | | | | | |
| **Chiwawa Hatchery** | | | | | | |
| Chiwawa Pond | 10,074 | 0.592 (0.067) | 0.902 (0.128) | 0.941 (0.274) | 0.849 (0.256) | 0.503 (0.140) |
| **Cle Elum Hatchery** | | | | | | |
| Clark Flat Pond | 16,002 | 0.342 (0.041) | 0.930 (0.151) | 0.702 (0.159) | 0.653 (0.151) | 0.223 (0.044) |
| Easton Pond | 12,741 | 0.227 (0.032) | 1.100 (0.238) | 0.863 (0.315) | 0.949 (0.338) | 0.216 (0.070) |
| Jack Creek Pond | 11,997 | 0.247 (0.038) | 0.661 (0.157) | NA | NA | NA |
| **East Bank Hatchery** | | | | | | |
| Carlton Pond | 5,052 | 0.571 (0.122) | 1.139 (0.366) | NA | NA | NA |
| Chelan River | 10,323 | 0.824 (0.123) | 0.773 (0.159) | 0.587 (0.171) | 0.453 (0.133) | 0.374 (0.095) |
| Dryden Pond | 20,724 | 0.682 (0.075) | 0.934 (0.152) | 0.854 (0.257) | 0.797 (0.237) | 0.544 (0.150) |
| Nason Acclimation F. | 10,099 | 0.835 (0.121) | 0.628 (0.107) | 1.272 (0.709) | 0.799 (0.454) | 0.667 (0.367) |
| **Entiat Hatchery** | | | | | | |
| Entiat Hatchery | 19,936 | 0.570 (0.054) | 1.087 (0.146) | 1.079 (0.246) | 1.172 (0.268) | 0.668 (0.139) |
| **Leavenworth Hatchery** | | | | | | |
| Leavenworth NFH | 19,952 | 0.618 (0.051) | 0.858 (0.093) | 0.766 (0.321) | 0.657 (0.277) | 0.406 (0.168) |
| **Methow Hatchery** | | | | | | |
| Chewuch Pond | 4,987 | 0.644 (0.158) | 1.124 (0.401) | 0.424 (0.193) | 0.477 (0.213) | 0.307 (0.114) |
| Goatwall Pond | 4,963 | 0.703 (0.271) | 1.134 (0.599) | 0.196 (0.097) | 0.223 (0.113) | 0.157 (0.052) |
| Methow Hatchery | 4,989 | 0.555 (0.140) | 1.066 (0.377) | 0.365 (0.145) | 0.389 (0.155) | 0.216 (0.067) |
| Twisp Pond | 4,984 | 0.525 (0.127) | 0.982 (0.328) | NA | NA | NA |
| **Wells Hatchery** | | | | | | |
| Wells Hatchery | 14,882 | 0.483 (0.080) | 0.884 (0.212) | 0.925 (0.426) | 0.818 (0.375) | 0.395 (0.169) |
| **Winthrop Hatchery** | | | | | | |
| Winthrop NFH | 19,864 | 0.590 (0.068) | 0.859 (0.133) | 1.021 (0.324) | 0.877 (0.281) | 0.517 (0.155) |

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 | 32,675 | 0.265 (0.045) | 0.724 (0.138) | 0.776 (0.160) | 0.562 (0.142) | 0.149 (0.028) |
| **Wells Hatchery** | | | | | | |
| Antoine Creek | 4,996 | 0.734 (0.391) | 0.678 (0.384) | 0.447 (0.197) | 0.303 (0.202) | 0.223 (0.088) |
| Methow Hatchery | 4,988 | 0.645 (0.198) | 1.039 (0.349) | 1.400 (0.616) | 1.455 (0.753) | 0.938 (0.392) |
| Omak Pond | 4,986 | 0.524 (0.132) | 0.827 (0.231) | 1.124 (0.415) | 0.930 (0.398) | 0.488 (0.170) |
| Salmon Creek | 4,985 | 1.276 (0.706) | 0.301 (0.174) | 1.573 (1.077) | 0.474 (0.411) | 0.604 (0.403) |
| St. Marys Pond | 4,993 | 0.100 (0.033) | 1.097 (0.430) | 1.601 (1.548) | 1.756 (1.753) | 0.176 (0.166) |
| Twisp River | 2,491 | 1.225 (1.178) | 0.351 (0.350) | 0.562 (0.250) | 0.197 (0.202) | 0.242 (0.086) |
| Wells Hatchery | 4,978 | 1.074 (0.437) | 0.671 (0.289) | 0.916 (0.331) | 0.615 (0.323) | 0.660 (0.219) |
| Winthrop NFH | 2,341 | 0.590 (0.234) | 0.822 (0.367) | 0.462 (0.163) | 0.380 (0.186) | 0.224 (0.065) |
| **Winthrop Hatchery** | | | | | | |
| Twisp Pond | 3,977 | 0.266 (0.134) | 1.941 (1.227) | 0.724 (0.554) | 1.405 (1.169) | 0.374 (0.248) |
| Winthrop NFH | 29,384 | 0.405 (0.054) | 1.054 (0.160) | 0.735 (0.111) | 0.775 (0.145) | 0.314 (0.041) |

Appendix Table B9. Continued.

| Hatchery/<br>Release site | Number<br>released | Release<br>to McNary Dam | McNary<br>to John Day Dam | John Day to<br>Bonneville Dam | McNary to<br>Bonneville Dam | Release to Bonneville<br>Dam |
|---|---|---|---|---|---|---|
| | | | **Coho salmon** | | | |
| **Cascade Hatchery** | | | | | | |
| Early Winters Pond | 2,487 | 0.330 (0.106) | 1.068 (0.453) | 0.770 (0.521) | 0.822 (0.572) | 0.271 (0.167) |
| Eightmile Pond | 2,457 | 0.275 (0.069) | 1.518 (0.526) | 0.656 (0.323) | 0.996 (0.493) | 0.274 (0.117) |
| Mid-Valley Pond | 2,484 | 1.425 (0.961) | 0.350 (0.247) | 0.668 (0.363) | 0.234 (0.197) | 0.334 (0.168) |
| Rolfing Pond | 9,922 | 0.371 (0.062) | 0.782 (0.155) | 0.749 (0.216) | 0.586 (0.185) | 0.217 (0.058) |
| Twisp Pond | 2,471 | 0.273 (0.068) | 1.587 (0.542) | NA | NA | NA |
| **Eagle Hatchery** | | | | | | |
| Prosser Hatchery | 9,973 | 0.516 (0.068) | 0.767 (0.131) | 1.235 (0.302) | 0.947 (0.241) | 0.489 (0.107) |
| **Wells Hatchery** | | | | | | |
| Twisp Pond | 2,499 | 0.402 (0.120) | 1.134 (0.409) | NA | NA | NA |
| **Willard Hatchery** | | | | | | |
| Chewuch Pond | 4,966 | 0.856 (0.401) | 0.358 (0.175) | 0.881 (0.277) | 0.316 (0.173) | 0.270 (0.076) |
| Coulter Pond | 4,977 | 0.594 (0.278) | 0.366 (0.180) | 1.381 (0.913) | 0.505 (0.401) | 0.300 (0.193) |
| Early Winters Pond | 2,477 | 0.305 (0.109) | 0.816 (0.365) | NA | NA | NA |
| Eightmile Pond | 2,478 | 0.444 (0.156) | 1.208 (0.532) | 0.498 (0.204) | 0.602 (0.281) | 0.267 (0.083) |
| Leavenworth NFH | 9,934 | 0.484 (0.088) | 0.795 (0.163) | 1.503 (0.722) | 1.194 (0.603) | 0.578 (0.272) |
| Mid-Valley Pond | 2,495 | 0.744 (0.490) | 0.505 (0.352) | 0.725 (0.478) | 0.366 (0.331) | 0.272 (0.169) |
| **Winthrop Hatchery** | | | | | | |
| Winthrop NFH | 4,949 | 0.356 (0.073) | 1.310 (0.340) | 0.606 (0.230) | 0.794 (0.319) | 0.282 (0.098) |
| **Yakima Hatchery** | | | | | | |
| Prosser Hacthery | 2,951 | 0.422 (0.099) | 0.484 (0.138) | 0.777 (0.252) | 0.377 (0.138) | 0.159 (0.045) |

Appendix Table B10. Detection probability estimates for yearling Chinook salmon, steelhead, and coho salmon released from upper-Columbia River hatcheries in 2020. Standard errors in parentheses.

| Hatchery/ Release site | Number released | McNary Dam | John Day Dam | Bonneville Dam |
|---|---|---|---|---|
| **Yearling Chinook salmon** | | | | |
| **Chiwawa Hatchery** | | | | |
| Chiwawa Pond | 10,074 | 0.041 (0.005) | 0.141 (0.013) | 0.130 (0.036) |
| **Cle Elum Hatchery** | | | | |
| Clark Flat Pond | 16,002 | 0.048 (0.006) | 0.082 (0.010) | 0.194 (0.039) |
| Easton Pond | 12,741 | 0.062 (0.010) | 0.074 (0.013) | 0.127 (0.042) |
| Jack Creek Pond | 11,997 | 0.078 (0.013) | 0.078 (0.015) | 0.057 (0.039) |
| **East Bank Hatchery** | | | | |
| Carlton Pond | 5,052 | 0.043 (0.010) | 0.068 (0.017) | 0.027 (0.027) |
| Chelan River | 10,323 | 0.037 (0.006) | 0.068 (0.010) | 0.138 (0.036) |
| Dryden Pond | 20,724 | 0.041 (0.005) | 0.064 (0.008) | 0.069 (0.019) |
| Nason Acclimation F. | 10,099 | 0.030 (0.005) | 0.149 (0.014) | 0.088 (0.049) |
| **Entiat Hatchery** | | | | |
| Entiat Hatchery | 19,936 | 0.042 (0.004) | 0.080 (0.008) | 0.066 (0.014) |
| **Leavenworth Hatchery** | | | | |
| Leavenworth NFH | 19,952 | 0.048 (0.004) | 0.127 (0.010) | 0.143 (0.059) |
| **Methow Hatchery** | | | | |
| Chewuch Pond | 4,987 | 0.033 (0.009) | 0.050 (0.014) | 0.146 (0.055) |
| Goatwall Pond | 4,963 | 0.019 (0.008) | 0.039 (0.014) | 0.196 (0.066) |
| Methow Hatchery | 4,989 | 0.032 (0.009) | 0.054 (0.014) | 0.212 (0.066) |
| Twisp Pond | 4,984 | 0.036 (0.009) | 0.076 (0.018) | NA |
| **Wells Hatchery** | | | | |
| Wells Hatchery | 14,882 | 0.037 (0.006) | 0.056 (0.010) | 0.077 (0.033) |
| **Winthrop Hatchery** | | | | |
| Winthrop NFH | 19,864 | 0.036 (0.004) | 0.074 (0.008) | 0.093 (0.028) |
| **Steelhead** | | | | |
| **Chiwawa Hatchery** | | | | |
| Chiwawa River | 32,675 | 0.019 (0.004) | 0.128 (0.012) | 0.130 (0.025) |
| **Wells Hatchery** | | | | |
| Antoine Creek | 4,996 | 0.006 (0.003) | 0.054 (0.011) | 0.364 (0.145) |
| Methow Hatchery | 4,988 | 0.010 (0.004) | 0.068 (0.010) | 0.119 (0.050) |
| Omak Pond | 4,986 | 0.020 (0.006) | 0.126 (0.017) | 0.137 (0.048) |
| Salmon Creek | 4,985 | 0.006 (0.004) | 0.090 (0.016) | 0.105 (0.070) |
| St. Marys Pond | 4,993 | 0.036 (0.014) | 0.155 (0.037) | 0.100 (0.095) |
| Twisp River | 2,491 | 0.005 (0.005) | 0.073 (0.021) | 0.214 (0.078) |
| Wells Hatchery | 4,978 | 0.006 (0.002) | 0.052 (0.008) | 0.219 (0.073) |
| Winthrop NFH | 2,341 | 0.018 (0.008) | 0.101 (0.023) | 0.308 (0.090) |
| **Winthrop Hatchery** | | | | |
| Twisp Pond | 3,977 | 0.012 (0.007) | 0.034 (0.014) | 0.111 (0.074) |
| Winthrop NFH | 29,384 | 0.016 (0.002) | 0.076 (0.006) | 0.184 (0.024) |

Appendix Table B10. Continued.

| Hatchery/ Release site | Number released | McNary Dam | John Day Dam | Bonneville Dam |
|---|---|---|---|---|
| | | **Coho Salmon** | | |
| **Cascade Hatchery** | | | | |
| Early Winters Pond | 2,487 | 0.034 (0.013) | 0.064 (0.020) | 0.226 (0.140) |
| Eightmile Pond | 2,457 | 0.042 (0.013) | 0.072 (0.019) | 0.250 (0.108) |
| Mid-Valley Pond | 2,484 | 0.007 (0.005) | 0.090 (0.020) | 0.231 (0.117) |
| Rolfing Pond | 9,922 | 0.032 (0.006) | 0.102 (0.012) | 0.271 (0.073) |
| Twisp Pond | 2,471 | 0.042 (0.013) | 0.086 (0.022) | 0.111 (0.105) |
| **Eagle Hatchery** | | | | |
| Prosser Hatchery | 9,973 | 0.040 (0.006) | 0.064 (0.008) | 0.175 (0.039) |
| **Wells Hatchery** | | | | |
| Twisp Pond | 2,499 | 0.029 (0.010) | 0.098 (0.022) | 0.048 (0.047) |
| **Willard Hatchery** | | | | |
| Chewuch Pond | 4,966 | 0.008 (0.004) | 0.092 (0.015) | 0.265 (0.076) |
| Coulter Pond | 4,977 | 0.012 (0.006) | 0.108 (0.019) | 0.167 (0.108) |
| Early Winters Pond | 2,477 | 0.037 (0.015) | 0.083 (0.025) | NA |
| Eightmile Pond | 2,478 | 0.022 (0.009) | 0.051 (0.015) | 0.305 (0.096) |
| Leavenworth NFH | 9,934 | 0.022 (0.004) | 0.129 (0.013) | 0.106 (0.050) |
| Mid-Valley Pond | 2,495 | 0.009 (0.006) | 0.095 (0.023) | 0.222 (0.139) |
| **Winthrop Hatchery** | | | | |
| Winthrop NFH | 4,949 | 0.030 (0.007) | 0.075 (0.013) | 0.273 (0.095) |
| **Yakima Hatchery** | | | | |
| Prosser Hatchery | 2,951 | 0.063 (0.016) | 0.140 (0.026) | 0.333 (0.096) |

# Appendix C: Environmental Conditions and Salmonid Passage Timing

## Methods

In August 2020 we obtained data on daily flow, temperature, spill, and dissolved gas saturation (TDG) at Snake River dams from Columbia River DART (1996-) and collection counts of yearling Chinook salmon and steelhead (hatchery and wild combined) compiled by the Smolt Monitoring Program (FPC 2020a). We created plots to compare daily measures of flow, temperature, and spill, and TDG in 2020 to selected recent years, and to long-term daily quantiles from values during 1989-2020 for flow, 1996-2020 for temperature, and 2006-2020 for spill and TDG.

We combined collection count data with daily estimates of the proportion of fish using the juvenile bypass system (equivalent to daily estimates of PIT-tag detection probabilities) to calculate daily estimates of the number of smolts passing Lower Granite Dam. For visual comparison, we normalized the daily estimates by dividing by the annual total, and created plots of these daily passage proportions to compare with those during 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 the average daily flow at Lower Monumental Dam during the period between the 25$^{th}$ and 75$^{th}$ 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 and management actions in 2020 resulted in a year with overall average water temperatures (but with high variability day-to-day), lower than average flow, and extremely high spill for most of the migration season. Mean flow at Little Goose Dam in 2020 during the main migration period 1 April-15 June was 80.4 kcfs, which was below the long-term (1993-2020) mean of 93.2 kcfs. Daily flow values were well below long-term daily means for most of April; in late April and May, a number of short pulses in flow resulted in rapid fluctuations from below to above the daily mean (Appendix Figure C1).

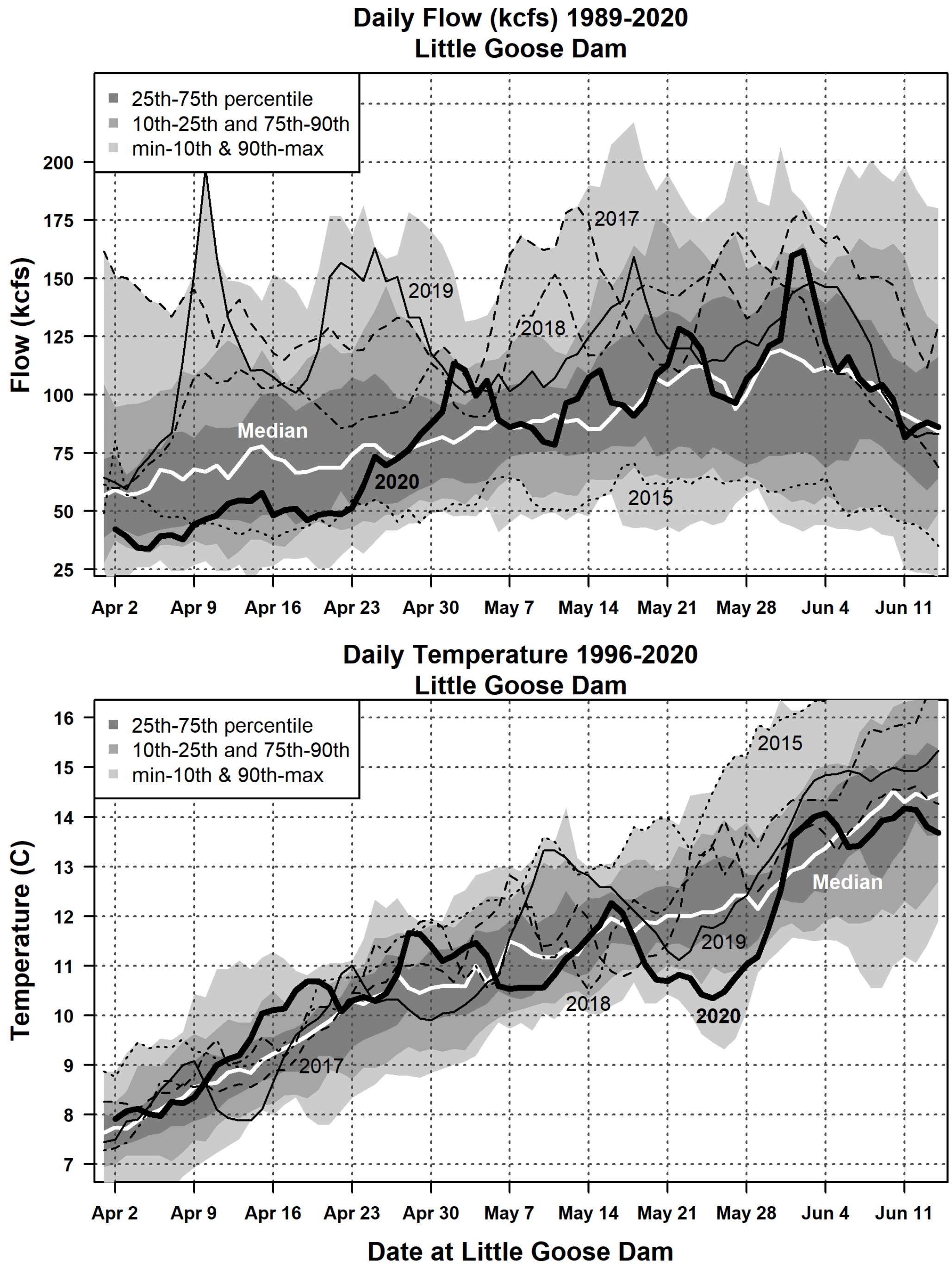
Mean water temperature at Little Goose Dam during the 2020 migration period was 11.0 °C, which was near the long-term mean of 11.2 °C. However, during late April and May when there were rapid changes in flow there were also sharp fluctuations in daily water temperature (Appendix Figure C1). Multiple peaks in water temperature were observed in May and June, including extremely rapid warming during the first few days of June. These fluctuations in water temperature did not appear to closely correlate with the fluctuations in flow.

Mean spill discharge at the Snake River dams during the 2020 migration was 52.4 kcfs, which was far above the 2006-2020 mean of 35.5 kcfs and was the highest mean spill in our time series, except for the high-flow year 2017. Daily spill discharge was only slightly above average for most of April, rose to well above average in late April, and stayed very high for the remainder of the migration period (Appendix Figure C2).

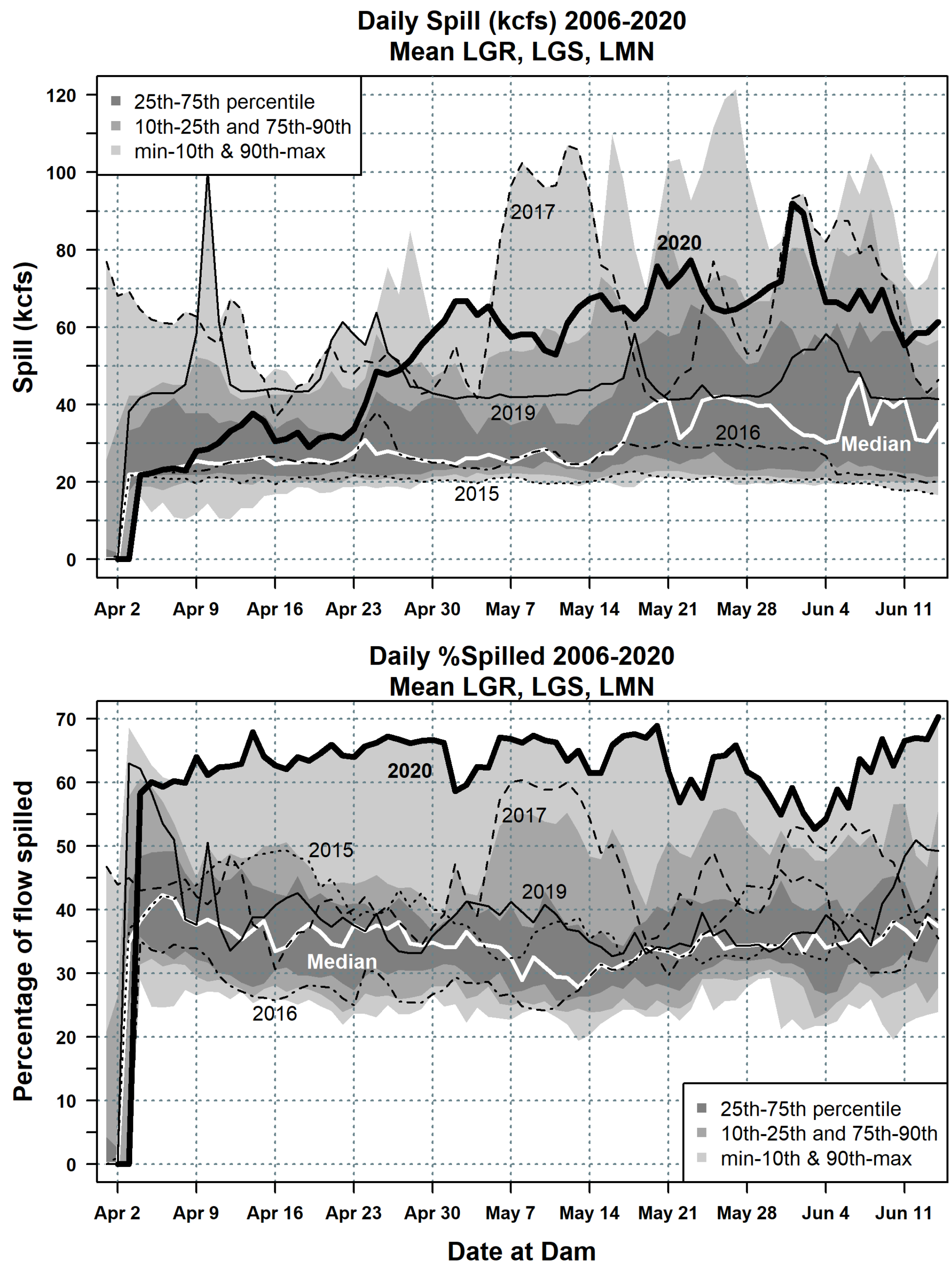
Spill as a percentage of flow at Snake River dams averaged 60.7% in 2020, which was nearly double the long-term (2006-2020) mean of 36.4% and was by far the highest recorded mean spill percent on record. Daily mean spill percentages in 2020 were extremely high for the entire migration period (Appendix Figure C2).

Dissolved gas saturation was higher in 2020 than in most years in the 2006-2020 period, especially in May and early June (Appendix Figure C3). Dissolved gas saturation rose quickly in late April and stayed above 120% until the second week of June, briefly surpassing 125% for a couple of days at the very end of May.

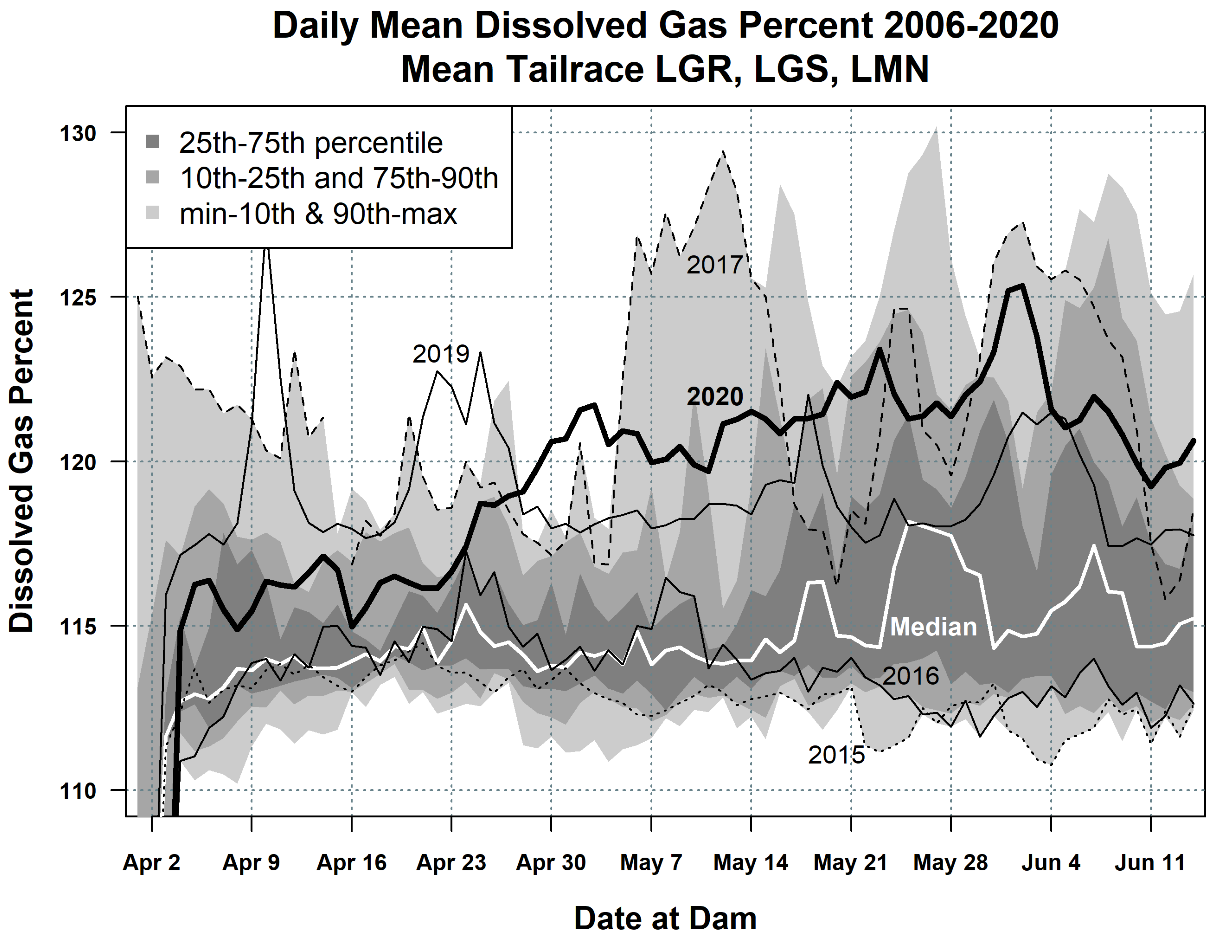
Flow and temperature were highly variable in 2020, with multiple spikes in both daily time series (Appendix Figure C1). Spikes in flow around May 1 and May 14 appeared to be associated with spikes in smolt passage at Lower Granite Dam (Appendix Figure C4). However, earlier spikes in smolt passage around April 15 and April 20 occurred during a period of below-average flow; these earlier pulses of migration may be related to the warmer than average water temperature around that time.



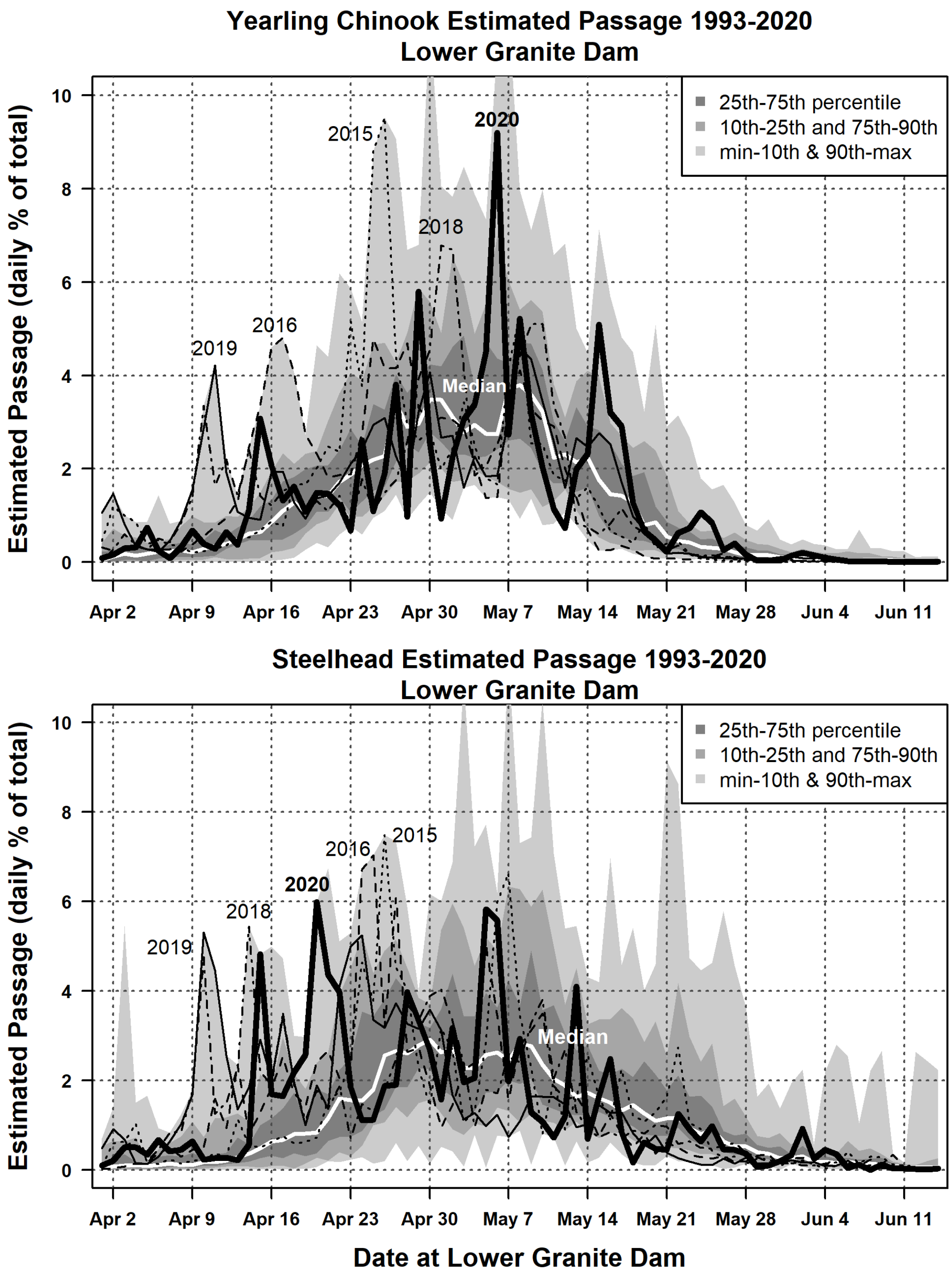

Appendix Figure C1. Upper panel shows daily mean flow at Little Goose Dam from April to mid-June. Lines show daily mean flows for 2020 and selected recent years and long-term median. Shaded areas illustrate daily temperature quantiles from 1989-2020. Lower panel uses the same format to show daily mean temperature at Little Goose Dam. Quantiles for daily temperature are calculated from 1996-2020.




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 2020 and selected recent years and long-term median. Shaded areas indicate daily quantiles for 2006-2020.




Appendix Figure C3. Daily mean percentage of dissolved gas averaged across Lower Granite, Little Goose and Lower Monumental Dam from April to mid-June 2020. Lines show daily percentage for 2020 and selected recent years and long-term median. Shaded areas indicate daily quantiles for 2006-2020.




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 2020, the long-term median, and selected recent years. Shaded areas indicate smolt-passage quantiles from 1993 to 2020.

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