Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2016

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Executive Summary

In 2016, we completed the 24th year of a study to estimate survival and travel time of juvenile Pacific salmon *Oncorhynchus* spp. passing dams and reservoirs on the Snake and Columbia Rivers. All estimates were derived from detections of fish tagged with passive integrated transponder (PIT) tags.

We tagged and released a total of 17,974 hatchery steelhead *O. mykiss*, 14,775 wild steelhead, and 22,145 wild yearling Chinook salmon *O. tshawytscha* at Lower Granite Dam on the Snake River. In addition to detections of these fish, we used detections of yearling Chinook and steelhead tagged by other researchers upstream from Lower Granite Dam and at other hatcheries and traps on the Snake and Columbia Rivers.

Detection sites were the juvenile bypass systems at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dam, as well as the Bonneville corner collector and PIT-tag detector trawl operated in the Columbia River estuary. Survival estimates were calculated using a statistical model for tag-recapture data from single release groups (the single-release model). Primary research objectives in 2016 were:

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

In 2016, we estimated reach survival and travel time for hatchery and wild yearling Chinook salmon, hatchery sockeye *O. nerka* and coho salmon *O. kisutch*, and hatchery and wild steelhead. During most of the migration season, detections of yearling Chinook salmon and steelhead were sufficient to estimate survival and detection probabilities for daily or weekly groups leaving Lower Granite and McNary Dam.

Hatchery and wild fish were combined in some analyses. For PIT-tagged fish detected or released at Lower Granite Dam, overall percentages by origin were 68% hatchery and 32% wild for yearling Chinook and 76% hatchery and 24% wild for steelhead. Based on collection counts at Lower Granite Dam by the Fish Passage Center and on our estimates of daily detection probability, we estimated that 86.4% of the overall yearling Chinook salmon run in 2016 was of hatchery origin. We could not calculate this number for steelhead because separate collection counts of hatchery and wild fish were not available.

All estimates of survival in reaches between dams were calculated from tailrace to tailrace. Estimates of average survival and associated standard errors (SE) are listed by reach in Table E1 for combined groups of wild and hatchery yearling Chinook salmon and steelhead.

Table E1. Average survival estimates by reach for groups of combined hatchery and wild yearling Chinook salmon and steelhead during 2016 (standard errors in parentheses).

	Yearling Chinook salmon (SE)	Steelhead (SE)
Snake River Trap to Lower Granite Dam	0.936 (0.015)	0.998 (0.016)
Lower Granite to Little Goose Dam	0.956 (0.006)	0.990 (0.007)
Little Goose to Lower Monumental Dam	0.912 (0.010)	0.918 (0.016)
Lower Monumental to McNary Dam[a]	0.872 (0.013)	0.813 (0.025)
Lower Monumental to Ice Harbor	0.990 (0.014)	1.006 (0.035)
Ice Harbor to McNary	0.887 (0.013)	0.821 (0.045)
McNary to John Day Dam	0.796 (0.039)	0.927 (0.074)
John Day to Bonneville Dam[b]	0.871 (0.047)	0.709 (0.071)
Snake River Trap to Bonneville Dam[c]	0.473 (0.043)	0.443 (0.032)

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

We also estimated average survival through the entire hydropower system from the Snake River smolt trap at the head of Lower Granite reservoir to the tailrace of Bonneville Dam (eight hydroelectric projects). 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 (Table E1). For combined groups of wild and hatchery Snake River fish, estimated survival through the entire hydropower system was 0.473 (95% CI 0.388-0.558) for yearling Chinook and 0.443 (0.380-0.506) for steelhead.

We estimated survival for hatchery fish originating upstream from the confluence of the Columbia and Yakima Rivers. For yearling Chinook salmon, estimated survival to McNary Dam ranged from 0.796 (0.032) for Chelan Hatchery fish released to Dryden Pond on the Wenatchee River, to 0.273 (0.012) for Cle Elum Hatchery fish released to Jack Creek Pond. For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.691 (0.063) for Wells Hatchery fish released to the Methow River to 0.210 (0.024) for Wells Hatchery fish released to Twisp Acclimation Pond on the Methow River.

For smolts that arrived at Lower Granite Dam, we estimated that 20.2% of yearling Chinook (wild and hatchery combined) and 23.7% of steelhead were transported from a Snake River collector dam. These estimates were among the lowest on record (1993-2016); only estimates in 2015 were lower.

Low estimated proportions of transported smolts resulted in part from timing of the transportation program in 2016. We estimated that 74% of the yearling Chinook and 58% of the steelhead populations had already passed Lower Granite Dam by the time transportation began on 2 May. After transportation began, the proportion of fish that entered juvenile collection facilities was also lower than average because a large proportion of flow was spilled, with multiple dams using surface-passage structures to encourage spillway passage. As a result of this practice, fewer smolts were guided into the juvenile bypass system of dams with facilities for collection and transport.

In addition to estimates of survival, we calculated travel time for yearling Chinook salmon and steelhead over individual reaches between dams and over the entire hydropower system from Lower Granite to Bonneville Dam (461 km). For both species, median travel time through the entire hydropower system was shorter than the long-term average during April but approached average over the rest of the season.

The estimated proportion of PIT-tagged fish detected as they passed monitoring sites at dams was higher in 2016 than in 2015, which were the lowest we have recorded at most dams. The increase in detection was mostly due to increased flows reducing the proportion of fish passing through spill or surface passage routes

We believe the need is now urgent to develop PIT-tag detection capability through passage routes other than the juvenile bypass systems. Specifically, the region should continue to place high priority on development and installation of PIT-monitoring systems for normal spill bays as well as for surface-passage structures. As we have suggested in recent years, higher rates of detection are necessary if we are to maintain or enhance the precision of survival estimates based on data collected from annual efforts to PIT-tag juvenile salmon.

Contents

Introduction

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

From 1993 through 2016, the National Marine Fisheries Service (NMFS) has estimated survival for these stocks as they pass Snake and Columbia River dams and reservoirs (Iwamoto et al. 1994; Muir et al. 1995, 1996, 2001a,b, 2003; Smith et al. 1998, 2000a,b, 2003, 2005, 2006; Hockersmith et al. 1999; Zabel et al. 2001, 2002; Faulkner et al. 2007-2016). These annual survival estimates are based on data from detections of juvenile salmonids marked with passive integrated transponder (PIT) tags (Prentice et al. 1990a). Here we report results from estimated survival for smolts that migrated in spring 2016, the 24th year of the study. Research objectives in 2016 were:

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

Survival from Release to Bonneville Dam

Methods

Experimental Design

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

During the 2016 migration season, survival estimates were based on detections of fish released from Lower Granite Dam, from hatcheries and traps in the Snake River Basin, and from hatcheries and dams in the Upper Columbia River. A large proportion of PIT-tagged yearling Chinook salmon *O. tshawytscha* used in this analysis were released in the Snake River upstream from Lower Granite Dam for the multi-agency Comparative Survival Study (Schaller et al. 2007).

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

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

The farthest downstream detection site was in the Columbia River estuary, where NMFS operated a pair-trawl detection system (Ledgerwood et al. 2004). Since spring 2006, a PIT-tag detection system has been operated in the corner collector at Bonneville Dam Second Powerhouse. Using the SR model, detection probability at the last downstream site (e.g., pair-trawl system) is required for an estimate of survival probability to the last downstream detection site (Bonneville Dam). In 2016, detection probabilities at Bonneville Dam and in the pair trawl were relatively low but sufficient to estimate survival from John Day to Bonneville tailrace for most stocks.

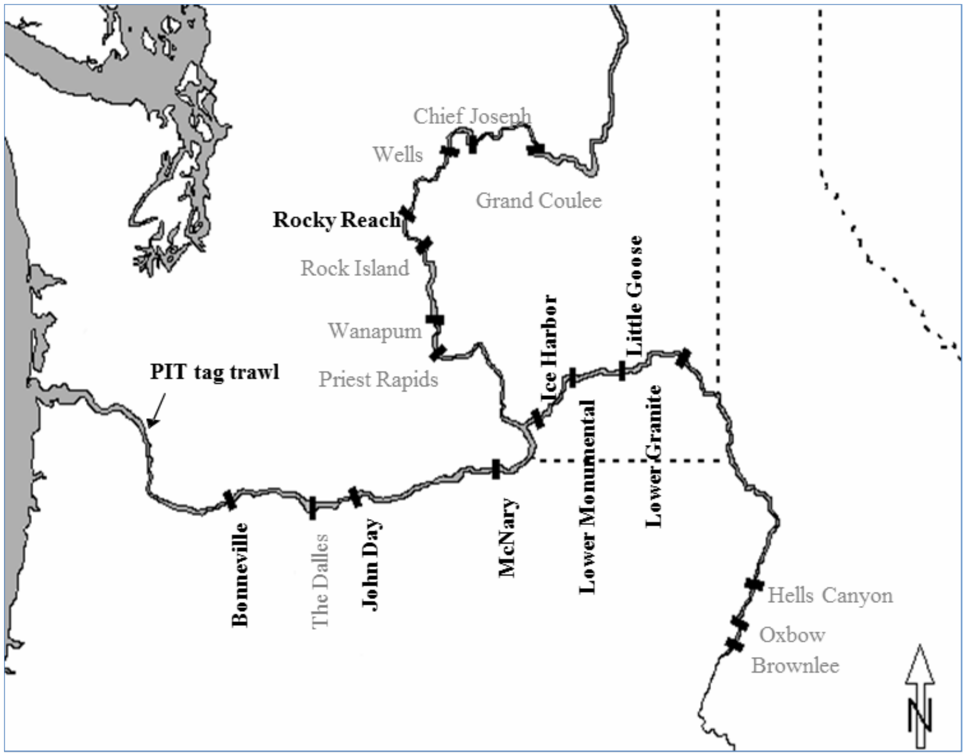

Figure 1. Study area showing the eight sites with PIT-tag detection capability in boldface, including seven dams and the PIT-tag trawl in the Columbia River estuary. Dams with names in gray do not have detection facilities.

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

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

At Ice Harbor Dam, detection rates were low again in 2016. A PIT-tag detection system was first operated in the Ice Harbor juvenile bypass facility in 2005. However, because of high levels of spill that year, too few smolts were detected there to partition survival between Lower Monumental and McNary Dams. From 2006 to 2016, detections at Ice Harbor have been sufficient to partition survival through this reach. However, low detection rates at Lower Monumental and Ice Harbor have often resulted in estimates with poor precision.

For fish released in the Upper Columbia River, we estimated survival in the following three reaches:

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

Study Fish

Releases from Lower Granite Dam—During 2016, we collected hatchery and wild steelhead *O. mykiss* and wild yearling Chinook salmon at the Lower Granite Dam juvenile facility. These fish were PIT tagged and released to the tailrace for the express purpose of estimating their subsequent survival. Fish were collected in approximate proportion to the numbers arriving at Lower Granite Dam except during the early and late periods of the migration season, when we tagged relatively more fish to ensure adequate detection numbers for estimates during these periods.

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

For both yearling Chinook salmon and steelhead tagged and released upstream from Lower Granite Dam, we created virtual daily "release groups" according to date of detection at the dam. At Lower Granite Dam, each daily group of fish detected and returned to the river was combined with fish tagged and released from the dam on the same date. Detections from daily release groups were then pooled into weekly groups.

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

At Lower Granite Dam, we PIT tagged and released 17,974 hatchery steelhead, 14,775 wild steelhead, and 22,145 wild yearling Chinook salmon from 13 April through 11 June 2016 (Table 1). From these numbers, total mortalities were 8, 10, and 41 for hatchery steelhead, wild steelhead, and wild yearling Chinook salmon, respectively. Each of these mortality rates was well below 1% of the total number of fish handled.

Table 1. Number by date of PIT–tagged hatchery steelhead, wild steelhead, and yearling Chinook salmon released at Lower Granite Dam for survival estimates in 2016. Also included are tagging mortalities and shed tags.

	Hatchery Steelhead			**Wild Steelhead**			**Wild Yearling Chinook**		
Release date	Number released	Mort-alities	Shed tags	Number released	Mort-alities	Shed tags	Number released	Mort-alities	Shed tags
13-Apr	913	-	-	278	-	-	2,833	5	-
14-Apr	477	-	1	289	-	2	1,789	3	1
20-Apr	1,366	2	1	562	-	1	1,251	3	-
21-Apr	1,789	-	1	818	1	1	1,456	4	-
27-Apr	1,912	-	-	407	-	-	930	2	-
28-Apr	1,750	1	1	1,007	-	-	1,191	2	1
3-May	674	-	-	456	-	-	798	1	-
4-May	675	-	-	528	-	-	759	-	-
5-May	681	-	-	708	-	1	1,047	3	1
6-May	675	-	-	400	-	1	889	1	-
7-May	707	-	1	289	-	1	1,220	4	-
10-May	496	-	2	916	-	1	2,015	5	1
11-May	499	-	-	608	-	-	980	1	-
12-May	1,057	-	-	872	1	-	1,506	1	-
13-May	422	-	-	1,046	-	2	300	-	-
14-May	3	-	-	670	1	2	110	-	-
17-May	355	-	-	316	-	-	500	1	-
18-May	361	-	-	1,052	2	6	571	1	-
19-May	693	1	-	562	1	1	132	1	-
20-May	358	-	1	692	-	1	500	1	-
21-May	5	-	-	402	1	1	206	-	-
24-May	208	-	1	233	1	1	262	-	1
25-May	209	1	-	197	-	1	227	-	-
26-May	566	-	-	219	-	-	207	-	1
27-May	1	-	-	224	-	1	88	-	-
28-May	66	-	-	257	1	-	234	-	-
1-Jun	231	1	2	89	-	-	46	1	1
2-Jun	161	-	-	56	-	-	31	-	-
3-Jun	182	1	-	68	-	-	53	1	-
4-Jun	72	-	-	63	-	-	14	-	-
7-Jun	85	-	-	87	-	-	-	-	-
8-Jun	83	-	-	99	-	-	-	-	-
9-Jun	81	-	-	122	-	-	-	-	-
10-Jun	80	-	-	121	-	-	-	-	-
11-Jun	81	1	-	62	1	-	-	-	-
	17,974	8	11	14,775	10	24	22,145	41	7

A total of 97,311 yearling Chinook salmon (66,037 hatchery origin, 31,274 wild) were either collected, tagged, and released to the tailrace of Lower Granite Dam or detected at the dam and returned to the tailrace. A total of 77,806 steelhead (58,976 hatchery origin and 18,830 wild) were similarly tagged and released or detected and returned to the tailrace of Lower Granite Dam.

We estimated that 86.4% of the overall run of yearling Chinook salmon in 2016 was of hatchery origin. This estimate was based on counts of the run at large (both tagged and non-tagged fish) by the Fish Passage Center and our own estimates of daily detection probability at Lower Granite Dam (based on tagged fish only). We could not estimate the proportion of hatchery steelhead in the run at large because separate counts for hatchery and wild fish were not available. In the combined PIT-tagged groups used to estimate survival, estimated proportions of hatchery fish were 68% for yearling Chinook salmon and 76% for steelhead.

Releases from McNary Dam—For tagged yearling Chinook and steelhead released from locations throughout the Snake and Upper Columbia River, we created virtual daily "release groups" according to day of detection at McNary Dam. Daily release groups included only fish returned to the tailrace, and detections of daily groups were pooled into weekly groups for analyses. We estimated survival from McNary to John Day and from John Day to Bonneville Dam for weekly groups only, as detection data in 2016 were too sparse to estimate survival for daily groups.

Releases from Hatcheries and Smolt Traps—In 2016, most hatcheries in the Snake and Upper Columbia River Basins released PIT-tagged fish as part of research independent of the NMFS survival study. We analyzed data from hatchery releases of PIT-tagged yearling Chinook, sockeye *O. nerka*, coho *O. kisutch*, and steelhead to provide estimates of survival and detection probability. We provided estimates from release to Lower Granite Dam and to points downstream of Lower Granite Dam for fish originating in the Snake River Basin and from release to McNary Dam and to points downstream of McNary Dam for fish originating in the Upper Columbia River Basin.

We also estimated survival to Lower Granite Dam and to points downstream for releases of PIT-tagged wild and hatchery yearling Chinook salmon and steelhead from the Salmon (White Bird), Snake, and Grand Ronde traps, and from other smolt traps throughout the Snake River Basin.

Data Analysis

Tagging and detection data were downloaded on 4 August 2016 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 data anomalies. Records were eliminated where appropriate, and all eliminated PIT-tag codes were recorded with the reasons for their elimination. Very few records were eliminated (<0.1%).

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

All analyses reported here used data downloaded on 4 August 2016. It is possible that data in the PTAGIS database may be updated or corrected after this date. Thus, estimates we provide or data used for analyses in the future may differ slightly from those presented here.

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

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

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

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

When estimates of survival through a particular river section were available for a series of release groups of the same stock, we calculated a weighted average of these estimates over the migration season (Muir et al. 2001a). When these series extended across all or most of the season, we considered this weighted average as the seasonal average for the year. For each group, weights were inversely proportional to their respective estimated relative variances (coefficient of variation squared).

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

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

Estimated survival from the Snake River trap to Bonneville Dam presents an important instance of estimation through an extended reach. The Snake River trap is located near the head of Lower Granite reservoir, so estimated survival from the trap to Bonneville Dam covers essentially the entire eight-project hydropower system negotiated by juvenile salmonids from the Snake River Basin. For yearling Chinook salmon and steelhead, we constructed this estimate from three components:

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

Results

Snake River Yearling Chinook Salmon

Survival Probabilities—For weekly groups of yearling Chinook salmon, we estimated survival probability from Lower Granite to multiple Snake River dams over 10 consecutive weeks during 23 March-31 May. Mean estimated survival was 0.956 (SE 0.006) from Lower Granite to Little Goose, 0.912 (0.010) from Little Goose to Lower Monumental, and 0.872 (0.013) from Lower Monumental to McNary Dam (Tables 2 and 5). For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.752 (0.011).

Table 2. Estimated survival probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or tagged and released to the tailrace at Lower Granite Dam in 2016. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for daily groups. Standard errors in parentheses.

Estimated survival of yearling Chinook salmon groups from Lower Granite Dam (SE)					
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
23–29 Mar	1,604	0.930 (0.040)	0.804 (0.073)	0.810 (0.094)	0.605 (0.052)
30 Mar–5 Apr	1,699	0.894 (0.040)	0.784 (0.064)	0.930 (0.096)	0.652 (0.053)
6–12 Apr	7,167	0.943 (0.016)	0.926 (0.035)	0.894 (0.045)	0.781 (0.031)
13–19 Apr	19,043	0.964 (0.010)	0.884 (0.018)	0.892 (0.023)	0.760 (0.015)
20–26 Apr	25,477	0.940 (0.010)	0.918 (0.020)	0.918 (0.026)	0.793 (0.018)
27 Apr–3 May	18,480	0.987 (0.018)	0.848 (0.032)	0.905 (0.044)	0.757 (0.026)
4 –10 May	15,879	0.966 (0.013)	0.937 (0.024)	0.799 (0.031)	0.723 (0.023)
11–17 May	4,502	0.949 (0.018)	0.858 (0.041)	0.785 (0.052)	0.640 (0.032)
18–24 May	2,008	0.944 (0.034)	0.939 (0.122)	0.741 (0.121)	0.657 (0.070)
25–31 May	859	0.987 (0.125)	0.662 (0.409)	0.886 (0.608)	0.578 (0.186)
Weighted mean[a]		**0.956 (0.006)**	**0.912 (0.010)**	**0.872 (0.013)**	**0.752 (0.011)**

a Weighted mean estimates for daily groups (22 Mar–30 May; see Table 5)

For weekly groups of yearling Chinook salmon, we estimated survival probabilities from McNary Dam to multiple dams on the Columbia River for seven consecutive weeks during 13 April-31 May. Overall weighted mean survival was 0.796 (SE 0.039) from McNary to John Day, 0.871 (0.047) from John Day to Bonneville, and 0.672 (0.060) for the combined reach from McNary to Bonneville Dam (Table 3).

We calculated the product of average estimates from Lower Granite to McNary and from McNary to Bonneville Dam to provide an overall survival estimate of 0.505 (SE 0.046) from Lower Granite to Bonneville Dam. For wild and hatchery yearling Chinook salmon released from the Snake River trap, estimated survival was 0.936 (0.015) from release to the tailrace of Lower Granite Dam. Thus, estimated survival probability through all eight hydropower projects encountered by Snake River yearling Chinook salmon was 0.473 (SE 0.043).

Table 3. Estimated survival probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned to the tailrace of McNary Dam in 2016. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival of yearling Chinook salmon groups from McNary Dam (SE)		
Date at McNary Dam	Number Released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
13–19 Apr	1,654	0.758 (0.060)	0.586 (0.214)	0.444 (0.158)
20–26 Apr	9,050	0.833 (0.028)	1.073 (0.290)	0.894 (0.240)
27 Apr–3 May	18,132	0.843 (0.034)	0.877 (0.110)	0.740 (0.088)
4–10 May	11,699	0.776 (0.059)	0.968 (0.187)	0.751 (0.134)
11–17 May	8,561	0.738 (0.059)	0.824 (0.137)	0.608 (0.089)
18–24 May	2,364	0.457 (0.046)	0.846 (0.262)	0.386 (0.114)
25–31 May	582	0.314 (0.073)	0.450 (0.232)	0.142 (0.066)
Weighted mean		**0.796 (0.039)**	**0.871 (0.047)**	**0.672 (0.060)**

We also estimated separate probabilities of survival from Lower Granite to McNary Dam for weekly groups of hatchery vs. wild yearling Chinook (Table 4). Weighted mean estimated survival from Lower Granite to McNary Dam was lower for wild than for hatchery groups, and weekly estimates from Lower Granite to McNary Dam were consistently lower for wild fish compared to hatchery in the same week of release. Survival estimates for weekly release groups were not consistently different between hatchery and wild fish in the shorter component reaches for fish released in the same week, with the exception of the reach from Lower Monumental to McNary Dam.

Table 4. Estimated survival probabilities for weekly groups of Snake River hatchery and wild yearling Chinook salmon detected and returned or tagged and released to the tailrace at Lower Granite Dam in 2016. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival of weekly groups from Lower Granite Dam(SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
			Hatchery yearling Chinook		
23–29 Mar	1,503	0.921 (0.042)	0.775 (0.072)	0.845 (0.100)	0.603 (0.053)
30 Mar–5 Apr	1,542	0.871 (0.041)	0.794 (0.068)	0.973 (0.105)	0.672 (0.058)
6–12 Apr	5,775	0.964 (0.021)	0.914 (0.043)	0.907 (0.054)	0.799 (0.037)
13–19 Apr	10,880	0.955 (0.015)	0.908 (0.027)	0.960 (0.037)	0.833 (0.026)
20–26 Apr	21,186	0.998 (0.016)	0.883 (0.027)	0.903 (0.033)	0.795 (0.022)
27 Apr–3 May	14,617	1.030 (0.027)	0.847 (0.045)	0.884 (0.057)	0.770 (0.034)
4–10 May	9,128	1.064 (0.028)	0.893 (0.041)	0.793 (0.047)	0.754 (0.035)
11–17 May	813	0.980 (0.056)	0.824 (0.109)	1.097 (0.212)	0.886 (0.135)
Weighted mean		**0.983 (0.016)**	**0.885 (0.013)**	**0.908 (0.021)**	**0.788 (0.018)**
			Wild yearling Chinook		
6–12 Apr	1,392	0.920 (0.024)	0.922 (0.056)	0.838 (0.077)	0.711 (0.054)
13–19 Apr	8,163	0.955 (0.012)	0.876 (0.025)	0.837 (0.030)	0.701 (0.018)
20–26 Apr	4,291	0.951 (0.014)	0.935 (0.025)	0.866 (0.038)	0.770 (0.030)
27 Apr–3 May	3,863	0.995 (0.023)	0.832 (0.045)	0.882 (0.065)	0.730 (0.040)
4–10 May	6,751	0.966 (0.014)	0.929 (0.028)	0.768 (0.038)	0.690 (0.029)
11–17 May	3,689	0.947 (0.018)	0.860 (0.043)	0.740 (0.052)	0.602 (0.032)
18–24 May	1,826	0.941 (0.035)	0.867 (0.110)	0.778 (0.125)	0.634 (0.067)
25–31 May	817	0.991 (0.127)	0.678 (0.420)	0.881 (0.605)	0.592 (0.190)
Weighted mean		**0.956 (0.006)**	**0.904 (0.013)**	**0.825 (0.017)**	**0.703 (0.017)**

We estimated survival probabilities for daily groups of yearling Chinook salmon (hatchery and wild combined) either detected and returned to the tailrace or PIT-tagged and released to the tailrace of Lower Granite Dam. Low downstream detection rates required us to pool groups over multiple days during late May in order to create sufficient sample sizes for survival probability estimates.

Statistical sampling error in the resulting daily estimates was considerably lower in 2016 than in 2015, allowing some analysis of patterns in survival over time through Snake River reaches (Table 5; Figure 2). It appeared that during the 2016 migration season, estimated survival for Chinook between Lower Granite and McNary Dam increased slightly in early April, was fairly steady through the rest of April, and then slightly declined in May.

Table 5. Estimated survival probabilities for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or PIT tagged and released to the tailrace at Lower Granite Dam in 2016. Daily groups were pooled as needed for sufficient sample size on the dates indicated. Weighted means are of independent estimates for daily groups. Standard errors in parentheses.

Estimated survival of daily yearling Chinook salmon groups from Lower Granite Dam (SE)					
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
22–25 Mar	116	0.851 (0.118)	0.708 (0.174)	1.200 (0.455)	0.722 (0.238)
26 Mar	220	0.922 (0.076)	1.157 (0.341)	0.679 (0.258)	0.724 (0.175)
27 Mar	331	0.967 (0.093)	0.648 (0.112)	0.794 (0.168)	0.497 (0.083)
28 Mar	540	0.993 (0.085)	0.820 (0.147)	0.927 (0.220)	0.755 (0.136)
29 Mar	408	0.884 (0.084)	0.815 (0.157)	0.667 (0.147)	0.480 (0.070)
30 Mar	241	0.821 (0.080)	0.736 (0.132)	1.141 (0.290)	0.689 (0.151)
31 Mar	255	1.085 (0.176)	0.532 (0.123)	1.017 (0.232)	0.587 (0.115)
1 Apr	313	1.099 (0.162)	0.639 (0.164)	0.738 (0.205)	0.519 (0.101)
2–3 Apr	433	0.773 (0.052)	0.971 (0.144)	1.323 (0.344)	0.993 (0.219)
4 Apr	234	0.970 (0.118)	0.806 (0.175)	0.714 (0.170)	0.558 (0.099)
5 Apr	223	0.860 (0.106)	0.999 (0.252)	0.671 (0.183)	0.577 (0.107)
6 Apr	250	0.909 (0.089)	1.077 (0.261)	0.631 (0.198)	0.617 (0.140)
7 Apr	364	0.910 (0.071)	0.973 (0.149)	0.748 (0.143)	0.662 (0.098)
8 Apr	606	0.923 (0.050)	1.092 (0.146)	0.959 (0.190)	0.967 (0.154)
9 Apr	706	0.878 (0.041)	1.006 (0.110)	0.870 (0.135)	0.769 (0.094)
10 Apr	848	0.916 (0.040)	0.952 (0.091)	0.982 (0.146)	0.857 (0.108)
11 Apr	1,740	0.963 (0.034)	0.823 (0.061)	0.921 (0.086)	0.729 (0.055)
12 Apr	2,653	0.972 (0.028)	0.916 (0.061)	0.895 (0.076)	0.796 (0.052)
13 Apr	6,200	0.951 (0.015)	0.894 (0.033)	0.829 (0.037)	0.704 (0.022)
14 Apr	5,281	0.966 (0.019)	0.876 (0.036)	0.904 (0.047)	0.765 (0.031)
15 Apr	3,116	0.959 (0.025)	0.953 (0.050)	0.882 (0.062)	0.806 (0.045)
16 Apr	1,455	0.928 (0.034)	0.913 (0.060)	1.026 (0.093)	0.870 (0.067)
17 Apr	1,342	0.994 (0.043)	0.816 (0.061)	1.105 (0.125)	0.896 (0.091)
18 Apr	939	0.906 (0.039)	0.969 (0.076)	0.935 (0.096)	0.820 (0.070)
19 Apr	710	0.925 (0.043)	0.914 (0.077)	0.860 (0.100)	0.727 (0.070)
20 Apr	2,261	0.945 (0.020)	0.945 (0.036)	0.904 (0.057)	0.807 (0.044)
21 Apr	3,022	0.927 (0.019)	0.971 (0.035)	0.872 (0.049)	0.785 (0.038)
22 Apr	3,698	0.954 (0.032)	1.019 (0.065)	0.932 (0.073)	0.906 (0.053)
23 Apr	3,431	1.020 (0.038)	0.876 (0.060)	0.884 (0.072)	0.789 (0.049)
24 Apr	4,122	0.970 (0.031)	0.915 (0.058)	0.901 (0.072)	0.800 (0.050)
25 Apr	4,962	0.977 (0.031)	0.909 (0.062)	0.803 (0.066)	0.714 (0.043)
26 Apr	3,981	1.042 (0.044)	0.832 (0.083)	0.917 (0.112)	0.795 (0.068)
27 Apr	3,941	0.947 (0.029)	0.893 (0.075)	0.907 (0.098)	0.767 (0.056)

Table 5. Continued.

Estimated survival of daily yearling Chinook salmon groups from Lower Granite Dam (SE)					
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
28 Apr	4,687	1.023 (0.035)	0.797 (0.064)	0.932 (0.093)	0.760 (0.052)
29 Apr	3,140	0.904 (0.047)	0.954 (0.116)	0.935 (0.141)	0.807 (0.079)
30 Apr	3,227	0.986 (0.057)	0.852 (0.096)	0.923 (0.127)	0.776 (0.074)
1 May	1,430	1.048 (0.071)	0.884 (0.120)	0.934 (0.168)	0.865 (0.116)
2 May	658	1.270 (0.154)	0.535 (0.089)	0.909 (0.174)	0.618 (0.099)
3 May	1,397	1.034 (0.050)	0.900 (0.080)	0.714 (0.080)	0.664 (0.056)
4 May	1,865	0.957 (0.042)	0.919 (0.071)	0.858 (0.106)	0.755 (0.080)
5 May	2,669	0.938 (0.031)	0.970 (0.053)	0.657 (0.056)	0.597 (0.044)
6 May	2,795	0.933 (0.026)	0.919 (0.045)	0.861 (0.075)	0.738 (0.057)
7 May	2,679	0.951 (0.022)	0.934 (0.048)	0.913 (0.079)	0.811 (0.060)
8 May	1,686	1.163 (0.087)	1.002 (0.140)	0.642 (0.096)	0.748 (0.068)
9 May	1,416	1.178 (0.087)	0.680 (0.086)	0.932 (0.140)	0.747 (0.084)
10 May	2,769	0.955 (0.028)	0.972 (0.077)	0.724 (0.076)	0.672 (0.050)
11 May	1,383	0.957 (0.036)	0.821 (0.066)	0.859 (0.107)	0.675 (0.070)
12 May	1,676	0.939 (0.022)	0.905 (0.064)	0.725 (0.070)	0.616 (0.043)
13–16 May	892	1.021 (0.058)	0.747 (0.092)	0.920 (0.149)	0.701 (0.086)
17–20 May	1,916	0.966 (0.031)	0.914 (0.100)	0.685 (0.094)	0.605 (0.054)
21–25 May	887	0.980 (0.086)	1.632 (0.884)	0.601 (0.374)	0.961 (0.302)
26–30 May	607	0.886 (0.129)	0.377 (0.194)	1.992 (1.305)	0.666 (0.288)
Weighted mean		**0.956 (0.006)**	**0.912 (0.010)**	**0.872 (0.013)**	**0.752 (0.011)**

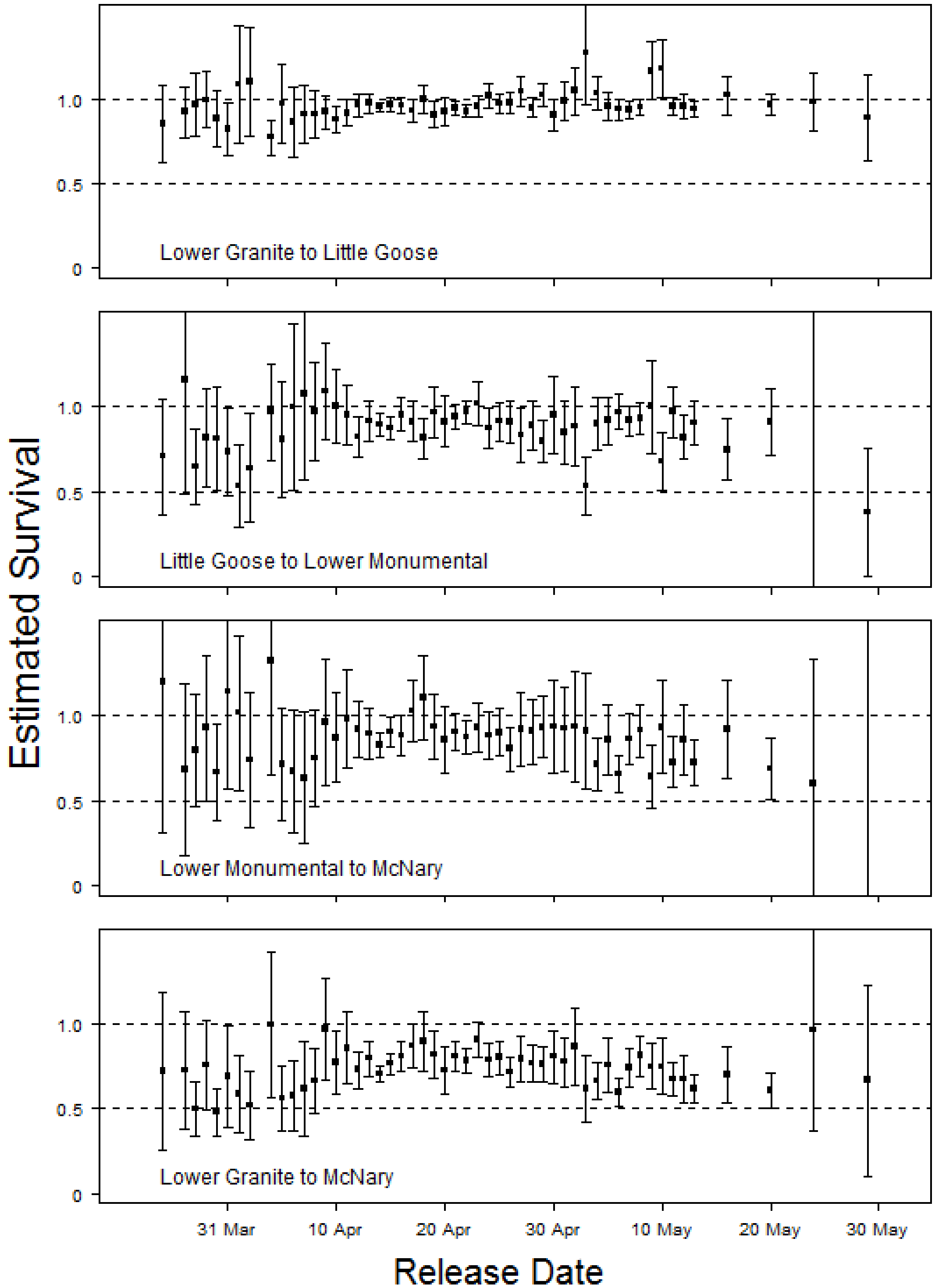

Figure 2. Estimated survival probabilities through various reaches versus release date at Lower Granite Dam for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined), 2016. Whiskers extend one standard error above and below point estimates.

Detection Probabilities—For weekly groups of yearling Chinook salmon, estimates of detection probability varied throughout the season with changing flow volumes, spill levels, and degrees of smolt readiness in fish (Tables 6-8). Detection probability estimates were generally highest at Little Goose and McNary and lowest at Lower Monumental and Bonneville Dams. Detection probability estimates were typically higher for wild than for hatchery fish released during the same week (Table 8).

Table 6. Estimated detection probabilities for weekly groups of Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or PIT tagged and released to the tailrace of Lower Granite Dam in 2016. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
23–29 Mar	1,604	0.374 (0.020)	0.210 (0.020)	0.218 (0.023)
30 Mar–5 Apr	1,699	0.361 (0.020)	0.269 (0.022)	0.248 (0.024)
6–12 Apr	7,167	0.442 (0.010)	0.268 (0.010)	0.239 (0.012)
13–19 Apr	19,043	0.406 (0.005)	0.266 (0.006)	0.274 (0.007)
20–26 Apr	25,477	0.361 (0.005)	0.255 (0.005)	0.289 (0.007)
27 Apr–3 May	18,480	0.293 (0.006)	0.171 (0.006)	0.246 (0.009)
4–10 May	15,879	0.307 (0.006)	0.236 (0.006)	0.276 (0.010)
11–17 May	4,502	0.477 (0.012)	0.188 (0.010)	0.385 (0.021)
18–24 May	2,008	0.459 (0.020)	0.084 (0.012)	0.284 (0.032)
25–31 May	859	0.267 (0.037)	0.020 (0.014)	0.235 (0.078)

Table 7. Estimated detection probabilities for Snake River yearling Chinook salmon (hatchery and wild combined) detected and returned or released to the tailrace of McNary Dam in 2016. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon groups from McNary Dam (SE)		
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
13–19 Apr	1,654	0.446 (0.038)	0.203 (0.074)
20–26 Apr	9,050	0.419 (0.015)	0.118 (0.032)
27 Apr–3 May	18,132	0.146 (0.007)	0.197 (0.024)
4 –10 May	11,699	0.085 (0.007)	0.161 (0.029)
11–17 May	8,561	0.097 (0.009)	0.204 (0.030)
18–24 May	2,364	0.237 (0.026)	0.252 (0.075)
25–31 May	582	0.257 (0.066)	0.531 (0.249)

Table 8. Estimated detection probabilities for Snake River hatchery and wild yearling Chinook salmon detected and returned or released to the tailrace of Lower Granite Dam in 2016. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

		Estimated detection probability of groups from Lower Granite Dam (SE)		
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery Yearling Chinook		
23–29 Mar	1,503	0.363 (0.021)	0.216 (0.021)	0.214 (0.024)
30 Mar–5 Apr	1,542	0.358 (0.021)	0.272 (0.023)	0.242 (0.025)
6–12 Apr	5,775	0.415 (0.011)	0.244 (0.011)	0.226 (0.013)
13–19 Apr	10,880	0.382 (0.008)	0.297 (0.008)	0.250 (0.009)
20–26 Apr	21,186	0.325 (0.006)	0.206 (0.006)	0.276 (0.008)
27 Apr–3 May	14,617	0.250 (0.007)	0.161 (0.008)	0.220 (0.010)
4–10 May	9,128	0.201 (0.007)	0.179 (0.008)	0.233 (0.012)
11–17 May	813	0.372 (0.027)	0.140 (0.022)	0.268 (0.044)
		Wild Yearling Chinook		
6–12 Apr	1,392	0.529 (0.019)	0.360 (0.024)	0.292 (0.027)
13–19 Apr	8,163	0.447 (0.008)	0.229 (0.008)	0.299 (0.010)
20–26 Apr	4,291	0.434 (0.010)	0.419 (0.012)	0.327 (0.015)
27 Apr–3 May	3,863	0.410 (0.012)	0.180 (0.011)	0.322 (0.020)
4–10 May	6,751	0.422 (0.008)	0.301 (0.010)	0.336 (0.016)
11–17 May	3,689	0.499 (0.013)	0.199 (0.012)	0.412 (0.024)
18–24 May	1,826	0.474 (0.021)	0.091 (0.013)	0.297 (0.034)
25–31 May	817	0.266 (0.037)	0.020 (0.014)	0.235 (0.078)

Snake River Steelhead

Survival Probabilities—For weekly groups of steelhead, we estimated probabilities of survival from Lower Granite Dam to multiple downstream dams for 8 consecutive weeks during 30 March-24 May. Average estimated survival was 0.990 (SE 0.007) from Lower Granite to Little Goose, 0.918 (0.016) from Little Goose to Lower Monumental, and 0.813 (0.025) from Lower Monumental to McNary Dam (Table 9). For the combined reach from Lower Granite to McNary Dam, estimated survival averaged 0.730 (0.020).

Table 9. Estimated survival probabilities for weekly groups of juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of Lower Granite Dam in 2016. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for daily groups. Standard errors in parentheses.

	Estimated survival of steelhead groups from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
30 Mar–5 Apr	462	1.188 (0.122)	1.240 (0.417)	0.557 (0.225)	0.820 (0.190)
6–12 Apr	3,392	1.013 (0.036)	0.857 (0.056)	1.054 (0.103)	0.915 (0.076)
13–19 Apr	12,348	0.997 (0.015)	0.871 (0.025)	0.883 (0.044)	0.767 (0.034)
20–26 Apr	21,192	0.959 (0.011)	0.999 (0.022)	0.855 (0.027)	0.819 (0.021)
27 Apr–3 May	11,694	1.004 (0.016)	0.896 (0.031)	0.755 (0.040)	0.680 (0.030)
4–10 May	10,465	0.980 (0.022)	0.905 (0.035)	0.735 (0.037)	0.652 (0.026)
11–17 May	8,615	0.973 (0.022)	0.938 (0.053)	0.612 (0.044)	0.558 (0.029)
18–24 May	5,467	1.040 (0.044)	0.810 (0.082)	0.694 (0.096)	0.585 (0.061)
Weighted mean*		**0.990 (0.007)**	**0.918 (0.016)**	**0.813 (0.025)**	**0.730 (0.020)**

* Weighted mean of estimates for daily groups (22 Mar–30 May; see Table 12)

For steelhead detected and returned to the tailrace of McNary Dam, we estimated probabilities of survival to multiple dams downstream for 10 consecutive weeks during 6 April-14 June. Detection rates were poor at John Day and Bonneville Dam and in the pair trawl detection system; thus, precision of these estimates was low. We pooled weekly groups into 5 biweekly groups to help increase precision. Mean estimated survival from the pooled weekly groups was 0.927 (SE 0.074) from McNary to John Day, 0.709 (SE 0.071) from John Day to Bonneville, and 0.608 (SE 0.040) for the entire reach from McNary to Bonneville Dam (Table 10).

Table 10. Estimated survival probabilities for biweekly groups of juvenile Snake River steelhead (hatchery and wild combined) from McNary Dam in 2016. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

	Estimated survival of steelhead groups from McNary Dam (SE)			
Date at McNary Dam	Number released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
6 Apr–19 Apr	1,558	0.937 (0.106)	1.082 (0.993)	1.014 (0.924)
20 Apr–3 May	10,223	1.008 (0.047)	0.676 (0.072)	0.681 (0.065)
4–17 May	6,993	0.864 (0.073)	0.648 (0.082)	0.560 (0.052)
18–31 May	3,197	0.485 (0.060)	1.119 (0.274)	0.543 (0.115)
1–14 Jun	610	0.793 (0.502)	0.399 (0.305)	0.317 (0.136)
Weighted mean		**0.927 (0.074)**	**0.709 (0.071)**	**0.608 (0.040)**

We calculated the product of mean estimates from Lower Granite to McNary and from McNary to Bonneville Dam. This product provided an overall survival estimate of 0.444 (SE 0.032) 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 0.998 (0.016). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.443 (0.032).

Survival probabilities were estimated separately for weekly groups of hatchery vs. wild steelhead through individual and combined reaches (Table 11). Estimated survival differed substantially between wild and hatchery steelhead in some weeks. Average estimated survival over the combined reach between Lower Granite and McNary Dam was usually higher for hatchery than for wild steelhead released in the same week..

Table 11. Estimated survival probabilities for weekly groups of juvenile Snake River hatchery and wild steelhead detected and returned or tagged and released to the tailrace of Lower Granite Dam, 2016. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

	Estimated survival for groups from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
	Hatchery steelhead				
30 Mar–5 Apr	429	1.192 (0.131)	1.186 (0.399)	0.569 (0.231)	0.804 (0.193)
6–12 Apr	3,105	1.022 (0.040)	0.844 (0.058)	1.099 (0.113)	0.947 (0.084)
13–19 Apr	10,688	0.998 (0.017)	0.862 (0.026)	0.910 (0.049)	0.783 (0.038)
20–26 Apr	18,950	0.965 (0.013)	0.992 (0.024)	0.848 (0.029)	0.812 (0.022)
27 Apr–3 May	9,307	1.005 (0.018)	0.889 (0.033)	0.796 (0.047)	0.711 (0.034)
4–10 May	7,137	0.972 (0.027)	1.014 (0.048)	0.671 (0.040)	0.661 (0.029)
11–17 May	4,657	0.982 (0.029)	1.026 (0.077)	0.586 (0.056)	0.591 (0.038)
18–24 May	2,347	1.053 (0.072)	0.843 (0.132)	0.704 (0.140)	0.625 (0.087)
Weighted mean		**0.988 (0.009)**	**0.938 (0.025)**	**0.821 (0.041)**	**0.755 (0.032)**
	Wild steelhead				
6–12 Apr	287	0.956 (0.078)	1.029 (0.250)	0.645 (0.211)	0.635 (0.146)
13–19 Apr	1,660	0.966 (0.029)	0.982 (0.081)	0.707 (0.089)	0.671 (0.067)
20–26 Apr	2,242	0.968 (0.019)	0.988 (0.048)	0.885 (0.076)	0.846 (0.063)
27 Apr–3 May	2,387	0.961 (0.030)	0.990 (0.086)	0.578 (0.074)	0.549 (0.055)
4–10 May	3,328	0.948 (0.035)	0.733 (0.047)	0.889 (0.088)	0.618 (0.052)
11–17 May	3,958	0.961 (0.035)	0.835 (0.071)	0.627 (0.071)	0.503 (0.042)
18–24 May	3,120	1.024 (0.056)	0.774 (0.101)	0.648 (0.126)	0.513 (0.079)
Weighted mean		**0.966 (0.006)**	**0.907 (0.044)**	**0.763 (0.052)**	**0.644 (0.053)**

We estimated survival for daily release groups of combined hatchery and wild steelhead either detected and returned to the tailrace or released to the tailrace of Lower Granite Dam on the same day. The most notable pattern was a decrease during May in estimated survival from Lower Granite to McNary Dam (Table 12; Figure 3).

Table 12. Estimated survival probabilities for daily groups of Snake River juvenile steelhead (hatchery and wild combined) detected and returned or PIT tagged and released to the tailrace of Lower Granite Dam in 2016. Daily groups pooled as needed for sufficient sample size on the dates indicated. Weighted means are of independent estimates for daily groups. Standard errors in parentheses.

		Estimated survival of daily steelhead groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
22–29 Mar	114	0.908 (0.067)	0.517 (0.126)	3.020 (2.812)	1.418 (1.288)
30 Mar–5 Apr	462	1.188 (0.122)	1.240 (0.417)	0.557 (0.225)	0.820 (0.190)
6–8 Apr	611	0.938 (0.094)	0.803 (0.149)	1.220 (0.395)	0.918 (0.266)
9–10 Apr	1,106	1.002 (0.052)	0.832 (0.087)	1.453 (0.274)	1.211 (0.204)
11 Apr	796	0.963 (0.078)	1.179 (0.169)	0.773 (0.144)	0.878 (0.127)
12 Apr	879	1.094 (0.080)	0.715 (0.088)	0.935 (0.149)	0.731 (0.099)
13 Apr	2,633	0.960 (0.023)	0.928 (0.045)	0.765 (0.070)	0.682 (0.056)
14 Apr	2,239	1.000 (0.033)	0.876 (0.061)	0.860 (0.096)	0.753 (0.071)
15 Apr	1,897	1.033 (0.046)	0.861 (0.082)	0.756 (0.104)	0.672 (0.077)
16 Apr	1,278	0.944 (0.037)	0.985 (0.112)	0.663 (0.128)	0.617 (0.101)
17–18 Apr	2,570	0.964 (0.036)	0.841 (0.052)	1.289 (0.168)	1.045 (0.128)
19 Apr	1,731	1.117 (0.062)	0.806 (0.067)	0.900 (0.107)	0.811 (0.085)
20 Apr	3,417	1.015 (0.020)	0.926 (0.034)	0.850 (0.061)	0.799 (0.052)
21 Apr	4,139	0.990 (0.019)	0.911 (0.032)	0.943 (0.062)	0.850 (0.050)
22 Apr	2,767	0.920 (0.041)	1.086 (0.087)	0.839 (0.084)	0.838 (0.064)
23 Apr	2,721	0.972 (0.053)	0.905 (0.081)	0.902 (0.086)	0.793 (0.054)
24 Apr	2,979	0.945 (0.039)	1.003 (0.076)	0.875 (0.076)	0.830 (0.052)
25 Apr	2,773	1.012 (0.041)	1.147 (0.101)	0.749 (0.077)	0.869 (0.060)
26 Apr	2,396	0.994 (0.045)	0.963 (0.087)	0.718 (0.081)	0.688 (0.057)
27 Apr	3,992	1.004 (0.025)	0.892 (0.048)	0.813 (0.072)	0.728 (0.055)
28 Apr	3,983	1.006 (0.022)	0.949 (0.056)	0.710 (0.066)	0.678 (0.051)
29–30 Apr	1,165	1.043 (0.092)	0.875 (0.180)	0.734 (0.195)	0.670 (0.120)
1 May	479	0.869 (0.107)	1.216 (0.296)	0.562 (0.177)	0.593 (0.135)
2 May	463	1.334 (0.214)	0.736 (0.170)	0.541 (0.130)	0.531 (0.092)

Table 12. Continued.

		Estimated survival of daily steelhead groups from Lower Granite Dam (SE)			
Date at Lower Granite Dam	Number released	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam
3 May	1,612	1.008 (0.047)	0.799 (0.066)	0.809 (0.102)	0.651 (0.069)
4 May	1,734	0.940 (0.039)	0.839 (0.064)	0.762 (0.089)	0.601 (0.058)
5 May	1,773	1.063 (0.078)	0.738 (0.074)	0.737 (0.084)	0.578 (0.054)
6 May	1,567	0.959 (0.061)	0.935 (0.084)	0.816 (0.101)	0.732 (0.078)
7 May	1,524	0.932 (0.046)	1.071 (0.096)	0.632 (0.078)	0.631 (0.061)
8 May	938	1.061 (0.105)	1.050 (0.207)	0.582 (0.119)	0.648 (0.070)
9 May	921	0.898 (0.084)	1.363 (0.294)	0.682 (0.166)	0.835 (0.120)
10 May	2,008	0.989 (0.050)	0.856 (0.089)	0.746 (0.101)	0.632 (0.063)
11 May	1,599	0.927 (0.050)	1.008 (0.122)	0.484 (0.074)	0.453 (0.048)
12 May	2,480	0.981 (0.038)	0.826 (0.072)	0.697 (0.085)	0.564 (0.053)
13 May	1,937	0.913 (0.040)	1.139 (0.162)	0.538 (0.092)	0.559 (0.058)
14 May	1,101	1.049 (0.091)	0.807 (0.139)	0.761 (0.168)	0.644 (0.105)
15 May	327	0.947 (0.125)	1.942 (0.912)	0.247 (0.121)	0.453 (0.084)
16–17 May	1,171	1.122 (0.085)	0.857 (0.154)	0.879 (0.240)	0.845 (0.184)
18 May	1,625	1.019 (0.067)	0.918 (0.144)	0.530 (0.112)	0.496 (0.077)
19 May	1,387	0.950 (0.076)	0.971 (0.192)	0.664 (0.172)	0.613 (0.113)
20–21 May	1,750	1.169 (0.100)	0.689 (0.127)	0.822 (0.220)	0.661 (0.141)
22–30 May	2,678	0.947 (0.091)	1.538 (0.858)	0.285 (0.164)	0.415 (0.071)
Weighted mean		**0.990 (0.007)**	**0.918 (0.016)**	**0.813 (0.025)**	**0.730 (0.020)**

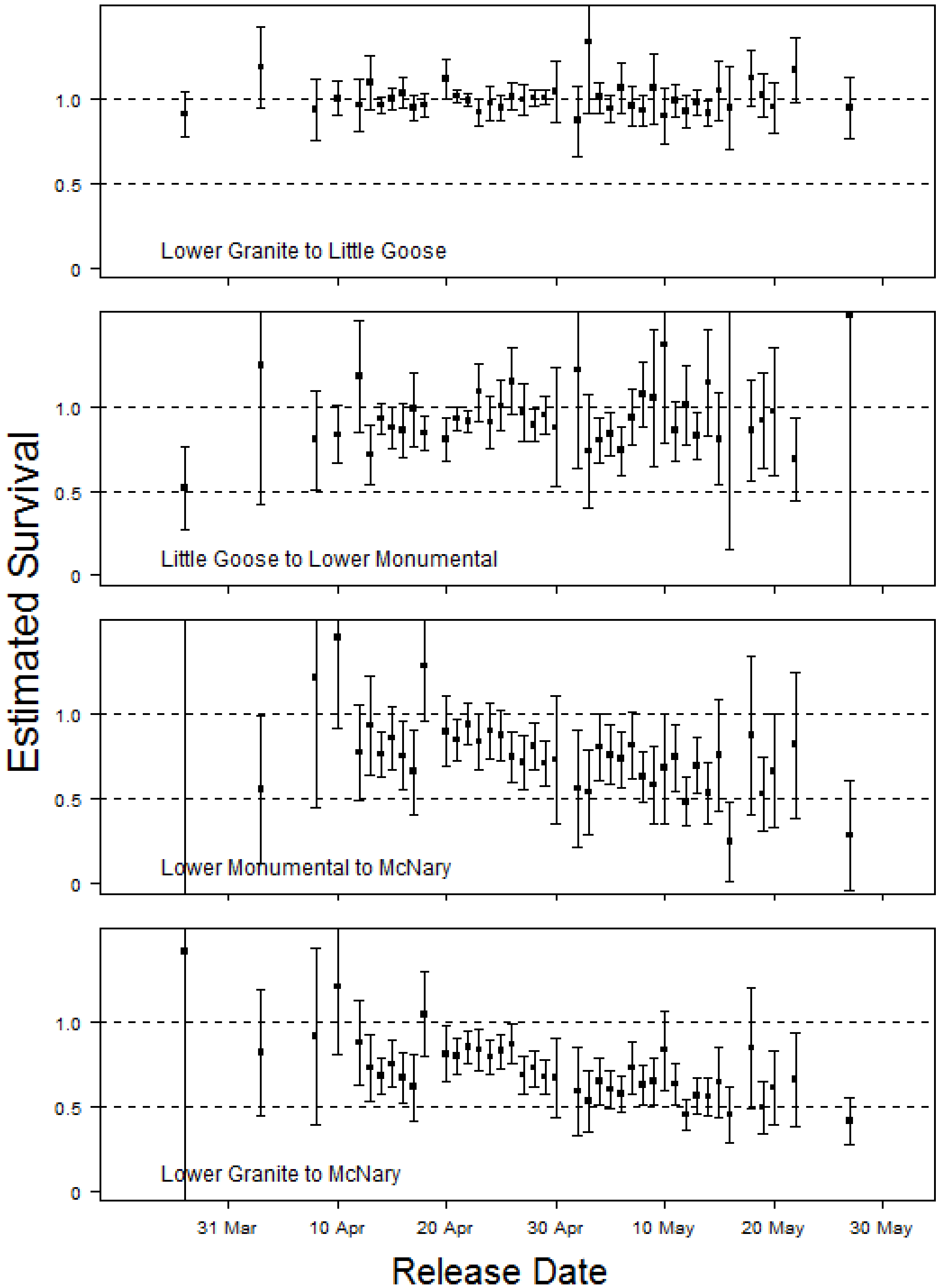

Figure 3. Estimated survival probabilities through various reaches versus release date at Lower Granite Dam for daily groups of Snake River steelhead (hatchery and wild combined), 2016. Whiskers extend one standard error above and below point estimates.

Detection Probabilities—For weekly groups of steelhead, estimated detection probabilities were low at all Snake and Columbia River dams (Tables 13-15). Detection probability estimates were highest at Bonneville and lowest at McNary and John Day Dam. Detection probability estimates were generally higher for wild fish than for hatchery fish released in the same week (Table 15).

Table 13. Estimated detection probability for juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of Lower Granite Dam, 2016. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

Estimated detection probability of steelhead groups from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
30 Mar–5 Apr	462	0.262 (0.033)	0.079 (0.027)	0.126 (0.034)
6–12 Apr	3,392	0.316 (0.014)	0.246 (0.015)	0.125 (0.012)
13–19 Apr	12,348	0.370 (0.007)	0.325 (0.009)	0.130 (0.007)
20–26 Apr	21,192	0.315 (0.005)	0.264 (0.006)	0.181 (0.006)
27 Apr–3 May	11,694	0.361 (0.007)	0.244 (0.008)	0.191 (0.010)
4–10 May	10,465	0.217 (0.006)	0.209 (0.008)	0.226 (0.010)
11–17 May	8,615	0.319 (0.009)	0.138 (0.008)	0.252 (0.014)
18–24 May	5,467	0.254 (0.012)	0.108 (0.011)	0.166 (0.018)

Table 14. Estimated detection probability for juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of McNary Dam, 2016. Daily groups were pooled for biweekly estimates. Standard errors in parentheses.

Estimated detection probability of steelhead groups from McNary Dam (SE)			
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
6 Apr–19 Apr	1,558	0.194 (0.024)	0.167 (0.152)
20 Apr–3 May	10,223	0.128 (0.007)	0.327 (0.032)
4–17 May	6,993	0.063 (0.006)	0.367 (0.035)
18–31 May	3,197	0.074 (0.011)	0.291 (0.063)
1–14 Jun	610	0.023 (0.016)	0.434 (0.188)

Table 15. Estimated detection probabilities for juvenile Snake River hatchery and wild steelhead from the tailrace at Lower Granite Dam, 2016. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

		Estimated detection probability of groups from Lower Granite Dam		
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery steelhead		
30 Mar–5 Apr	429	0.248 (0.034)	0.082 (0.028)	0.117 (0.033)
6–12 Apr	3,105	0.300 (0.014)	0.246 (0.015)	0.118 (0.012)
13–19 Apr	10,688	0.352 (0.008)	0.337 (0.009)	0.121 (0.007)
20–26 Apr	18,950	0.290 (0.005)	0.257 (0.006)	0.177 (0.006)
27 Apr–3 May	9,307	0.345 (0.008)	0.255 (0.010)	0.183 (0.010)
4–10 May	7,137	0.192 (0.007)	0.193 (0.009)	0.222 (0.011)
11–17 May	4,657	0.320 (0.012)	0.132 (0.010)	0.237 (0.017)
18–24 May	2,347	0.225 (0.018)	0.090 (0.014)	0.147 (0.022)
		Wild steelhead		
6–12 Apr	287	0.492 (0.050)	0.242 (0.060)	0.233 (0.064)
13–19 Apr	1,660	0.498 (0.019)	0.245 (0.022)	0.191 (0.023)
20–26 Apr	2,242	0.508 (0.014)	0.313 (0.017)	0.211 (0.018)
27 Apr–3 May	2,387	0.443 (0.017)	0.199 (0.018)	0.233 (0.026)
4–10 May	3,328	0.284 (0.013)	0.251 (0.016)	0.240 (0.022)
11–17 May	3,958	0.319 (0.014)	0.146 (0.013)	0.281 (0.025)
18–24 May	3,120	0.279 (0.017)	0.125 (0.016)	0.197 (0.032)

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 0.925 (SE 0.008) for Clearwater Hatchery fish released to the North Fork of the Clearwater River to 0.371 (0.005) for Lookingglass Hatchery fish released to Catherine Creek Pond (Appendix Table B1).

For steelhead, estimated survival to Lower Granite Dam ranged from 0.954 (0.015) for Magic Valley Hatchery releases to the Little Salmon River to 0.638 (0.006) for Hagerman Hatchery fish released from Sawtooth Hatchery (Appendix Table B2).

For sockeye salmon released at Redfish Lake Creek Trap in spring, estimated survival to Lower Granite Dam ranged from 0.543 (0.076) for Oxbow Hatchery fish to 0.321 (0.022) for Springfield Hatchery fish (Appendix Table B3).

Snake River Smolt Trap Release Groups—For tagged wild and hatchery juvenile salmonids released from Snake River Basin smolt traps, survival probability estimates were generally inversely related to distance between the respective traps and Lower Granite Dam (Appendix Table B7). Estimated detection probabilities were considerably higher than in 2015 (not shown) and similar among release groups of the same species and rearing type from different traps (Appendix Table B8).

For wild chinook and steelhead, estimated detection probabilities at Snake River dams were consistently higher than those of hatchery conspecifics released from the same location (i.e., Grande Ronde, Salmon, and Snake River traps). These higher detection probabilities could be due to fish size (Zabel et al. 2005) but could also be partly due to differences in migration timing.

Upper Columbia River Hatchery Release Groups—We estimated probabilities of survival from release at Upper Columbia River hatcheries to McNary Dam and dams further downstream for yearling Chinook, coho salmon, and steelhead. These estimates varied among hatcheries and release locations (Appendix Table B9), as did estimates of detection probability (Appendix Table B10).

We estimated survival for hatchery fish originating upstream from the confluence of the Columbia and Yakima Rivers. For Chelan Hatchery yearling Chinook salmon, estimated survival to McNary Dam ranged from 0.796 (0.032) for fish released to Dryden Pond on the Wenatchee River to 0.273 (0.012) for fish released to Jack Creek Pond.

For Upper Columbia River steelhead, estimated survival to McNary Dam ranged from 0.619 (0.063) for releases from the hatchery to 0.210 (0.024) for releases to Twisp Acclimation Pond on the Methow River.

For coho salmon, estimated survival to McNary Dam ranged from 0.453 (0.022) for Winthrop Hatchery fish released from Winthrop Hatchery, to 0.264 (0.046) for Willard Hatchery fish released to Rolfing Pond on the Wenatchee River.

Survival Between Lower Monumental and Ice Harbor Dam

At Ice Harbor Dam, detections in 2016 were extremely poor and lower than at most other dams (Table 16). A PIT-tag detection system became operational at Ice Harbor in 2005. In most years since then, detections have been sufficient to estimate survival from Lower Monumental to Ice Harbor and from Ice Harbor to McNary Dam.

For yearling Chinook salmon in 2016, mean estimated survival was 0.990 (SE 0.014) from Lower Monumental to Ice Harbor Dam and 0.887 (0.013) from Ice Harbor to McNary Dam. For steelhead, estimated mean survival through these same respective reaches was 1.006 (0.035) and 0.821 (0.045).

Table 16. Estimated survival and detection probabilities from Lower Monumental to Ice Harbor Dam for groups of Snake River yearling Chinook salmon and steelhead released from Lower Granite Dam (hatchery and wild combined), 2016. Daily groups were pooled for weekly estimates.

		Estimated survival probability		
Date at Lower Granite	Number released	Lower Monumental to Ice Harbor Dam	Ice Harbor to McNary Dam	**Detection probability Ice Harbor Dam**
		Hatchery and wild yearling Chinook salmon		
23 Mar–29 Mar	1,604	0.906 (0.129)	0.887 (0.130)	0.078 (0.013)
30 Mar–5 Apr	1,699	0.965 (0.132)	0.971 (0.141)	0.070 (0.012)
6–12 Apr	7,167	0.981 (0.064)	0.918 (0.064)	0.074 (0.006)
13–19 Apr	19,043	1.019 (0.037)	0.867 (0.033)	0.072 (0.003)
20–26 Apr	25,477	0.994 (0.044)	0.909 (0.043)	0.046 (0.002)
27 Apr–3 May	18,480	0.985 (0.054)	0.929 (0.053)	0.066 (0.004)
4–10 May	15,879	0.937 (0.049)	0.856 (0.049)	0.056 (0.003)
11–17 May	4,502	0.986 (0.111)	0.794 (0.092)	0.037 (0.005)
18–24 May	2,008	1.069 (0.213)	0.719 (0.141)	0.049 (0.010)
25–31 May	859	1.616 (0.735)	0.945 (0.410)	0.058 (0.020)
Weighted mean		**0.990 (0.014)**	**0.887 (0.013)**	**0.057 (0.004)**
		Hatchery and wild steelhead		
30 Mar–5 Apr	462	0.674 (0.458)	0.796 (0.507)	0.015 (0.011)
6–12 Apr	3,392	1.124 (0.166)	0.970 (0.157)	0.033 (0.006)
13–19 Apr	12,348	1.064 (0.077)	0.838 (0.068)	0.044 (0.004)
20–26 Apr	21,192	0.948 (0.046)	0.922 (0.048)	0.041 (0.002)
27 Apr–3 May	11,694	0.957 (0.064)	0.834 (0.062)	0.062 (0.005)
4–10 May	10,465	0.972 (0.057)	0.770 (0.050)	0.082 (0.005)
11–17 May	8,615	1.268 (0.124)	0.507 (0.052)	0.052 (0.005)
18–24 May	5,467	1.055 (0.163)	0.674 (0.113)	0.051 (0.008)
Weighted mean		**1.006 (0.035)**	**0.821 (0.045)**	**0.048 (0.005)**

Travel Time and Migration Rates

Methods

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

- Lower Granite Dam to Little Goose Dam (60 km)
- Little Goose Dam to Lower Monumental Dam (46 km)
- Lower Monumental Dam to McNary Dam (119 km)
- Lower Granite Dam to McNary Dam (225 km)
- Lower Granite Dam to Bonneville Dam (461 km)
- McNary Dam to John Day Dam (123 km)
- John Day Dam to Bonneville Dam (113 km)
- McNary Dam to Bonneville Dam (236 km)

Between any two dams, travel time could be calculated only for individual fish that were detected at both the upstream and downstream dam. We defined travel time as the number of days between last detection at the upstream dam and first detection at the downstream dam. Generally, the last detection at an upstream dam was on a monitor near the outfall site, which ensured that fish would arrive in the tailrace within minutes of detection.

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

Migration rate was calculated as length of the reach of interest (km) divided by travel time (d) and included the potential delays noted above. We calculated the 20th percentile, median, and 80th percentile travel time and migration rate for each group.

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

Tagged fish that pass dams without being detected must have passed via turbines or spillways. Thus dam passage time for non-detected fish is typically minutes to hours shorter than that for detected fish, all of which pass the dam via the juvenile bypass system.

Results

We computed travel time statistics from the tailrace of Lower Granite and McNary Dam to multiple downstream sites for weekly groups of yearling Chinook salmon and juvenile steelhead. Estimated travel time decreased over the migration season (Tables 17-22). For both species, estimated migration rates were generally highest in the lower river sections, and travel time between Lower Granite and Bonneville Dam was shorter through April than in all previous recorded years (1997-2015). Starting in May, travel times converged with the mean in recent years for Chinook and exceeded the recent mean for steelhead (Figure 4).

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

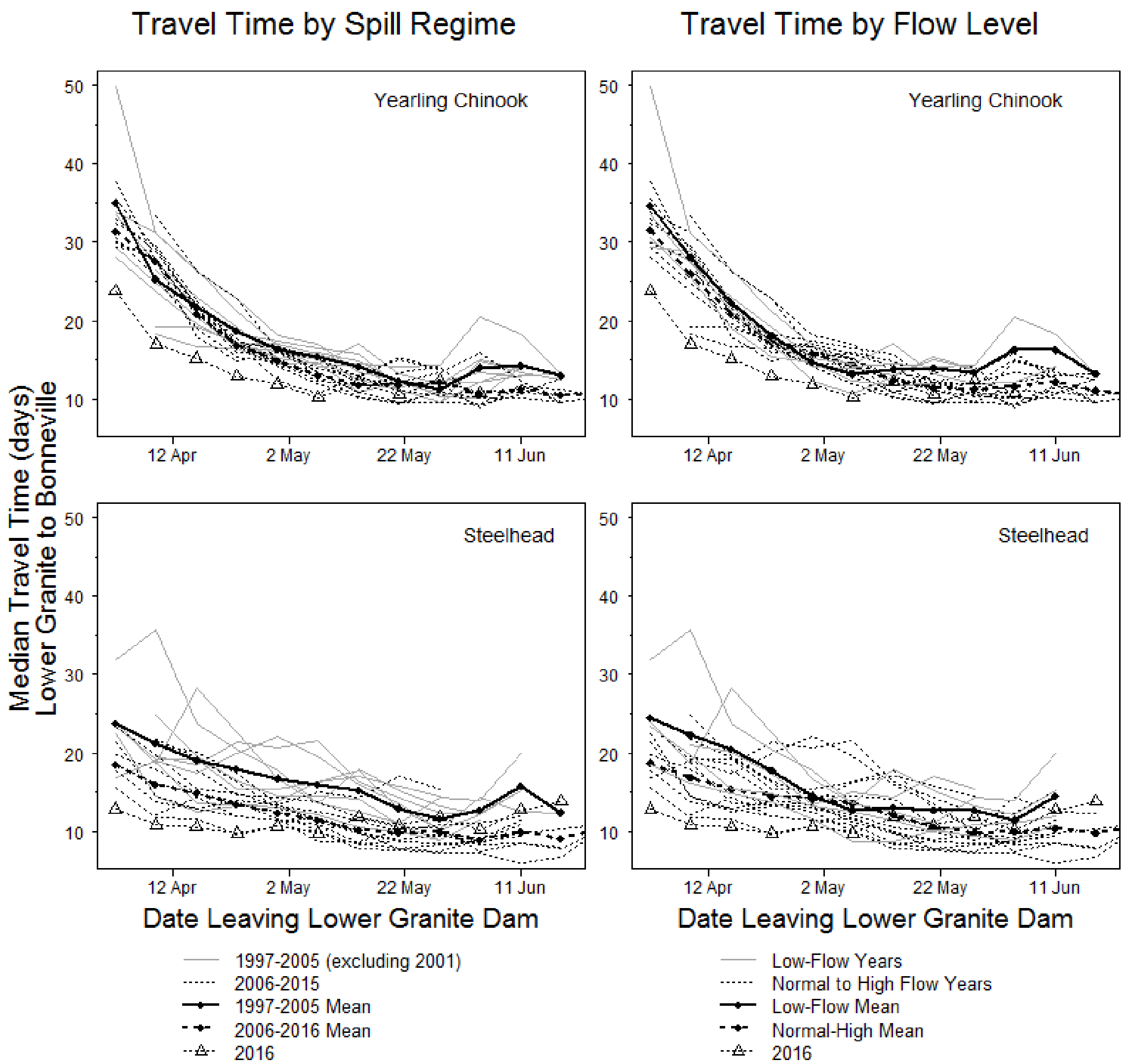

Figure 4. Median travel time (d) from Lower Granite Dam to Bonneville Dam for yearling Chinook salmon and steelhead for the period 1997-2016 (excluding 2001). Years are shown by spill regime (left) and flow level (right).

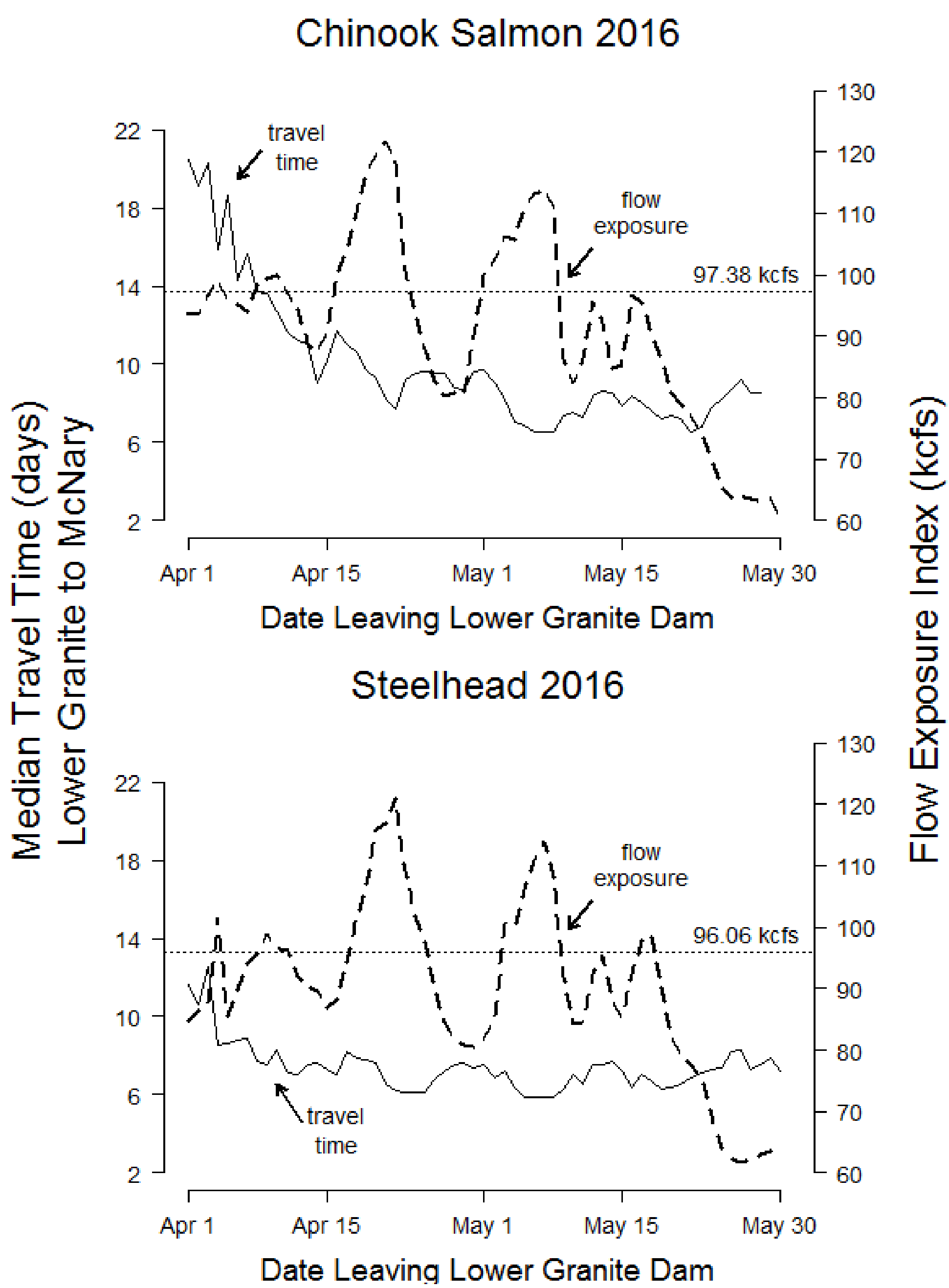

Figure 5. Travel time (d) for yearling Chinook salmon and steelhead from Lower Granite to McNary Dam and index of flow exposure at Lower Monumental Dam (kcfs) for daily groups of PIT-tagged fish during 2016 (see Appendix C). Dashed horizontal lines represent the annual average flow exposure index, weighted by the number of PIT-tagged fish in each group.

Table 17. Travel time statistics for combined hatchery and wild Snake River yearling Chinook salmon detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2016.

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

Date at Lower Granite Dam	Lower Granite to Little Goose Dam N	20%	Median	80%	Little Goose to Lower Monumental N	20%	Median	80%	Lower Monumental to McNary Dam N	20%	Median	80%
30 Mar–5 Apr	548	5.9	9.3	15.6	51	2.0	2.9	4.2	50	4.1	5.4	7.8
6–12 Apr	2,987	3.1	4.1	6.0	268	1.5	2.0	2.9	194	3.9	5.0	6.4
13–19 Apr	7,455	2.8	3.8	5.6	874	1.4	1.8	2.3	697	3.4	4.1	5.5
20–26 Apr	8,639	2.9	3.9	5.3	1,004	1.2	1.6	2.0	912	2.8	3.3	4.3
27 Apr–3 May	5,342	3.0	3.8	5.0	394	1.3	1.6	2.1	302	2.6	3.1	3.8
4–10 May	4,701	1.9	2.4	3.0	1,036	1.1	1.3	1.8	678	2.5	3.0	3.5
11–17 May	2,039	2.7	3.1	3.9	316	1.3	1.7	2.2	199	2.9	3.3	3.8
18–24 May	870	2.0	2.4	2.7	62	1.2	1.4	1.7	27	3.0	3.3	3.6
25–31 May	226	2.4	2.9	3.5	2	1.7	1.8	1.8	1	3.5	3.5	3.5
1–7 Jun	24	2.0	2.3	2.6	2	1.6	1.7	1.7	0	NA	NA	NA

Date at Lower Granite Dam	Lower Granite to McNary Dam N	20%	Median	80%	Lower Granite to Bonneville Dam N	20%	Median	80%
30 Mar–5 Apr	211	14.1	18.8	25.4	81	19.8	23.8	29.2
6–12 Apr	904	9.6	11.9	15.8	326	14.5	17.0	20.9
13–19 Apr	3,046	8.3	10.1	12.9	1,103	12.9	15.2	17.9
20–26 Apr	4,445	7.6	9.2	10.9	2,099	11.6	12.9	14.5
27 Apr–3 May	2,807	7.5	8.8	10.5	1,294	10.8	11.9	13.4
4–10 May	3,093	6.1	6.7	8.2	1,256	9.2	10.2	11.3
11–17 May	1,095	7.5	8.4	9.4	245	11.0	12.2	13.3
18–24 May	370	6.5	7.2	8.4	75	9.9	10.6	11.8
25–31 May	114	7.7	8.6	9.9	15	11.3	12.4	13.3
1–7 Jun	15	6.6	7.3	8.6	8	10.4	10.8	12.0

Table 18. Migration rate statistics for combined hatchery and wild Snake River yearling Chinook salmon detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2016.

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	548	3.8	6.4	10.2	51	11.0	15.9	22.8	50	15.3	22.2	29.2
6–12 Apr	2,987	9.9	14.6	19.2	268	15.9	22.4	30.5	194	18.5	23.7	30.5
13–19 Apr	7,455	10.8	15.6	21.4	874	20.3	25.6	31.7	697	21.6	28.8	35.2
20–26 Apr	8,639	11.3	15.5	20.8	1,004	22.4	29.7	37.7	912	27.5	35.8	42.8
27 Apr–3 May	5,342	12.0	15.6	19.9	394	22.2	28.4	34.3	302	31.6	38.4	45.8
4–10 May	4,701	20.1	25.3	31.6	1,036	25.8	34.3	41.8	678	33.5	40.2	47.4
11–17 May	2,039	15.5	19.5	22.1	316	20.7	27.4	34.6	199	31.2	36.4	41.5
18–24 May	870	22.1	25.2	30.0	62	27.4	34.1	37.7	27	32.9	36.5	40.1
25–31 May	226	16.9	20.8	24.6	2	25.0	26.1	27.5	1	34.2	34.2	34.2
1–7 Jun	24	22.8	25.6	30.8	2	27.1	27.5	28.0	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	211	8.9	12.0	15.9	81	15.8	19.4	23.3
6–12 Apr	904	14.2	18.9	23.4	326	22.1	27.1	31.7
13–19 Apr	3,046	17.5	22.2	27.0	1,103	25.8	30.3	35.8
20–26 Apr	4,445	20.6	24.6	29.7	2,099	31.7	35.8	39.7
27 Apr–3 May	2,807	21.3	25.7	29.9	1,294	34.3	38.7	42.8
4–10 May	3,093	27.5	33.4	37.0	1,256	40.7	45.3	50.2
11–17 May	1,095	23.8	26.8	30.1	245	34.6	37.8	41.9
18–24 May	370	26.9	31.2	34.9	75	38.9	43.7	46.7
25–31 May	114	22.6	26.2	29.4	15	34.8	37.0	40.7
1–7 Jun	15	26.3	30.6	34.2	8	38.3	42.5	44.4

Table 19. Travel time and migration rate statistics for combined hatchery and wild Snake River yearling Chinook salmon detected and returned or tagged and released to the tailrace at McNary Dam, 2016.

	Hatchery and wild yearling Chinook salmon from McNary Dam											
Date at	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
McNary Dam	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
6–12 Apr	15	3.4	4.4	6.5	1	1.9	1.9	1.9	7	4.9	5.1	7.6
13–19 Apr	559	3.8	4.5	5.7	68	1.6	1.8	2.0	149	4.9	5.8	6.9
20–26 Apr	3,160	3.0	3.5	4.5	406	1.5	1.7	2.0	953	4.5	4.9	5.9
27 Apr–3 May	2,225	3.0	3.5	4.3	382	1.4	1.6	1.9	2,642	4.2	4.7	5.2
4–10 May	773	2.7	3.2	4.0	116	1.3	1.5	1.7	1,416	3.7	3.9	4.5
11–17 May	612	2.9	3.3	4.2	103	1.3	1.5	1.8	1,059	3.6	4.1	4.6
18–24 May	256	3.0	3.4	4.2	56	1.6	1.7	1.9	230	4.1	4.6	5.1
25–31 May	47	2.8	3.1	3.6	9	1.5	1.7	1.8	43	4.2	4.7	5.3
1–7 Jun	15	2.8	3.2	3.6	1	1.5	1.5	1.5	7	4.1	4.5	4.7
8–14 Jun	9	2.5	2.9	3.1	2	1.4	1.5	1.5	5	3.8	3.8	4.2
	Migration rate (km/d)											
6–12 Apr	15	18.8	28.0	36.3	1	60.4	60.4	60.4	7	31.1	46.5	48.1
13–19 Apr	559	21.5	27.5	32.4	68	55.7	64.6	72.4	149	34.4	40.6	48.4
20–26 Apr	3,160	27.5	34.6	41.7	406	57.1	67.3	76.9	953	40.3	48.3	52.8
27 Apr–3 May	2,225	28.5	35.3	41.4	382	60.4	69.3	77.9	2,642	45.1	49.9	55.9
4–10 May	773	30.8	38.6	46.2	116	64.9	75.8	85.0	1,416	52.0	60.2	64.3
11–17 May	612	29.4	37.0	42.9	103	64.6	77.4	85.0	1,059	51.0	58.0	65.0
18–24 May	256	29.3	35.8	41.0	56	59.5	66.9	72.4	230	46.0	51.1	57.1
25–31 May	47	34.5	39.7	44.1	9	61.4	64.9	73.4	43	44.4	50.4	55.9
1–7 Jun	15	34.2	38.3	44.7	1	75.8	75.8	75.8	7	50.1	51.9	57.1
8–14 Jun	9	39.0	42.3	50.0	2	76.4	76.9	77.9	5	56.3	61.6	62.6

Table 20. Travel time statistics for combined hatchery and wild Snake River steelhead detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2016.

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	144	2.8	3.2	4.8	11	2.4	2.6	5.1	0	NA	NA	NA
6–12 Apr	1,086	2.1	2.8	3.6	104	1.6	2.6	5.6	64	2.7	3.4	5.3
13–19 Apr	4,555	2.0	2.4	3.1	657	1.4	2.2	4.0	281	2.5	3.0	4.2
20–26 Apr	6,408	1.9	2.2	2.9	1,111	1.2	1.7	2.7	605	2.1	2.8	3.8
27 Apr–3 May	4,237	2.0	2.2	3.0	700	1.5	2.0	3.1	299	2.6	3.0	3.8
4–10 May	2,229	1.9	2.0	2.4	418	1.1	1.4	2.4	332	2.2	2.8	3.4
11–17 May	2,675	2.0	2.6	3.2	330	1.4	2.0	3.0	168	2.6	3.0	3.7
18–24 May	1,447	1.9	2.0	2.3	97	1.2	1.8	2.3	59	2.5	2.9	3.8
25–31 May	337	2.0	2.1	3.0	5	1.6	2.0	2.4	0	NA	NA	NA
1–7 Jun	156	2.0	2.1	2.4	2	1.5	2.1	2.6	4	3.3	3.8	5.1
8–14 Jun	38	1.9	2.1	2.3	1	2.3	2.3	2.3	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	8.4	10.3	12.5	42	11.5	12.8	16.6
6–12 Apr	297	6.2	7.5	10.7	381	9.8	10.8	13.6
13–19 Apr	941	6.4	7.5	9.6	1,249	9.6	10.6	12.8
20–26 Apr	2,577	5.5	6.5	8.4	3,346	8.8	9.8	11.7
27 Apr–3 May	1,343	6.3	7.3	8.7	1,229	9.8	10.7	11.8
4–10 May	1,507	5.3	6.2	7.4	1,415	8.8	9.8	11.3
11–17 May	1,194	6.5	7.4	8.6	769	10.7	11.8	13.4
18–24 May	522	5.9	6.4	7.5	310	9.8	10.8	12.8
25–31 May	145	6.4	8.1	9.3	89	10.5	11.8	12.9
1–7 Jun	95	6.0	6.9	7.9	91	8.9	10.2	12.8
8–14 Jun	30	5.2	6.2	9.0	28	11.1	12.7	15.1

Table 21. Migration rate statistics for combined hatchery and wild Snake River steelhead detected and returned or tagged and released to the tailrace at Lower Granite Dam, 2016.

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	144	12.5	18.5	21.1	11	9.0	17.4	19.4	0	NA	NA	NA
6–12 Apr	1,086	16.9	21.1	28.8	104	8.2	17.4	28.4	64	22.6	34.7	44.7
13–19 Apr	4,555	19.1	25.2	30.5	657	11.6	20.8	32.6	281	28.7	39.5	48.2
20–26 Apr	6,408	20.5	27.6	31.1	1,111	16.8	27.7	39.7	605	31.0	41.9	56.4
27 Apr–3 May	4,237	19.9	27.0	30.3	700	15.0	23.5	30.9	299	31.7	39.1	45.1
4–10 May	2,229	25.4	29.6	32.1	418	19.4	31.7	41.8	332	35.1	42.8	55.1
11–17 May	2,675	18.5	23.3	30.0	330	15.4	22.9	32.4	168	32.2	40.1	46.3
18–24 May	1,447	26.2	29.7	31.6	97	20.3	26.3	37.4	59	31.0	40.9	46.7
25–31 May	337	20.3	28.2	30.8	5	19.5	23.0	27.9	0	NA	NA	NA
1–7 Jun	156	24.8	28.4	30.8	2	17.4	22.2	30.7	4	23.4	31.7	36.0
8–14 Jun	38	26.5	28.7	31.4	1	19.9	19.9	19.9	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	18.0	21.9	26.7	42	27.8	36.0	39.9
6–12 Apr	297	21.0	30.0	36.5	381	33.8	42.6	47.0
13–19 Apr	941	23.4	30.0	35.0	1,249	35.9	43.6	48.2
20–26 Apr	2,577	26.7	34.8	41.2	3,346	39.4	46.8	52.3
27 Apr–3 May	1,343	26.0	30.9	35.5	1,229	38.9	43.1	47.1
4–10 May	1,507	30.4	36.6	42.7	1,415	40.9	46.8	52.4
11–17 May	1,194	26.3	30.4	34.7	769	34.3	38.9	43.3
18–24 May	522	29.8	35.0	38.1	310	36.0	42.6	46.8
25–31 May	145	24.2	27.9	35.0	89	35.8	38.9	43.8
1–7 Jun	95	28.4	32.6	37.4	91	36.0	45.3	51.9
8–14 Jun	30	24.9	36.1	43.3	28	30.6	36.2	41.7

Table 22. Travel time and migration rate statistics for combined hatchery and wild Snake River steelhead detected and returned or tagged and released to the tailrace at McNary Dam, 2016.

Date at McNary Dam	**Hatchery and wild juvenile steelhead from McNary Dam**											
	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
6–12 Apr	21	3.6	4.3	6.3	2	1.4	1.5	1.5	11	3.5	3.8	4.6
13–19 Apr	262	3.3	3.9	5.2	49	1.2	1.3	1.4	253	4.3	4.6	5.3
20–26 Apr	586	3.0	3.6	4.9	105	1.2	1.3	1.5	573	3.6	4.4	4.9
27 Apr–3 May	730	3.0	3.5	4.5	181	1.3	1.4	1.7	1,704	3.8	4.6	4.9
4–10 May	268	2.9	3.4	4.2	49	1.2	1.4	1.6	654	3.7	4.1	4.8
11–17 May	112	2.4	3.3	4.0	36	1.4	1.7	2.0	782	3.9	4.5	5.3
18–24 May	95	3.0	3.5	4.5	26	1.5	1.7	2.0	405	4.2	4.8	5.4
25–31 May	20	3.3	3.5	4.2	8	1.5	1.6	1.9	100	3.9	4.7	5.2
1–7 Jun	8	2.4	3.1	4.1	1	1.4	1.4	1.4	64	3.5	4.0	4.9
8–14 Jun	3	2.1	2.2	2.8	1	2.3	2.3	2.3	20	3.9	4.5	5.0
	Migration rate (km/d)											
6–12 Apr	21	19.5	28.9	34.0	2	73.4	76.4	79.6	11	51.6	61.3	67.0
13–19 Apr	262	23.9	31.4	37.5	49	79.0	89.0	95.0	253	44.7	51.5	55.0
20–26 Apr	586	25.3	34.6	41.4	105	75.8	85.6	92.6	573	48.4	53.9	65.2
27 Apr–3 May	730	27.6	35.2	41.1	181	67.3	78.5	86.3	1,704	48.3	51.6	61.3
4–10 May	268	29.3	36.6	42.4	49	69.8	83.1	91.9	654	49.6	57.7	63.4
11–17 May	112	30.8	36.8	50.4	36	57.7	65.7	80.7	782	44.4	51.9	61.1
18–24 May	95	27.2	35.3	40.9	26	56.8	65.7	73.9	405	43.4	49.6	55.9
25–31 May	20	29.2	34.9	37.6	8	58.5	69.3	75.8	100	45.6	50.4	60.1
1–7 Jun	8	30.0	39.2	51.5	1	79.0	79.0	79.0	64	48.5	58.6	66.5
8–14 Jun	3	43.5	55.7	59.1	1	49.6	49.6	49.6	20	47.5	52.2	61.0

Proportion Transported of Spring Migrants

Methods

To estimate the proportion of non-tagged fish that were transported, we proceeded through the following steps:

1. Compile daily collection counts at Lower Granite Dam from the Smolt Monitoring Program (fpc.org).

2. Use PIT-tag data to derive daily estimates of detection probability at Lower Granite Dam, following the methods of Sandford and Smith (2002). Virtually every PIT-tagged fish that enters a collection system is detected; thus, the probability of detecting a PIT-tagged fish on a given day is the de facto probability of the fish entering the collection system on that day.

3. For each day, divide the daily collection count by the detection probability estimate for that day to get an estimate of the total number of fish (tagged and untagged) that passed Lower Granite Dam on that day. This also gives rise to daily estimates of the total number of fish in the Lower Granite Dam collection system and the number of fish that passed via other routes (i.e., "non-detected" or "non-bypassed").

4. For each daily group of PIT-tagged fish leaving Lower Granite Dam (i.e. detected and returned to the river), tabulate the number that were next detected at Little Goose Dam (i.e. next entered a collection system) and the number that passed Little Goose undetected and next entered a collection system at Lower Monumental Dam.

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

5. Assume that for the group of untagged fish arriving at Lower Granite Dam on a given day, the proportion of Lower Granite equivalents first collected at Lower Granite, Little Goose, and Lower Monumental Dams is the same as that of the group of PIT-tagged fish arriving on that day. (The number of PIT-tagged fish that arrived but were not detected at Lower Granite is estimated from steps 2 and 3.)

6. For each daily group of fish arriving at Lower Granite Dam, estimate the proportion of those that entered the collection system at each collector dam and were transported from that dam.

   For groups arriving at Lower Granite Dam after the transportation starting date at a collector dam, the proportion transported is 100%.

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

7. For each daily group of the run-at-large, calculate the product of three quantities:
   i. Estimated number of fish in the group passing Lower Granite Dam that day (step 3)
   ii. Estimated proportion of fish first entering the collection system at each dam (steps 4-5)
   iii. Estimated proportion of fish entering the collection system that were transported (step 6)

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

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

Results

In 2016, collection for transportation began on 2 May at Lower Granite, Little Goose, and Lower Monumental Dams, and the first barge operated on 2 May at each of these collector dams. Until these dates, smolts collected at Snake River dams were bypassed back to the river. Estimated percentages of non-tagged spring/summer Chinook salmon transported during the entire 2016 season were 19.3% for wild and 21.0% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 24.4% for wild and 22.9% for hatchery smolts.

These estimates represent the proportion of smolts that arrived at Lower Granite Dam and were subsequently transported, either from Lower Granite or from one of the downstream collector dams. Estimates for 2016 were among the lowest recorded in our time series of estimates; only estimates in 2015 were lower (1993-2015; Figure 6; Table 23).

Before 2006, collected fish were transported throughout the season, starting from the first day on which the collection system was supplied with water. Between 2007 and 2013, collected fish were bypassed until a designated date at each dam, and the beginning date of transportation was staggered at each downstream dam (e.g., a few days later at Little Goose Dam than at Lower Granite Dam). The 2014 season was the first during which transportation began simultaneously at all three collector dams, and this approach continued in 2016.

By the time collection for transportation began at Lower Granite Dam on 2 May 2016, about 76% of wild yearling Chinook, 72% of hatchery yearling Chinook, 58% of steelhead (hatchery and wild combined) had already passed the dam. During general transportation operations, we estimated that for yearling Chinook salmon, approximately 73% of wild and 62% of hatchery smolts that arrived at Lower Granite Dam were transported, either from Lower Granite or from a downstream collector dam. The difference in proportion of transported fish between rear-types is due to a difference in the probability of entering the collection system.

Available data for steelhead did not differentiate between hatchery and wild fish (smolt sampling reports do not distinguish), so we were unable to estimate with as much precision the difference in proportions of transported hatchery vs. wild fish. We estimated that, on average, 58% of steelhead passed Lower Granite Dam before collection for transportation began, and 51% of steelhead that passed after 2 May were transported. During the period in which transportation occurred, 53% of steelhead that passed Lower Granite Dam were eventually collected and transported.

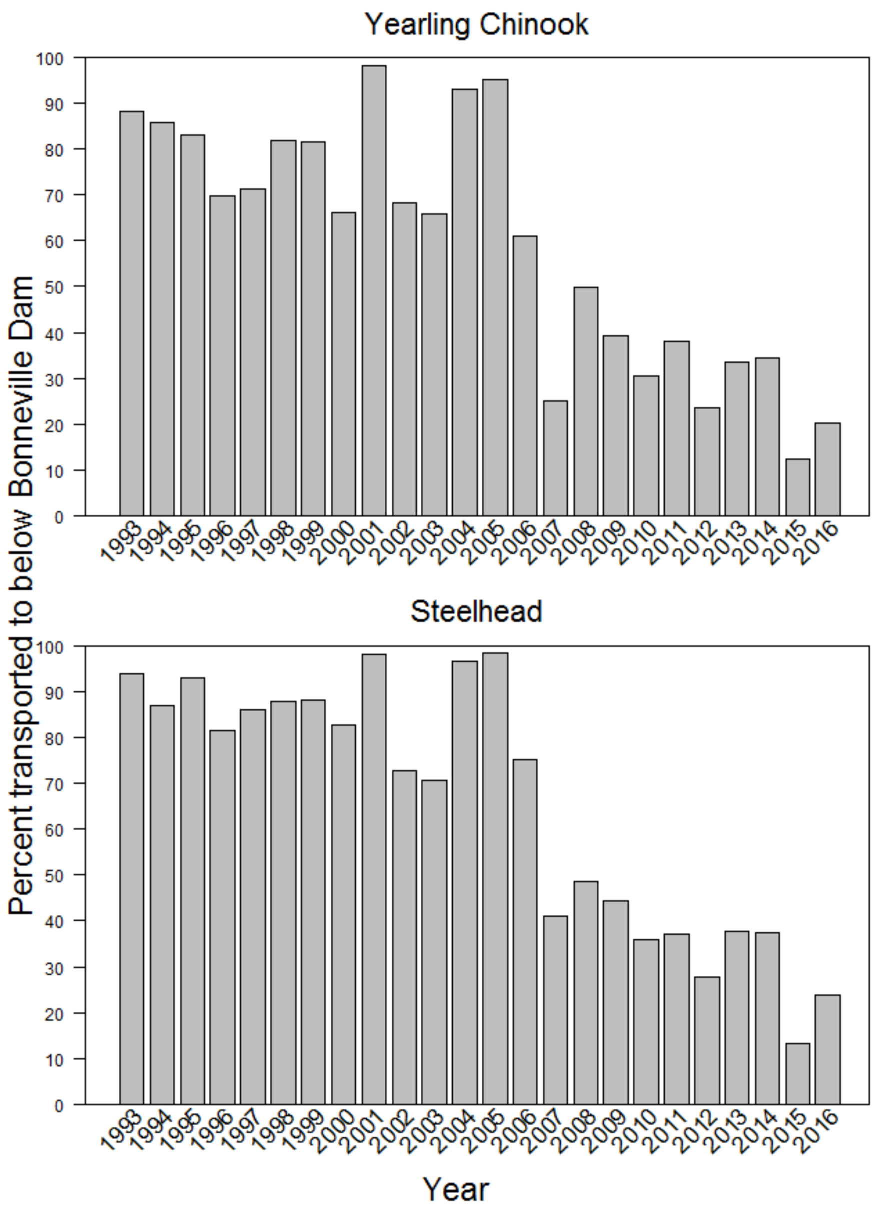

Figure 6. Estimated percent of yearling Chinook salmon and steelhead (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2016).

Table 23. Annual estimated percentages of migrating Snake River yearling Chinook salmon and steelhead that were transported (1993-2016). Estimates are shown for hatchery and wild fish separately. Separate arithmetic means are shown for each estimate over all years and across years with a common transportation operating schedule.

	Estimated percentage of fish transported (%)					
	Yearling Chinook Salmon			**Juvenile Steelhead**		
Year	Hatchery	Wild	Mean	Hatchery	Wild	Mean
1993	88.1	88.5	88.3	94.7	93.2	94.0
1994	84.0	87.7	85.9	82.2	91.3	86.8
1995	79.6	86.4	83.0	94.3	91.8	93.1
1996	68.7	71.0	69.9	82.9	79.8	81.4
1997	71.5	71.1	71.3	84.5	87.5	86.0
1998	81.4	82.5	82.0	87.3	88.2	87.8
1999	77.3	85.9	81.6	88.5	87.6	88.1
2000	61.9	70.4	66.2	81.5	83.9	82.7
2001	97.3	99.0	98.2	96.7	99.3	98.0
2002	64.2	72.1	68.2	70.4	75.2	72.8
2003	61.5	70.4	66.0	68.4	72.9	70.7
2004	92.9	93.2	93.1	97.3	95.7	96.5
2005	95.0	95.1	95.1	98.0	98.7	98.4
2006	62.3	59.9	61.1	76.0	74.6	75.3
2007	25.4	24.8	25.1	41.1	41.1	41.1
2008	45.3	54.3	49.8	46.6	50.5	48.6
2009	38.3	40.4	39.4	42.7	46.1	44.4
2010	22.6	38.2	30.4	34.8	36.8	35.8
2011	40.7	35.2	38.0	37.8	36.1	37.0
2012	24.7	22.7	23.7	26.7	28.4	27.6
2013	31.0	36.1	33.6	35.0	40.0	37.8
2014	38.3	30.9	34.6	34.6	39.9	37.3
2015	13.6	11.4	12.5	13.9	12.4	13.2
2016	21.0	19.3	20.2	22.9	24.4	23.7
Mean						
1993-2016	**57.8**	**60.3**	**59.0**	**64.3**	**65.5**	**64.9**
1993-2006	**77.6**	**80.9**	**79.3**	**85.9**	**87.1**	**86.5**
2007-2016	**30.1**	**31.3**	**30.7**	**34.1**	**35.1**	**34.6**

For both yearling Chinook salmon and steelhead, a larger percentage of the total run passed before transportation began in 2016 than in 2015; however, a larger percentage was transported after the program began in 2016 than in 2015. As a result, the overall percentages of transported fish in 2016 were not as low as those in 2015, but they were still the second lowest recorded in our time series.

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

Comparisons of Annual Survival Estimates

Comparison Among Years

We made two types of comparisons among annual survival estimates from 2016 and those obtained during the previous 23 years of the NMFS survival study. First, for Snake River hatchery yearling Chinook salmon, we compared estimated survival to Lower Granite Dam with distance of the respective hatcheries from the dam.

Second, for Snake and Columbia River yearling Chinook, steelhead, and sockeye salmon, we compared estimates of overall seasonal survival through specific reaches during 2016 with overall seasonal (tailrace-to-tailrace) survival estimates for those same reaches in all previous study years for which these data were available.

Snake River Stocks

Yearling Chinook Salmon—For yearling Chinook salmon from most Snake River Basin hatcheries, estimated survival to Lower Granite Dam in 2016 was similar to estimates from recent years. Mean survival was higher than the long-term mean for fish from most hatcheries (Table 24). Over the years of the study, we have consistently observed an inverse relationship between estimated survival and distance of the release site to Lower Granite Dam. This relationship is illustrated for hatchery yearling Chinook salmon in Figure 7 (R^2 = 0.807, P = 0.006).

For combined wild and hatchery yearling Chinook salmon in 2016, mean estimated survival was 0.752 (95% CI 0.730-0.774) from Lower Granite to McNary Dam and 0.672 (0.554-0.790) from McNary to Bonneville Dam (Tables 25-26; Figures 8-9). These estimates were similar to the long-term mean for both reaches, with the Lower Granite to McNary Dam estimate slightly above the long-term mean of 0.736 and the McNary to Bonneville Dam estimate slightly below the long-term mean of 0.703.

Table 24. Estimated survival for yearling Chinook salmon from selected Snake River Basin hatcheries to the tailrace of Lower Granite Dam, 1993-2016. Distance to Lower Granite Dam is shown for each hatchery (km). Standard errors in parentheses following each survival estimate. Simple arithmetic means across all years are given.

	Estimated Survival of hatchery yearling Chinook salmon (SE)							
Year	Dworshak (116 km)	Kooskia (176 km)	Lookingglass* (209 km)	Rapid River (283 km)	McCall (457 km)	Pahsimeroi (630 km)	Sawtooth (747 km)	Mean
1993	0.647 (0.028)	0.689 (0.047)	0.660 (0.025)	0.670 (0.017)	0.498 (0.017)	0.456 (0.032)	0.255 (0.023)	0.554 (0.060)
1994	0.778 (0.020)	0.752 (0.053)	0.685 (0.021)	0.526 (0.024)	0.554 (0.022)	0.324 (0.028)	0.209 (0.014)	0.547 (0.081)
1995	0.838 (0.034)	0.786 (0.024)	0.617 (0.015)	0.726 (0.017)	0.522 (0.011)	0.316 (0.033)	0.230 (0.015)	0.576 (0.088)
1996	0.776 (0.017)	0.744 (0.010)	0.567 (0.014)	0.588 (0.007)	0.531 (0.007)	NA	0.121 (0.017)	0.555 (0.096)
1997	0.576 (0.017)	0.449 (0.034)	0.616 (0.017)	0.382 (0.008)	0.424 (0.008)	0.500 (0.008)	0.508 (0.037)	0.494 (0.031)
1998	0.836 (0.006)	0.652 (0.024)	0.682 (0.006)	0.660 (0.004)	0.585 (0.004)	0.428 (0.021)	0.601 (0.033)	0.635 (0.046)
1999	0.834 (0.011)	0.653 (0.031)	0.668 (0.009)	0.746 (0.006)	0.649 (0.008)	0.584 (0.035)	0.452 (0.019)	0.655 (0.045)
2000	0.841 (0.009)	0.734 (0.027)	0.688 (0.011)	0.748 (0.007)	0.689 (0.010)	0.631 (0.062)	0.546 (0.030)	0.697 (0.035)
2001	0.747 (0.002)	0.577 (0.019)	0.747 (0.003)	0.689 (0.002)	0.666 (0.002)	0.621 (0.016)	0.524 (0.023)	0.653 (0.032)
2002	0.819 (0.011)	0.787 (0.036)	0.667 (0.012)	0.755 (0.003)	0.592 (0.006)	0.678 (0.053)	0.387 (0.025)	0.669 (0.055)
2003	0.720 (0.008)	0.560 (0.043)	0.715 (0.012)	0.691 (0.007)	0.573 (0.006)	0.721 (0.230)	0.595 (0.149)	0.654 (0.028)
2004	0.821 (0.003)	0.769 (0.017)	0.613 (0.004)	0.694 (0.003)	0.561 (0.002)	0.528 (0.017)	0.547 (0.018)	0.648 (0.044)
2005	0.823 (0.003)	0.702 (0.021)	0.534 (0.004)	0.735 (0.002)	0.603 (0.003)	0.218 (0.020)	0.220 (0.020)	0.549 (0.092)
2006	0.853 (0.007)	0.716 (0.041)	0.639 (0.014)	0.764 (0.004)	0.634 (0.006)	0.262 (0.024)	0.651 (0.046)	0.645 (0.071)
2007	0.817 (0.007)	0.654 (0.015)	0.682 (0.010)	0.748 (0.004)	0.554 (0.007)	0.530 (0.038)	0.581 (0.015)	0.652 (0.040)
2008	0.737 (0.011)	0.631 (0.015)	0.694 (0.008)	0.801 (0.004)	0.578 (0.007)	0.447 (0.011)	0.336 (0.012)	0.603 (0.062)
2009	0.696 (0.007)	0.633 (0.012)	0.699 (0.009)	0.728 (0.005)	0.513 (0.005)	0.510 (0.006)	0.367 (0.007)	0.592 (0.050)
2010	0.898 (0.017)	0.744 (0.030)	0.682 (0.025)	0.786 (0.019)	0.566 (0.014)	0.384 (0.023)	0.427 (0.018)	0.641 (0.072)
2011	0.722 (0.006)	0.729 (0.014)	0.572 (0.009)	0.766 (0.006)	0.631 (0.007)	0.498 (0.005)	0.521 (0.007)	0.634 (0.041)
2012	0.743 (0.008)	0.652 (0.013)	0.689 (0.009)	0.718 (0.014)	0.571 (0.006)	0.581 (0.006)	0.473 (0.008)	0.632 (0.036)
2013	0.794 (0.015)	0.609 (0.026)	0.703 (0.019)	0.735 (0.011)	0.656 (0.011)	0.606 (0.016)	0.564 (0.011)	0.667 (0.031)
2014	0.816 (0.009)	0.595 (0.011)	0.673 (0.009)	0.757 (0.008)	0.714 (0.008)	0.794 (0.008)	0.646 (0.008)	0.714 (0.031)
2015	0.768 (0.018)	0.532 (0.027)	0.655 (0.035)	0.811 (0.024)	0.729 (0.030)	0.771 (0.036)	0.696 (0.036)	0.709 (0.035)
2016	0.714 (0.007)	0.684 (0.012)	0.704 (0.007)	0.815 (0.005)	0.654 (0.006)	0.772 (0.008)	0.676 (0.006)	0.717 (0.022)
Mean	**0.776 (0.015)**	**0.668 (0.017)**	**0.660 (0.010)**	**0.710 (0.020)**	**0.594 (0.015)**	**0.529 (0.034)**	**0.464 (0.034)**	**0.629 (0.012)**

* Released at Imnaha River Weir.

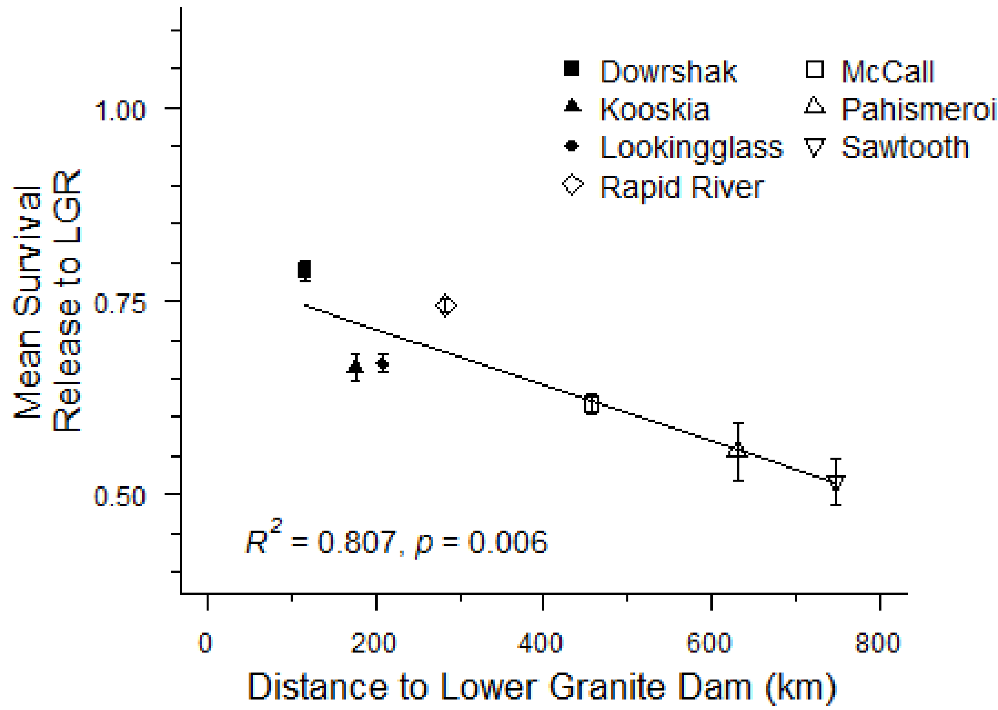

Figure 7. Mean estimated survival from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2016 vs. distance (km) to Lower Granite Dam. The coefficient of determination between survival and migration distance is also shown, along with a *P*-value for a test of the null hypothesis of zero correlation. Whiskers show standard errors.

Table 25. Annual weighted means of survival probability estimates for yearling Chinook salmon (hatchery and wild combined), 1995–2016. Standard errors in parentheses. Shaded columns are reaches that comprise two dams and reservoirs (i.e., two projects); the following column gives the square root of the two–project estimate to facilitate comparison with other single-project estimates. Simple arithmetic means are given across all available years (1993-2016).

Annual survival estimates for hatchery and wild yearling Chinook salmon (SE)								
Year	Trap to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	L Monumental to Ice Harbor and Ice Harbor to McNary	McNary to John Day Dam	John Day to Bonneville Dam	John Day to The Dalles and The Dalles to Bonneville Dam
1995	0.905 (0.010)	0.882 (0.004)	0.925 (0.008)	0.876 (0.038)	0.936	NA	NA	NA
1996	0.977 (0.025)	0.926 (0.006)	0.929 (0.011)	0.756 (0.033)	0.870	NA	NA	NA
1997	NA	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.893	NA	NA	NA
1998	0.924 (0.009)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)	NA	NA
1999	0.940 (0.009)	0.949 (0.002)	0.925 (0.004)	0.904 (0.007)	0.951	0.853 (0.027)	0.814 (0.065)	0.902
2000	0.929 (0.014)	0.938 (0.006)	0.887 (0.009)	0.928 (0.016)	0.963	0.898 (0.054)	0.684 (0.128)	0.827
2001	0.954 (0.015)	0.945 (0.004)	0.830 (0.006)	0.708 (0.007)	0.841	0.758 (0.024)	0.645 (0.034)	0.803
2002	0.953 (0.022)	0.949 (0.006)	0.980 (0.008)	0.837 (0.013)	0.915	0.907 (0.014)	0.840 (0.079)	0.917
2003	0.993 (0.023)	0.946 (0.005)	0.916 (0.011)	0.904 (0.017)	0.951	0.893 (0.017)	0.818 (0.036)	0.904
2004	0.893 (0.009)	0.923 (0.004)	0.875 (0.012)	0.818 (0.018)	0.904	0.809 (0.028)	0.735 (0.092)	0.857
2005	0.919 (0.015)	0.919 (0.003)	0.886 (0.006)	0.903 (0.010)	0.950	0.772 (0.029)	1.028 (0.132)	1.014
2006	0.952 (0.011)	0.923 (0.003)	0.934 (0.004)	0.887 (0.008)	0.942	0.881 (0.020)	0.944 (0.030)	0.972
2007	0.943 (0.028)	0.938 (0.006)	0.957 (0.010)	0.876 (0.012)	0.936	0.920 (0.016)	0.824 (0.043)	0.908
2008	0.992 (0.018)	0.939 (0.006)	0.950 (0.011)	0.878 (0.016)	0.937	1.073 (0.058)	0.558 (0.082)	0.750
2009	0.958 (0.010)	0.940 (0.006)	0.982 (0.009)	0.855 (0.011)	0.925	0.866 (0.042)	0.821 (0.043)	0.906
2010	0.968 (0.040)	0.962 (0.011)	0.973 (0.019)	0.851 (0.017)	0.922	0.947 (0.021)	0.780 (0.039)	0.883
2011	0.943 (0.009)	0.919 (0.007)	0.966 (0.007)	0.845 (0.012)	0.919	0.893 (0.026)	0.766 (0.080)	0.875
2012	0.928 (0.012)	0.907 (0.009)	0.939 (0.010)	0.937 (0.016)	0.968	0.915 (0.023)	0.866 (0.058)	0.931
2013	0.845 (0.031)	0.922 (0.012)	0.983 (0.014)	0.904 (0.022)	0.951	0.931 (0.054)	0.823 (0.036)	0.907
2014	0.905 (0.015)	0.940 (0.007)	0.919 (0.010)	0.894 (0.017)	0.946	0.912 (0.053)	0.752 (0.104)	0.867
2015	0.909 (0.103)	0.857 (0.036)	0.964 (0.057)	0.802 (0.033)	0.896	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
Mean	**0.932 (0.008)**	**0.925 (0.007)**	**0.923 (0.009)**	**0.861 (0.012)**	**0.928 (0.007)**	**0.872 (0.018)**	**0.806 (0.026)**	**0.896 (0.015)**

Table 26. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling Chinook salmon (hatchery and wild combined), 1997–2016. Standard errors in parentheses. Simple arithmetic means are given; for Trap-LGR the mean extends as far back as 1993, for LGR-MCN the mean extends back to 1995.

Annual survival estimates for hatchery and wild yearling Chinook (SE)					
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1997	NA	0.653 (0.072)	NA	NA	NA
1998	0.924 (0.009)	0.770 (0.009)	NA	NA	NA
1999	0.940 (0.009)	0.792 (0.006)	0.704 (0.058)	0.557 (0.046)	0.524 (0.043)
2000	0.929 (0.014)	0.760 (0.012)	0.640 (0.122)	0.486 (0.093)	0.452 (0.087)
2001	0.954 (0.015)	0.556 (0.009)	0.501 (0.027)	0.279 (0.016)	0.266 (0.016)
2002	0.953 (0.022)	0.757 (0.009)	0.763 (0.079)	0.578 (0.060)	0.551 (0.059)
2003	0.993 (0.023)	0.731 (0.010)	0.728 (0.030)	0.532 (0.023)	0.528 (0.026)
2004	0.893 (0.009)	0.666 (0.011)	0.594 (0.074)	0.395 (0.050)	0.353 (0.045)
2005	0.919 (0.015)	0.732 (0.009)	0.788 (0.093)	0.577 (0.068)	0.530 (0.063)
2006	0.952 (0.011)	0.764 (0.007)	0.842 (0.021)	0.643 (0.017)	0.612 (0.018)
2007	0.943 (0.028)	0.783 (0.006)	0.763 (0.044)	0.597 (0.035)	0.563 (0.037)
2008	0.992 (0.018)	0.782 (0.011)	0.594 (0.066)	0.465 (0.052)	0.460 (0.052)
2009	0.958 (0.010)	0.787 (0.007)	0.705 (0.031)	0.555 (0.025)	0.531 (0.025)
2010	0.968 (0.040)	0.772 (0.012)	0.738 (0.039)	0.569 (0.032)	0.551 (0.038)
2011	0.943 (0.009)	0.746 (0.010)	0.687 (0.065)	0.513 (0.049)	0.483 (0.046)
2012	0.928 (0.012)	0.790 (0.016)	0.802 (0.051)	0.634 (0.042)	0.588 (0.040)
2013	0.845 (0.031)	0.781 (0.016)	0.796 (0.064)	0.622 (0.052)	0.525 (0.048)
2014	0.905 (0.015)	0.768 (0.015)	0.715 (0.107)	0.549 (0.083)	0.497 (0.075)
2015	0.909 (0.103)	0.680 (0.035)	0.629 (0.043)	0.428 (0.037)	0.389 (0.055)
2016	0.936 (0.015)	0.752 (0.011)	0.672 (0.060)	0.505 (0.046)	0.473 (0.043)
Mean	**0.932 (0.008)**	**0.736 (0.013)**	**0.703 (0.021)**	**0.527 (0.022)**	**0.493 (0.020)**

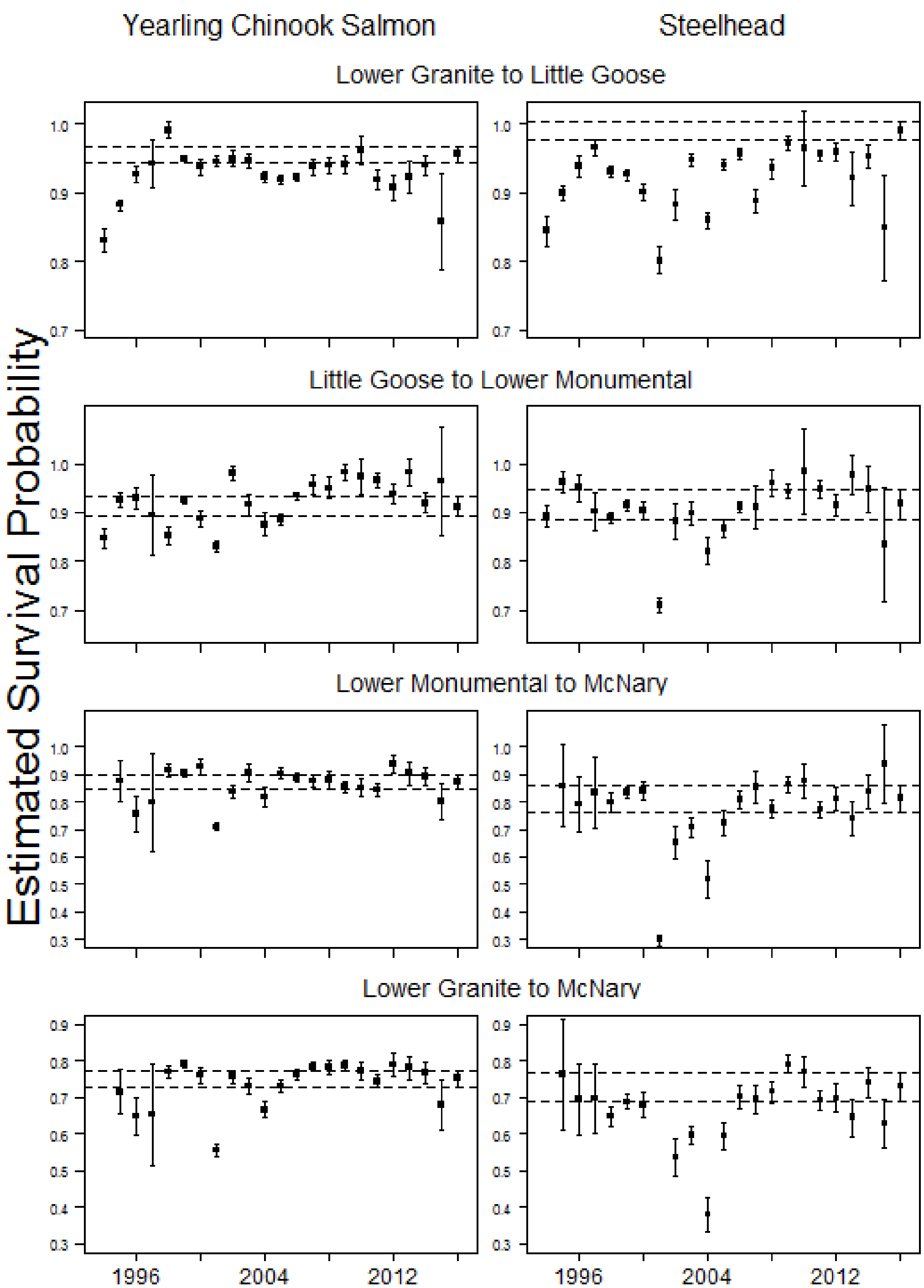

Figure 8. Annual weighted mean survival estimates for PIT-tagged yearling Chinook salmon and steelhead (hatchery and wild combined) through Snake River reaches, 1993-2016. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2016 estimates.

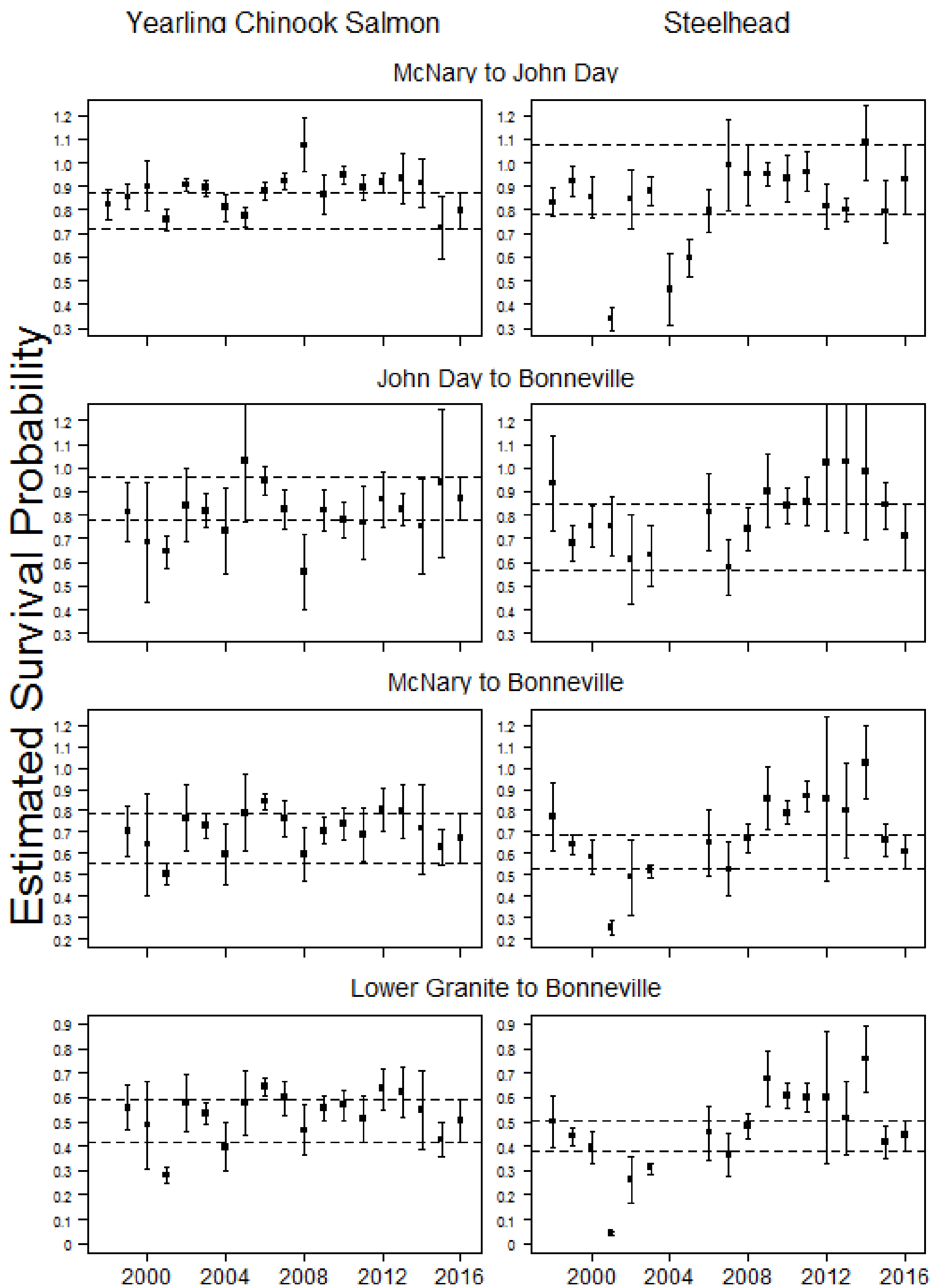

Figure 9. Annual weighted mean survival estimates for PIT-tagged Snake River yearling Chinook salmon and steelhead (hatchery and wild combined) through Columbia River reaches and from Lower Granite Dam to Bonneville Dam, 1993-2016. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2016 estimates.

For combined wild and hatchery yearling Chinook salmon in 2016, mean estimated survival was 0.473 (0.388-0.558) through the entire hydrosystem from the Snake River Trap to Bonneville Dam (Table 26). This estimate was slightly below the 19-year mean of 0.493 from 1997 to 2016, but considerably higher than the estimate of 0.389 from 2015. However, the difference between estimates in 2015 and 2016 was not significant (P = 0.23), due to the level of uncertainty in both estimates.

For wild yearling Chinook salmon in 2016, mean estimated survival was 0.703 (95% CI 0.670-0.736) from Lower Granite to McNary Dam; this estimate was close to the long-term average of 0.723. However, survival of these fish from McNary to Bonneville Dam was 0.490 (0.304-0.676), which was below the long-term average of 0.662 (Table 27). For these wild fish, the overall mean estimated survival through the entire hydrosystem of 0.330 (0.203-0.457) was below the long-term average of 0.440 and was among the lowest of our time series.

Steelhead—For combined wild and hatchery steelhead, mean estimated survival was 0.730 (95% CI 0.691-0.769) from Lower Granite to McNary Dam. For combined steelhead in this reach, this estimate was higher than both the estimate in 2015 and the long-term average of 0.639. However, in the reach from McNary to Bonneville, estimated survival in 2016 was 0.608 (0.530-0.686) and was slightly below both the estimate in 2015 and the long-term average of 0.650 (Tables 28-29; Figures 8-9). Estimated survival through the entire hydrosystem for these steelhead was 0.443 (0.380-0.506; Table 29), which was similar to the long-term average of 0.448 and higher than the corresponding estimate in 2015 (0.364). The difference between estimates in 2015 and 2016 was moderately statistically significant (P = 0.094).

For wild steelhead in 2016, mean estimated survival from Lower Granite to McNary Dam was 0.644 (0.540-0.748), and was close to the long-term average of 0.634 (Table 30). Estimated survival from McNary to Bonneville Dam was 0.436 (0.352-0.520), which was below the long-term average of 0.623 for these fish. For these wild steelhead, mean estimated survival through the entire hydrosystem was 0.269 (0.198-0.340) in 2016, which was also below the long-term average of 0.402.

Table 27. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling Chinook salmon (wild only) 1999–2016. Standard errors in parentheses. Simple arithmetic means are given; for Trap-LGR and LGR-MCN the mean extends back to 1998.

	Annual survival estimates for wild yearling Chinook				
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1999	0.951 (0.011)	0.791 (0.014)	0.620 (0.099)	0.490 (0.079)	0.466 (0.075)
2000	0.955 (0.023)	0.775 (0.014)	0.575 (0.156)	0.446 (0.121)	0.425 (0.116)
2001	0.921 (0.058)	0.525 (0.034)	0.437 (0.041)	0.230 (0.026)	0.211 (0.028)
2002	0.985 (0.038)	0.768 (0.026)	0.469 (0.120)	0.360 (0.093)	0.355 (0.092)
2003	0.943 (0.033)	0.729 (0.020)	0.757 (0.059)	0.552 (0.046)	0.520 (0.047)
2004	0.862 (0.013)	0.667 (0.023)	0.566 (0.164)	0.377 (0.110)	0.325 (0.095)
2005	0.964 (0.034)	0.661 (0.017)	0.681 (0.243)	0.450 (0.161)	0.434 (0.156)
2006	0.929 (0.019)	0.754 (0.010)	0.827 (0.085)	0.623 (0.064)	0.579 (0.061)
2007	0.903 (0.062)	0.773 (0.013)	0.780 (0.088)	0.603 (0.069)	0.544 (0.072)
2008	0.955 (0.036)	0.786 (0.020)	0.607 (0.127)	0.477 (0.101)	0.456 (0.098)
2009	0.940 (0.012)	0.765 (0.018)	0.606 (0.068)	0.464 (0.053)	0.436 (0.050)
2010	0.821 (0.047)	0.744 (0.021)	0.612 (0.063)	0.455 (0.049)	0.374 (0.045)
2011	0.954 (0.010)	0.743 (0.015)	0.955 (0.197)	0.710 (0.147)	0.677 (0.140)
2012	0.942 (0.013)	0.798 (0.020)	0.831 (0.065)	0.663 (0.054)	0.625 (0.052)
2013	0.791 (0.045)	0.778 (0.018)	0.685 (0.092)	0.553 (0.073)	0.422 (0.062)
2014	0.892 (0.017)	0.678 (0.022)	0.577 (0.074)	0.391 (0.052)	0.349 (0.047)
2015	0.867 (0.192)	0.524 (0.051)	0.843 (0.106)	0.442 (0.070)	0.383 (0.104)
2016	0.957 (0.019)	0.703 (0.017)	0.490 (0.095)	0.344 (0.067)	0.330 (0.065)
Mean	**0.918 (0.012)**	**0.723 (0.019)**	**0.662 (0.034)**	**0.479 (0.029)**	**0.440 (0.027)**

Table 28. Annual weighted means of survival probability estimates for steelhead (hatchery and wild combined), 1995–2016. Standard errors in parentheses. Shaded columns are reaches that comprise two dams and reservoirs (i.e., two projects); the following column gives the square root of the two–project estimate to facilitate comparison with other single-project estimates. Simple arithmetic means across all available years (1993–2016) are given.

Annual survival estimates for hatchery and wild steelhead

Year	Trap to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental	Lower Monumental to McNary Dam	L Monumental to Ice Harbor and Ice Harbor to McNary	McNary to John Day Dam	John Day to Bonneville Dam	John Day to The Dalles and The Dalles to Bonneville Dam
1995	0.945 (0.008)	0.899 (0.005)	0.962 (0.011)	0.858 (0.076)	0.926	NA	NA	NA
1996	0.951 (0.015)	0.938 (0.008)	0.951 (0.014)	0.791 (0.052)	0.889	NA	NA	NA
1997	0.964 (0.015)	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.913	NA	NA	NA
1998	0.924 (0.009)	0.930 (0.004)	0.889 (0.006)	0.797 (0.018)	0.893	0.831 (0.031)	0.935 (0.103)	0.967
1999	0.908 (0.011)	0.926 (0.004)	0.915 (0.006)	0.833 (0.011)	0.913	0.920 (0.033)	0.682 (0.039)	0.826
2000	0.964 (0.013)	0.901 (0.006)	0.904 (0.009)	0.842 (0.016)	0.918	0.851 (0.045)	0.754 (0.045)	0.868
2001	0.911 (0.007)	0.801 (0.010)	0.709 (0.008)	0.296 (0.010)	0.544	0.337 (0.025)	0.753 (0.063)	0.868
2002	0.895 (0.015)	0.882 (0.011)	0.882 (0.018)	0.652 (0.031)	0.807	0.844 (0.063)	0.612 (0.098)	0.782
2003	0.932 (0.015)	0.947 (0.005)	0.898 (0.012)	0.708 (0.018)	0.841	0.879 (0.032)	0.630 (0.066)	0.794
2004	0.948 (0.004)	0.860 (0.006)	0.820 (0.014)	0.519 (0.035)	0.720	0.465 (0.078)	NA	NA
2005	0.967 (0.004)	0.940 (0.004)	0.867 (0.009)	0.722 (0.023)	0.850	0.595 (0.040)	NA	NA
2006	0.920 (0.013)	0.956 (0.004)	0.911 (0.006)	0.808 (0.017)	0.899	0.795 (0.045)	0.813 (0.083)	0.902
2007	1.016 (0.026)	0.887 (0.009)	0.911 (0.022)	0.852 (0.030)	0.923	0.988 (0.098)	0.579 (0.059)	0.761
2008	0.995 (0.018)	0.935 (0.007)	0.961 (0.014)	0.776 (0.017)	0.881	0.950 (0.066)	0.742 (0.045)	0.861
2009	1.002 (0.011)	0.972 (0.005)	0.942 (0.008)	0.863 (0.014)	0.929	0.951 (0.026)	0.900 (0.079)	0.949
2010	1.017 (0.030)	0.965 (0.028)	0.984 (0.044)	0.876 (0.032)	0.936	0.931 (0.051)	0.840 (0.038)	0.907
2011	0.986 (0.017)	0.955 (0.004)	0.948 (0.010)	0.772 (0.014)	0.879	0.960 (0.043)	0.858 (0.051)	0.926
2012	1.001 (0.026)	0.959 (0.006)	0.914 (0.011)	0.811 (0.022)	0.901	0.814 (0.048)	1.021 (0.148)	1.010
2013	0.973 (0.032)	0.921 (0.020)	0.977 (0.020)	0.739 (0.031)	0.860	0.799 (0.025)	1.026 (0.154)	1.013
2014	1.018 (0.028)	0.953 (0.009)	0.947 (0.024)	0.836 (0.032)	0.914	1.082 (0.080)	0.982 (0.147)	0.991
2015	0.874 (0.046)	0.848 (0.039)	0.834 (0.060)	0.939 (0.073)	0.969	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
Mean	**0.950 (0.011)**	**0.921 (0.010)**	**0.906 (0.012)**	**0.770 (0.029)**	**0.873 (0.019)**	**0.827 (0.042)**	**0.805 (0.034)**	**0.897 (0.020)**

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

Annual survival estimates for hatchery and wild steelhead					
Year	Snake River Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1997	0.964 (0.015)	0.728 (0.053)	0.651 (0.082)	0.474 (0.069)	0.457 (0.067)
1998	0.924 (0.009)	0.649 (0.013)	0.770 (0.081)	0.500 (0.054)	0.462 (0.050)
1999	0.908 (0.011)	0.688 (0.010)	0.640 (0.024)	0.440 (0.018)	0.400 (0.017)
2000	0.964 (0.013)	0.679 (0.016)	0.580 (0.040)	0.393 (0.034)	0.379 (0.033)
2001	0.911 (0.007)	0.168 (0.006)	0.250 (0.016)	0.042 (0.003)	0.038 (0.003)
2002	0.895 (0.015)	0.536 (0.025)	0.488 (0.090)	0.262 (0.050)	0.234 (0.045)
2003	0.932 (0.015)	0.597 (0.013)	0.518 (0.015)	0.309 (0.011)	0.288 (0.012)
2004	0.948 (0.004)	0.379 (0.023)	NA	NA	NA
2005	0.967 (0.004)	0.593 (0.018)	NA	NA	NA
2006	0.920 (0.013)	0.702 (0.016)	0.648 (0.079)	0.455 (0.056)	0.418 (0.052)
2007	1.016 (0.026)	0.694 (0.020)	0.524 (0.064)	0.364 (0.045)	0.369 (0.047)
2008	0.995 (0.018)	0.716 (0.015)	0.671 (0.034)	0.480 (0.027)	0.478 (0.028)
2009	1.002 (0.011)	0.790 (0.013)	0.856 (0.074)	0.676 (0.059)	0.678 (0.060)
2010	1.017 (0.030)	0.770 (0.020)	0.789 (0.027)	0.608 (0.026)	0.618 (0.032)
2011	0.986 (0.017)	0.693 (0.013)	0.866 (0.038)	0.600 (0.029)	0.592 (0.030)
2012	1.001 (0.026)	0.698 (0.020)	0.856 (0.196)	0.597 (0.138)	0.598 (0.139)
2013	0.973 (0.032)	0.645 (0.026)	0.798 (0.112)	0.515 (0.075)	0.501 (0.075)
2014	1.018 (0.028)	0.740 (0.021)	1.023 (0.088)	0.757 (0.069)	0.771 (0.073)
2015	0.874 (0.046)	0.628 (0.033)	0.663 (0.039)	0.416 (0.033)	0.364 (0.034)
2016	0.998 (0.016)	0.730 (0.020)	0.608 (0.040)	0.444 (0.032)	0.443 (0.032)
Mean	**0.950 (0.011)**	**0.648 (0.030)**	**0.678 (0.042)**	**0.463 (0.038)**	**0.449 (0.040)**

Table 30. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River steelhead (wild only), 1999–2016. Standard errors in parentheses; simple arithmetic means are given; for Trap-LGR and LGR-MCN the mean extends back to 1998.

Annual survival estimates for wild steelhead					
Year	Snake River Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1999	0.910 (0.024)	0.746 (0.019)	0.634 (0.113)	0.473 (0.085)	0.430 (0.078)
2000	0.980 (0.027)	0.714 (0.028)	0.815 (0.102)	0.582 (0.076)	0.570 (0.076)
2001	0.958 (0.011)	0.168 (0.010)	0.209 (0.046)	0.035 (0.008)	0.034 (0.008)
2002	0.899 (0.023)	0.593 (0.039)	0.574 (0.097)	0.341 (0.062)	0.306 (0.056)
2003	0.893 (0.026)	0.597 (0.022)	0.500 (0.042)	0.299 (0.027)	0.267 (0.026)
2004	0.936 (0.007)	0.383 (0.029)	NA	NA	NA
2005	0.959 (0.008)	0.562 (0.046)	NA	NA	NA
2006	0.976 (0.036)	0.745 (0.040)	0.488 (0.170)	0.363 (0.128)	0.355 (0.125)
2007	1.050 (0.056)	0.730 (0.027)	0.524 (0.064)	0.383 (0.049)	0.402 (0.056)
2008	0.951 (0.029)	0.692 (0.029)	0.713 (0.093)	0.493 (0.068)	0.469 (0.066)
2009	0.981 (0.019)	0.763 (0.029)	0.727 (0.073)	0.555 (0.060)	0.544 (0.059)
2010	1.003 (0.049)	0.773 (0.041)	0.736 (0.110)	0.569 (0.090)	0.571 (0.095)
2011	0.983 (0.037)	0.730 (0.024)	0.660 (0.136)	0.482 (0.101)	0.474 (0.100)
2012	1.107 (0.070)	0.697 (0.047)	NA	NA	NA
2013	0.921 (0.057)	0.621 (0.055)	0.671 (0.142)	0.417 (0.096)	0.384 (0.091)
2014	1.000 (0.047)	0.620 (0.034)	1.057 (0.144)	0.655 (0.096)	0.655 (0.101)
2015	0.867 (0.139)	0.572 (0.050)	0.608 (0.051)	0.348 (0.042)	0.301 (0.101)
2016	0.958 (0.037)	0.644 (0.053)	0.436 (0.043)	0.281 (0.036)	0.269 (0.036)
Mean	**0.961 (0.012)**	**0.634 (0.034)**	**0.623 (0.049)**	**0.418 (0.040)**	**0.402 (0.041)**

Sockeye Salmon—For pooled groups of wild and hatchery sockeye salmon, estimated survival from Lower Granite to McNary Dam was 0.523 in 2016 (95% CI 0.439-0.624; Table 31). This estimate was lower than in 2015 and lower than the average of 0.629 for 1996-2016. For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.119 (0.073-0.194) in 2016. This estimate was among the lowest of our time series through this reach, and was well below the 1996-2016 average of 0.405; only 2001 had lower estimated survival than 2016.

Table 31. Estimated survival for sockeye salmon (hatchery and wild combined) from Lower Granite Dam tailrace to Bonneville Dam tailrace for fish originating in the Snake River and from Rock Island Dam tailrace to Bonneville Dam tailrace for fish originating in the upper Columbia River, 1996–2016. Standard errors in parentheses.

	Annual survival estimates Snake River sockeye		
Year	Lower Granite to McNary	McNary to Bonneville Dam	Lower Granite to Bonneville Dam
1996	0.283 (0.184)	NA	NA
1997	NA	NA	NA
1998	0.689 (0.157)	0.142 (0.099)	0.177 (0.090)
1999	0.655 (0.083)	0.841 (0.584)	0.548 (0.363)
2000	0.679 (0.110)	0.206 (0.110)	0.161 (0.080)
2001	0.205 (0.063)	0.105 (0.050)	0.022 (0.005)
2002	0.524 (0.062)	0.684 (0.432)	0.342 (0.212)
2003	0.669 (0.054)	0.551 (0.144)	0.405 (0.098)
2004	0.741 (0.254)	NA	NA
2005	0.388 (0.078)	NA	NA
2006	0.630 (0.083)	1.113 (0.652)	0.820 (0.454)
2007	0.679 (0.066)	0.259 (0.084)	0.272 (0.073)
2008	0.763 (0.103)	0.544 (0.262)	0.404 (0.179)
2009	0.749 (0.032)	0.765 (0.101)	0.573 (0.073)
2010	0.723 (0.039)	0.752 (0.098)	0.544 (0.077)
2011	0.659 (0.033)	NA	NA
2012	0.762 (0.032)	0.619 (0.084)	0.472 (0.062)
2013	0.691 (0.043)	0.776 (0.106)	0.536 (0.066)
2014	0.873 (0.054)	0.817 (0.115)	0.713 (0.110)
2015	0.702 (0.054)	0.531 (0.151)	0.373 (0.037)
2016	0.523 (0.047)	0.227 (0.059)	0.119 (0.030)
Mean	**0.629 (0.037)**	**0.558 (0.074)**	**0.405 (0.055)**

Table 31. Continued.

	Annual survival estimates upper Columbia River sockeye		
	Rock Island to McNary Dam	McNary to Bonneville Dam	Rock Island to Bonneville Dam
1996	NA	NA	NA
1997	0.397 (0.119)	NA	NA
1998	0.624 (0.058)	1.655 (1.617)	1.033 (1.003)
1999	0.559 (0.029)	0.683 (0.177)	0.382 (0.097)
2000	0.487 (0.114)	0.894 (0.867)	0.435 (0.410)
2001	0.657 (0.117)	NA	NA
2002	0.531 (0.044)	0.286 (0.110)	0.152 (0.057)
2003	NA	NA	NA
2004	0.648 (0.114)	1.246 (1.218)	0.808 (0.777)
2005	0.720 (0.140)	0.226 (0.209)	0.163 (0.147)
2006	0.793 (0.062)	0.767 (0.243)	0.608 (0.187)
2007	0.625 (0.046)	0.642 (0.296)	0.401 (0.183)
2008	0.644 (0.094)	0.679 (0.363)	0.437 (0.225)
2009	0.853 (0.076)	0.958 (0.405)	0.817 (0.338)
2010	0.778 (0.063)	0.627 (0.152)	0.488 (0.111)
2011	0.742 (0.088)	0.691 (0.676)	0.513 (0.498)
2012	0.945 (0.085)	0.840 (0.405)	0.794 (0.376)
2013	0.741 (0.068)	0.658 (0.217)	0.487 (0.155)
2014	0.428 (0.056)	0.565 (0.269)	0.242 (0.111)
2015	0.763 (0.182)	0.446 (0.200)	0.340 (0.130)
2016	0.807 (0.082)	0.545 (0.126)	0.448 (0.144)
Mean	**0.671 (0.033)**	**0.730 (0.082)**	**0.503 (0.059)**

Upper Columbia River Stocks

Sockeye Salmon—For Upper Columbia River sockeye salmon captured, tagged, and released to the tailrace of Rock Island Dam in 2016, estimated survival to McNary tailrace was 0.807 (95% CI 0.662-0.984; Table 31). This estimate was higher than both the long-term average of 0.671 and the 2015 estimate of 0.763. Estimated survival of sockeye from Rock Island to Bonneville Dam was 0.448 (0.242-0.828). This estimate was slightly below the mean of 0.503.

Yearling Chinook Salmon—For pooled groups of yearling Chinook from Upper Columbia River hatcheries, estimated survival from McNary tailrace to Bonneville tailrace was 0.807 (0.706-0.922). This estimate was about equal to the 1999-2016 average of 0.809 for that reach (Table 32). However, as has often been the case for this reach, the estimate was imprecise due to low detection rates at Bonneville Dam and the pair trawl.

Steelhead—For pooled groups of hatchery steelhead from Upper Columbia hatcheries, estimated survival from McNary to Bonneville tailrace in 2016 was 0.487 (0.428-0.554). This estimate was below the long-term average of 0.730 (Table 32).

Table 32. Mean estimated survival and standard error (SE) through the lower Columbia River for hatchery yearling Chinook salmon (1999–2016) and steelhead (2003–2016) originating in the upper Columbia. Data for steelhead estimates were not available prior to 2003. Multiple release sites were used in each year and were not always consistent among years.

	Annual survival estimates upper Columbia River			
Year	Release site to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
	Hatchery yearling Chinook salmon			
1999	0.572 (0.014)	0.896 (0.044)	0.795 (0.129)	0.712 (0.113)
2000	0.539 (0.025)	0.781 (0.094)	NA	NA
2001	0.428 (0.009)	0.881 (0.062)	NA	NA
2002	0.555 (0.003)	0.870 (0.011)	0.940 (0.048)	0.817 (0.041)
2003	0.625 (0.003)	0.900 (0.008)	0.977 (0.035)	0.879 (0.031)
2004	0.507 (0.005)	0.812 (0.019)	0.761 (0.049)	0.618 (0.038)
2005	0.545 (0.012)	0.751 (0.042)	NA	NA
2006	0.520 (0.011)	0.954 (0.051)	0.914 (0.211)	0.871 (0.198)
2007	0.584 (0.009)	0.895 (0.028)	0.816 (0.091)	0.730 (0.080)
2008	0.582 (0.019)	1.200 (0.085)	0.522 (0.114)	0.626 (0.133)
2009	0.523 (0.013)	0.847 (0.044)	1.056 (0.143)	0.895 (0.116)
2010	0.660 (0.014)	0.924 (0.040)	0.796 (0.046)	0.735 (0.037)
2011	0.534 (0.010)	1.042 (0.047)	0.612 (0.077)	0.637 (0.077)
2012	0.576 (0.012)	0.836 (0.035)	1.140 (0.142)	0.953 (0.115)
2013	0.555 (0.013)	0.965 (0.050)	1.095 (0.129)	1.056 (0.117)
2014	0.571 (0.013)	0.974 (0.047)	0.958 (0.122)	0.933 (0.114)
2015	0.512 (0.015)	0.843 (0.043)	1.032 (0.081)	0.870 (0.062)
2016	0.610 (0.009)	0.857 (0.027)	0.942 (0.068)	0.807 (0.055)
Mean	**0.555 (0.012)**	**0.902 (0.024)**	**0.890 (0.045)**	**0.809 (0.034)**
	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)
Mean	**0.417 (0.016)**	**0.895 (0.034)**	**0.827 (0.055)**	**0.730 (0.045)**

Comparison Among Snake and Columbia River Stocks

In 2016, estimated survival from McNary to Bonneville tailrace was lower for hatchery and wild spring/summer Chinook originating in the Snake River (0.672; 95% CI 0.554-0.790; Table 33) than for those originating in the Upper Columbia River Basin (0.796; 0.699-0.907), but the difference was not statistically significant ($P = 0.12$).

In contrast, for hatchery and wild steelhead migrating in this same reach during 2016, estimated survival was higher for Snake (0.608; 0.530-0.686; Table 33) than for Upper Columbia River fish (0.488; 0.440-0.542), and the difference was statistically significant ($P = 0.01$).

For hatchery and wild sockeye salmon, estimated survival from McNary to Bonneville tailrace was lower for stocks originating in the Snake (0.227; 0.138-0.375) than in the Upper Columbia River Basin (0.522; 0.364-0.749), and the difference was statistically significant ($P = 0.01$).

Table 33. Average survival estimates (with standard errors in parentheses) from McNary Dam tailrace to Bonneville Dam tailrace for various spring–migrating salmonid stocks (hatchery and wild combined) in 2016. In shaded rows, the estimate represents a weighted average of weekly estimated survival. In all other rows, all release cohorts were pooled for a single seasonal estimate. Release numbers for pooled cohorts are from points upstream of McNary Dam. All Chinook salmon are spring/summer run.

			Estimated survival (SE)		
Stock	Release location	Number released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
Snake River Chinook	McNary Dam tailrace	52,042	0.796 (0.039)	0.871 (0.047)	0.672 (0.060)
Upper Columbia Chinook	Upper Columbia sites[a]	160,653	0.855 (0.026)	0.931 (0.065)	0.796 (0.053)
Upper Columbia Chinook	Yakima River sites[b]	45,153	0.870 (0.038)	0.735 (0.139)	0.639 (0.119)
Upper Columbia Coho	Upper Columbia sites	62,337	0.842 (0.038)	0.969 (0.077)	0.816 (0.058)
Upper Columbia Coho	Yakima River sites	24,777	0.828 (0.073)	0.994 (0.236)	0.823 (0.188)
Snake River Sockeye	Snake River sites[c]	56,614	0.424 (0.073)	0.534 (0.156)	0.227 (0.059)
Upper Columbia Sockeye	Upper Columbia sites	15,418	1.050 (0.144)	0.497 (0.107)	0.522 (0.097)
Snake River Steelhead	McNary Dam Tailrace	22,581	0.927 (0.074)	0.709 (0.071)	0.608 (0.040)
Upper Columbia Steelhead	Upper Columbia sites	90,196	0.777 (0.031)	0.628 (0.038)	0.488 (0.026)

[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

For combined hatchery and wild Snake River yearling Chinook salmon in 2016, estimated survival from the Snake River Trap to Bonneville Dam tailrace was 47%. This estimate was a little below the long-term average of 49% (1999-2016). For wild Snake River Chinook salmon, overall mean estimated survival through the entire hydrosystem was 33%. This estimate was considerably lower than the long-term average of 44% and was among the lowest of our time series.

For combined hatchery and wild combined steelhead in 2016, estimated survival through the hydropower system was 44%, which was a little below the long-term mean of 45%. Thus, 2016 was the second consecutive year with below-average estimated survival for Snake River steelhead. These low estimates followed seven consecutive years of survival estimates that were 48% or higher. For wild steelhead, mean estimated survival through the entire hydrosystem was 27%, an estimate considerably lower than the long-term average of 40%.

Thus for various stocks, including Snake river Chinook salmon and steelhead, survival in 2016 was below average from McNary to Bonneville Dam but not through the rest of the hydropower system. For Snake River Chinook and steelhead, survival between McNary and Bonneville Dam was below average for both wild fish and hatchery and wild fish combined. Survival was below average in this reach for Columbia River steelhead, but not for Columbia River Chinook. It is not clear exactly what was to blame for these low estimates of survival in the lower Columbia River. No unusual operations were reported at the lower Columbia River dams in 2016. Therefore, we suspect the depressed rates of survival were likely due to a combination of lower flows, higher temperatures, and increased predation during May.

Estimated survival of Snake River sockeye between Lower Granite Dam and Bonneville Dam tailrace was 12%, and this estimate was the second lowest of our time series (1998-2016). Component survival estimates for the reaches from Lower Granite to McNary Dam and McNary to Bonneville Dam were both low.

High rates of fungal infection were reported among juvenile sockeye entering the bypass systems at both Lower Granite and Little Goose Dam (Fish Passage Advisory Committee notes, 26 May 2016). These fungal infections likely contributed to the high mortality rates experienced by Snake River sockeye in 2016. For sockeye reared at Springfield Hatchery, estimated survival from release at the Redfish Lake Creek trap to McNary Dam was only 9%. This estimate was lower than that for sockeye reared at

Oxboow Hatchery. For Upper Columbia River sockeye smolts, survival was also below average in the reach from McNary to Bonneville Dam, but the reason for low survival among these fish is not known at this time.

Environmental conditions were near average in 2016, with the exception of water temperature late in the season. Mean flow in the Snake River was above average in April and then decreased through May. Water temperatures in the Snake and Columbia Rivers were above average for much of the season, and by late May and early June, temperatures had approached the record highs experienced in 2015. Spill percentages were close to those seen in recent years. Lower flows and higher temperatures in May likely contributed to higher levels of mortality due to lengthening travel times late in the season combined with increased temperatures and greater predator activity.

Median estimated travel times for both Chinook and steelhead between Lower Granite Dam and Bonneville Dam in April were shorter in 2016 than any other year in our time series (1998-2016). This coincided with relatively high flows in April. Median travel times were closer to the long-term average in May and June as flows fell below average.

Since the institution of court-ordered spill in 2006 and the installation of surface collectors at four additional dams, average travel time between Lower Granite and Bonneville Dam has decreased for steelhead, but not as much for Chinook. Differences in travel time between low-flow vs. other years are not well pronounced for either species. Date is a stronger predictor of travel time for Chinook than either flow or spill.

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

Decreased forebay delay and overall shortened travel times can potentially decrease exposure to the elevated water temperatures that may occur late in spring or early summer. In steelhead, warmer water can trigger smolt reversion to the parr stage, which is accompanied by cessation of migration. Zaugg and Wagner (1973) found that gill $Na^{+}K^{+}$-ATPase (an indicator of migratory readiness) and migratory urge declined in steelhead at water temperatures of 13°C and above.

Suspended migration may influence survival estimates in that a PIT-tagged smolt that ceases migration will not be detected at further downstream dams. Therefore, reversion to parr cannot be distinguished from mortality using PIT-tag data. If significant numbers of fish revert to parr, survival estimates will be biased downward.

Parr reversion may have been a factor in the low survival estimates we observed for steelhead in 2001, when longer travel times were observed late in the season, and water temperatures exceeded 13°C (Zabel et al. 2002). Yet in May 2015, temperatures were well in excess of 13°C, but estimated survival did not decline as it did in 2001. Reduced travel times associated with surface passage may have alleviated a tendency toward parr reversion that would otherwise have been more pronounced for steelhead confronted with the high temperatures of 2015.

Predation is another factor that directly affects survival of migrating smolts (Collis et al. 2002). Avian piscivores are abundant along the Columbia River downstream from its confluence with the Snake River, and their populations and consumption rates are intensively monitored (Ryan et al. 2001, 2003; Roby et al. 2008, Evans et al. 2012).

In Lake Wallula (McNary Dam reservoir), Crescent Island harbors the second largest Caspian tern *Hydroprogne caspia* colony in North America, with an annual average of about 500 breeding pairs over the last 10 years. The island also has large populations of gulls *Larus* spp. Other avian piscivores in this area include the American white pelican *Pelecanus erythrorhynchos,* cormorant *Phalacrocorax auritus*, egret *Ardea alba*, and herons *A. herodias* and *Nycticorax nycticorax.*

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

Studies have shown that steelhead smolts are particularly susceptible to predation by birds (Hostetter et al. 2012). For example, Collis et al. (2001) found that over 15% of the PIT-tags from steelhead detected at Bonneville Dam in 1998 were later found on estuarine bird colonies. On the same colonies, they found only 2% of the PIT-tags from yearling Chinook salmon detected at Bonneville. Evans et al. (2015) found that avian predation probabilities in the lower Columbia River were two to four times higher for juvenile steelhead than for juvenile yearling Chinook.

We complied an index of percentages of PIT-tags detected at Lower Monumental Dam that were subsequently detected on bird colonies (Table 34). Based on this index, the proportions of PIT-tagged steelhead lost to piscivorous birds in Lake Wallula was lower during 2006-2012 than during 2001-2005.

Table 34. Percentages of PIT–tagged smolts detected at Lower Monumental Dam and subsequently detected on avian predator colonies in McNary reservoir, 1998-2012. Estimates are not adjusted for detection efficiency on individual colonies and therefore are minimum estimates of predation rates.

	Proportion of wild and hatchery smolts detected at Lower Monumental Dam and subsequently detected on Lake Wallula avian colony (%)	
Year	Yearling Chinook Salmon	Steelhead
1998	0.49	4.20
1999	0.90	4.51
2000	0.98	3.66
2001	5.59	21.06
2002	1.62	10.09
2003[a]	1.06	3.71
2004[b]	2.08	19.42
2005	1.37	9.15
2006	0.92	4.81
2007	0.80	3.59
2008	1.20	4.63
2009	1.57	3.78
2010	1.27	5.26
2011	1.03	3.37
2012	0.52	2.32

[a] Only Crescent Island Caspian tern colony sampled.
[b] Only Crescent Island and Foundation Island colonies sampled.

Correspondingly, steelhead survival between Lower Monumental and McNary Dams was lower during 2001-2005 and higher during 2006-2012. For both yearling Chinook salmon and steelhead detected at Lower Monumental Dam, we have observed a significant negative correlation between estimated survival to McNary Dam and percentage of PIT tags recovered on avian colonies (Figure 10).

The smaller proportion of smolts taken by birds during 2006-2012 was due in part to an increase in the total number of smolts (tagged and untagged) remaining in the river. This higher number of inriver migrant smolts in turn resulted from increased spill and expanded use of surface passage at Snake River dams (all 4 dams since 2009).

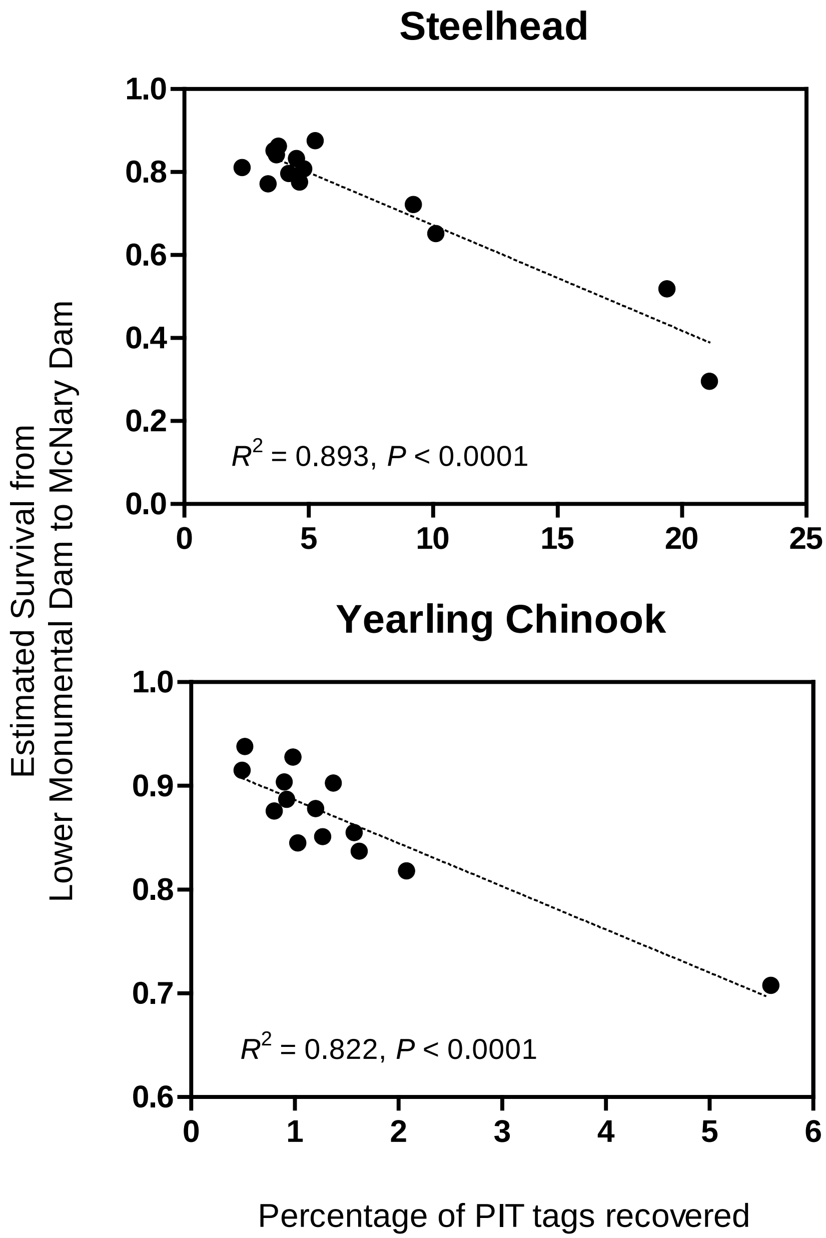

Figure 10. Estimated survival between Lower Monumental and McNary Dam vs. percentage of PIT-tags recovered on bird colonies from fish detected at Lower Monumental Dam, 1998-2012 (excluding 2003, which had incomplete recovery effort).

Piscivorous fish also contribute significantly to mortality of migrating Chinook salmon and steelhead smolts (Rieman et al. 1991). Reservoir-dwelling fish species that may prey heavily on migrating smolts include northern pikeminnow *Ptychocheilus oregonensis*, walleye *Sander vitreus*, and smallmouth bass *Micropterus dolomieu*. Reiman et al. (1991) found that fish predators (primarily pikeminnow) could consume nearly 14% of all smolts migrating through John Day reservoir. More recently, Porter (2012) reported that salmonid smolts accounted for 15% of identifiable prey items recovered from pikeminnow stomachs in 2012.

Since 1990, the Bonneville Power Administration has funded a sport reward fishery for northern pikeminnow in the lower Columbia River under the *Northern Pikeminnow Management Plan*. Abundance estimates of large (>250 mm FL) pikeminnow in The Dalles and John Day reservoirs have declined steadily since the inception of the sport reward program. In recent years, abundance estimates for large fish have been only one-tenth those in 1990 (Porter 2012).

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2016 were the second lowest recorded in our time series of estimates (1993-2016). This is mostly due to the arrival timing of both species in relation to start dates of transportation, as collection probabilities at the collector dams were not unusually low during transportation operations.

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

For survival estimates based on PIT-tag data, effective sample size is a result of both numbers of PIT-tagged fish migrating and detection rates during migration. Reduced sample sizes have become common in recent years as reliance on use of spill and surface passage has increased. Spill is now the primary management strategy used to increase survival of juvenile fish passing dams within the Federal Columbia River Power System.

This management strategy reduces detection rates by reducing the proportion of fish that pass dams via juvenile bypass systems. Other than the corner collector at Bonneville Dam, juvenile bypass systems provide the only dam-passage route for which PIT-tag monitoring technology is available.

While smolt survival might indeed be increased by emphasizing spillway passage, the quality of information gathered to verify higher rates of survival has been degraded as a result of reduced probabilities of PIT-tag detection. Three consequences of reduced detection probabilities are:

1) Reduced certainty in survival estimates; standard errors become larger and confidence intervals wider
2) Greater negative correlation between survival estimates in consecutive reaches. That is, there is an increased chance that sampling variability will result in estimates that are high in one reach and low in the next, or vice versa
3) Insufficient data to estimate survival at all in some cases.

All three consequences are most serious in the reaches from McNary to John Day and from John Day to Bonneville Dam, the two furthest downstream reaches for which we estimate smolt survival within the migration corridor.

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

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

Adding this capability will not only increase the proportions of fish detected at each dam, it will stabilize detection rates across the season. At present, fluctuations in spill and flow produce variable detection rates within each migration season. These variations can have negative consequences on the accuracy of estimates from mark-recapture models and can introduce bias to estimates of travel time. Detection capability in multiple passage routes will reduce this type of variation. Expanded monitoring ability will also advance our understanding of passage-route distributions throughout the migration season, producing valuable insight into fish passage behavior.

Finally, the ability to detect PIT-tagged fish in additional passage routes could increase the accuracy of survival estimates. Higher rates of detection will provide larger sample sizes for estimates with increased statistical power without additional marking. Furthermore, detection of fish passing multiple routes will reduce the possibility of bias introduced if survival is not equal between detected and non-detected fish.

For all of these reasons, we believe there is an urgent need to develop and install PIT-tag monitoring systems in passage routes other than juvenile bypass systems. In terms of their importance to survival estimates, the highest priority for new PIT-tag monitoring systems are the spillway(s) at Bonneville Dam and the surface-passage structures at Lower Granite and McNary Dams.

Because of consistently low detection rates at Bonneville Dam, the reach from John Day to Bonneville has been the weakest link in our ability to estimate survival through the entire hydropower system. At present, we rely on detections from the pair-trawl detection system operated in the estuary downstream from Bonneville Dam. However, rates of detection in the trawl are relatively low at present.

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

Lower Granite and McNary Dam are important "starting points" for our estimates of juvenile smolt survival. Increasing the number of detections at these two dams in particular will increase precision of estimates and modeling of in-season trends and patterns. These two sites are also critical for investigations of the relationship between juvenile migration timing and downstream survival or smolt-to-adult return rates. For either assessment, the "time-stamp" provided by detection of a PIT-tag is required.

The PIT tag is an important research tool that yields a great deal of valuable information that cannot be obtained by any other tagging method. For example, the PIT-tag allows monitoring of large numbers of individual fish through both the juvenile and adult migration. It is the only tagging method that allows direct comparison of smolt-to-adult return ratios between different treatment groups. Therefore, it is critical that we take the necessary steps to maximize the quantity and quality of information already offered by the PIT tag at current levels of tagging.

Conclusions and Recommendations

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

1) Develop PIT-tag detection capability in spillways and surface structures to improve detection rates and increase certainty in estimates of survival for juvenile salmonids passing Snake and Columbia River dams.

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

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

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

4) Increase the number of dams with PIT-tag detection facilities in the Columbia River Basin to improve survival estimation. We recommend installation of PIT-tag detection systems at The Dalles Dam and at upper Columbia River dams.

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Appendix A: Evaluation of Model Assumptions

Background

Using the Cormack-Jolly-Seber (CJS), or single-release (SR) model, the passage of a single PIT-tagged salmonid through the hydropower system is modeled as a sequence of events. Examples of such events are detection at Little Goose Dam or survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam. Each event has an associated probability of occurrence (technically, these probabilities are "conditional," as they are defined only if a certain condition is met, for example "probability of detection at Little Goose Dam *given* that the fish survived to Little Goose Dam").

The detection history is thus a record of the outcome of a series of events. (although detection history is an imperfect record of outcomes, since it cannot always distinguish between mortality and survival without detection). The SR model represents detection history data for a group of tagged fish as a multinomial distribution; each multinomial cell probability (detection history probability) is a function of the underlying survival and detection event probabilities. Three key assumptions lead to the multinomial cell probabilities used in the SR model:

A1) Fish in a single group of tagged fish have common event probabilities (each conditional detection or survival probability is common to all fish in the group).

A2) Event probabilities for each individual fish are independent from those for all other fish.

A3) Each event probability for an individual fish is conditionally independent from all other probabilities.

For a migrating PIT-tagged fish, assumption A3 implies that detection at any particular dam does not affect (or give information regarding) probabilities of subsequent events. For the tagged group as a whole, this means that detected and nondetected fish at a given dam have the same probability of survival in downstream reaches and have the same conditional probability of detection at downstream dams.

Methods

We used the methods presented by Burnham et al. (1987; pp 71-77) to assess the goodness-of-fit of the SR model to observed detection history data. In these tests, we compiled a series of contingency tables from detection history data for each group of tagged fish, and used χ^2 tests to identify systematic deviations from what was expected if the assumptions were met. We applied the tests to weekly groups of yearling Chinook salmon and steelhead (hatchery and wild combined) leaving Lower Granite and McNary Dam during the migration year (Snake River-origin fish only, i.e., the fish used for survival estimates reported in Tables 2-3 and 9-10).

If goodness-of-fit tests for a series of release groups resulted in more significant differences between observed and expected values than expected by chance, we compared observed and expected tables to determine the nature of the violation. While a consistent pattern of violations in assumption testing does not unequivocally pinpoint the cause of the violation, such patterns can be suggestive and may allow us to rule out some hypothesized causes.

Potential causes of assumption violations include

1) Inherent differences between individuals in survival or detection probability (e.g., in the propensity to be guided by bypass screens)
2) Differential mortality between the passage route that is monitored for PIT tags (juvenile collection system) and those that are not (spillways and turbines)
3) Behavioral responses to bypass and detection
4) Differences in passage timing for detected and non-detected fish if such differences result in exposure to different conditions downstream

However, inherent differences and behavioral responses cannot be distinguished using detection information alone. Conceptually, we make the distinction that inherent traits are those that characterized the fish before any hydrosystem experience, while behavioral responses occur as a result of particular hydrosystem experiences. For example, developing a preference for a particular passage route is a behavioral response, while size-related differences in passage-route selection are inherent. Of course, response to passage experience may also depend on inherent characteristics.

To describe each test we conducted, we follow the nomenclature of Burnham et al. (1987). For release groups from Lower Granite Dam, we analyzed 4-digit detection histories indicating status at Little Goose, Lower Monumental, and McNary Dams, and the final digit for detection anywhere below McNary Dam.

The first test for Lower Granite Dam groups was Burnham et al. (1987) Test 2.C2, which was based on the following contingency table:

Test 2.C2	First site detected below Little Goose		
df = 2	Lower Monumental	McNary	John Day or below
Not detected at Little Goose	n_{11}	n_{12}	n_{13}
Detected at Little Goose	n_{21}	n_{22}	n_{23}

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

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

Behavioral response to guidance at Little Goose could also cause violations of Test 2.C2. For example, if fish detected at Little Goose become more likely to be detected downstream, then they will tend to have more first downstream detections at Lower Monumental. If fish detected at Little Goose become less likely to be detected downstream, they will have fewer first detections at Lower Monumental.

Inherent differences among fish could also cause violations of Test 2.C2, and would be difficult to distinguish from behavioral responses.

The second test for Lower Granite Dam groups was Test 2.C3, based on the contingency table:

Test 2.C3	First site detected below Lower Monumental	
df = 1	McNary	John Day or below
Not detected at Lower Monumental	n_{11}	n_{12}
Detected at Lower Monumental	n_{21}	n_{22}

This table and corresponding implications are similar to those of Test 2.C2. All fish that were detected somewhere below Lower Monumental are cross-classified according to their history at Lower Monumental and according to their first detection site below Lower Monumental. If the respective counts for fish first detected at McNary are not in the same proportion as those first detected at John Day or below, it could indicate behavioral response to detection at Lower Monumental, inherent differences in detectability (i.e., guidability) among tagged fish in the group, or long-term differential mortality caused by different passage routes at Lower Monumental.

The next series of tests for Lower Granite Dam groups is called Test 3. The first in the series is called Test 3.SR3, based on the contingency table:

Test 3.SR3	Detected again at McNary or below?	
df = 1	YES	NO
Detected at Lower Monumental, not detected at Little Goose	n_{11}	n_{12}
Detected at Lower Monumental, detected at Little Goose	n_{21}	n_{22}

In this table, all fish detected at Lower Monumental are cross-classified according to their status at Little Goose and whether or not they were detected again downstream from Lower Monumental. As with the Test 2 series, differential mortality in different passage routes at Little Goose will not be detected by this test if all the mortality is expressed before the fish arrive at Lower Monumental. Differences in mortality expressed below McNary could cause violations, however, as could behavioral responses (possibly somewhat harder to detect because of the conditioning on detection at Lower Monumental) or inherent differences in detectability or survival between fish detected at Little Goose and those not detected there.

The second test in the Test 3 series is Test 3.Sm3, based on the contingency table:

Test 3.Sm3	Site first detected below Lower Monumental	
df = 1	McNary	John Day
Detected at Lower Monumental, not detected at Little Goose	n_{11}	n_{12}
Detected at Lower Monumental, detected at Little Goose	n_{21}	n_{22}

This test is sensitive to the same sorts of differences as Test 3.SR3, but tends to have somewhat less power. Because the table classifies only fish detected somewhere below Lower Monumental, it is not sensitive to differences in survival between Lower Monumental and McNary.

The final test for Lower Granite Dam groups is Test 3.SR4, based on the contingency table:

Test 3.SR4	Detected at John Day or below?	
df = 1	Yes	No
Detected at McNary, not detected previously	n_{11}	n_{12}
Detected at McNary, also detected previously	n_{21}	n_{22}

This table classifies all fish detected at McNary according to whether they had been detected at least once at Little Goose and Lower Monumental and whether they were detected again below McNary. A significant test indicates that some below-McNary parameter(s) differ between fish detected upstream of McNary and those not detected. The cause of such an assumption violation could be differences in indirect survival associated with detection at Little Goose and/or Lower Monumental (mortality expressed between McNary and the estuary PIT-trawl), inherent differences in survival or detection probabilities, or behavioral responses.

We did not include any contingency table tests when any of the expected cells of the table were less than 1.0, as the test statistic does not sufficiently approximate the asymptotic χ^2 distribution in these cases. (For Test 2.C2, when expected values in the "Lower Monumental" and "McNary" columns were all greater than 1.0, but one or two of the expected values in the "John Day or below" column were less than 1.0, we collapsed the "McNary" and "John Day or below" and calculated a one-degree-of-freedom test of the resulting 2-by-2 table). We combined the two test statistics in the Test 2 series and the three in the Test 3 series and then all tests together in a single overall χ^2 test statistic.

For release groups from McNary Dam, we analyzed 3-digit detection histories indicating status at John Day Dam, Bonneville Dam, and the estuary PIT-trawl.

Only two tests are possible for 3-digit detection histories. The first of these was Test 2.C2, based on the contingency table:

Test 2.C2	First site detected below John Day	
df = 1	BON	Trawl
Not detected at John Day	n_{11}	n_{12}
Detected at John Day	n_{21}	n_{22}

The second is Test 3.SR3, based on the contingency table:

Test 3.SR3	Detected at Trawl	
df = 1	Yes	No
Detected at Bonneville, not detected at John Day	n_{11}	n_{12}
Detected at Bonneville, detected at John Day	n_{21}	n_{22}

These tests are analogous to Tests 2.C3 and 3.SR4, respectively, for the Lower Granite Dam release groups. Potential causes of violations of the tests for McNary Dam groups are the same as those for Lower Granite Dam groups.

Results

For weekly Lower Granite Dam release groups in 2016 there were more significant ($\alpha = 0.05$) tests than expected by chance alone (5%) for steelhead but not for yearling Chinook salmon (Appendix Table A1). There were 10 weekly groups of yearling Chinook salmon. For these, the overall sum of the χ^2 test statistics was significant 4 times (40%). For 8 steelhead groups, the overall test was significant 4 times (50%). Counting all individual component tests (i.e., 2.C2, 3.SR3, etc.), 8 tests of 47 (17%) were significant for yearling Chinook salmon and 9 of 39 (23%) were significant for steelhead (Appendix Tables A1-A3). There is a 0.2% chance of 8 or more tests out of 47 being significant if the true $\alpha = 0.05$, and a 0.01% chance of 9 or more significant tests out of 39. This provides evidence that the results for both Chinook and steelhead indicate a significant number of assumption violations that cannot be explained by chance alone.

We diagnosed the patterns in the contingency tables that led to significant tests and results were similar to those we reported in past years. For weekly groups of yearling Chinook salmon and steelhead released from Lower Granite Dam, 12 of the 17 significant tests were for components of Test 2. This result provided evidence that fish had different probabilities of subsequent detection at downstream dams, depending on whether they were previously detected. For Chinook, all of their respective significant Test 2 results (all C2) showed fish detected at Little Goose Dam were less likely to be detected again downstream. For steelhead, all of the 4 significant Test 2.C2 tests showed that fish detected at Little Goose Dam were less likely to be detected downstream, while 3 of the 4 significant Test 2.C3 tests showed fish detected at Lower Monumental Dam were more likely to be detected at McNary Dam and one showed they were less likely to be detected at McNary Dam.

For weekly groups from McNary Dam, there were no significant contingency table test results for yearling Chinook, but two of the five (40%) component tests were significant for steelhead (Appendix Tables A4-A6). Both of the significant tests for steelhead were for test C2, with results showing that fish detected at John Day Dam were less likely to be detected at Bonneville Dam than fish not detected at John Day Dam. Low detection probabilities led to reduced power of these tests to detect significant differences when present. Therefore, a lack of significant results did not necessarily indicate that assumptions were met.

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 the contingency table tests in 2016, as in previous years. Zabel et al. (2002) and Zabel et al. (2005) provided evidence of inherent differences related to length of fish at tagging, and similar observations were made in 2015 data.

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

Another possibility is that changes in spill level among sequential dams were correlated with one another during passage of a cohort, and this resulted in correlated detection probabilities within subsets of the cohort.

To illustrate, suppose that spill at both Little Goose and Lower Monumental Dams is high early in the season and low late in the season. The earliest migrating fish from a cohort arrive at Little Goose Dam during high spill, and consequently have low probability of detection. These early fish will also tend to arrive at Lower Monumental during the period of high spill and low detection probability. The opposite will be true for the latest migrants from the cohort: they will encounter low spill and have high probability of detection. When the combined data for the cohort are analyzed, fish detected at Little Goose will be more likely to be detected at Lower Monumental than fish not detected at Little Goose Dam.

Although the contingency table tests described here do well at detecting some violations of CJS model assumptions, there are instances where assumptions could be violated without resulting in significant tests.

A specific example is that of acute differential post-detection mortality, where detected and non-detected fish have different rates of mortality between detection at a point of interest and at the subsequent detection point. This mortality would constitute a violation of assumption A3.

However, none of the contingency table tests described here would detect this violation because each test relies on data from fish with known fates, either at the site of interest or at sites downstream.

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

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

Appendix Table A1. Number of tests of goodness-of-fit to the single-release model conducted for weekly release groups of yearling Chinook salmon and steelhead (hatchery and wild combined) from Lower Granite Dam, and number of significant ($\alpha = 0.05$) test results, 2016.

Test		Species		Total
		Chinook	Steelhead	
Test 2.C2	Tests (n)	10	8	18
	Significant tests (n)	4	4	8
Test 2.C3	Tests (n)	9	8	17
	Significant tests (n)	0	4	4
Test 3.SR3	Tests (n)	9	8	17
	Significant tests (n)	0	1	1
Test 3.Sm3	Tests (n)	9	7	16
	Significant tests (n)	2	0	2
Test 3.SR4	Tests (n)	10	8	18
	Significant tests (n)	2	0	2
Test 2 sum	Tests (n)	10	8	18
	Significant tests (n)	4	5	9
Test 3 sum	Tests (n)	10	8	18
	Significant tests (n)	1	1	2
Test 2 + 3	Tests (n)	10	8	18
	Significant tests (n)	4	4	8

Appendix Table A2. Results of tests of goodness of fit to the single release model for release groups of yearling Chinook salmon (hatchery and wild) from Lower Granite to McNary Dam in 2016.

	Overall		Test 2		Test 2.C2		Test 2.C3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–29 Mar	1.46	0.962	0.82	0.845	0.79	0.673	0.03	0.866
30 Mar–5 Apr	10.70	0.098	6.60	0.086	4.64	0.099	1.96	0.161
6 Apr–12 Apr	4.51	0.608	2.29	0.514	2.24	0.327	0.06	0.813
13 Apr–19 Apr	23.31	**0.001**	18.39	**<0.001**	15.91	**<0.001**	2.48	0.115
20 Apr–26 Apr	21.67	**0.001**	13.82	**0.003**	11.37	**0.003**	2.45	0.118
27 Apr–3 May	20.31	**0.002**	13.85	**0.003**	13.83	**0.001**	0.02	0.897
4 May–10 May	18.08	**0.006**	12.15	**0.007**	11.28	**0.004**	0.87	0.350
11 May–17 May	1.82	0.936	1.61	0.658	1.27	0.530	0.33	0.564
18 May–24 May	3.57	0.735	2.88	0.411	1.25	0.536	1.63	0.202
25 May–31 May	0.92	0.820	0.35	0.840	0.35	0.840	.	.
Total (df)	106.33 (57)	**<0.001**	72.74 (29)	**<0.001**	62.92 (20)	**<0.001**	9.82 (9)	0.365

	Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
23 Mar–29 Mar	0.64	0.888	0.15	0.698	0.32	0.570	0.16	0.687
30 Mar–5 Apr	4.10	0.251	1.32	0.250	2.75	0.097	0.02	0.878
6 Apr–12 Apr	2.22	0.529	1.30	0.255	0.92	0.338	0.00	0.981
13 Apr–19 Apr	4.92	0.178	0.62	0.430	0.04	0.850	4.26	**0.039**
20 Apr–26 Apr	7.86	**0.049**	2.26	0.133	0.09	0.762	5.51	**0.019**
27 Apr–3 May	6.46	0.091	0.25	0.616	5.42	**0.020**	0.79	0.374
4 May–10 May	5.93	0.115	1.22	0.270	4.58	**0.032**	0.13	0.723
11 May–17 May	0.21	0.975	0.00	0.992	0.04	0.838	0.17	0.680
18 May–24 May	0.69	0.876	0.38	0.536	0.22	0.636	0.08	0.775
25 May–31 May	0.58	0.448	.	.	.	.	0.58	0.448
Total (df)	33.59 (28)	0.215	7.50 (9)	0.585	14.39 (9)	0.109	11.70 (10)	0.310

Appendix Table A3. Results of tests of goodness of fit to the single release model for release groups of juvenile steelhead (hatchery and wild) from Lower Granite to McNary Dam in 2016.

Release period	Overall χ^2	Overall *P*-value	Test 2 χ^2	Test 2 *P*-value	Test 2.C2 χ^2	Test 2.C2 *P*-value	Test 2.C3 χ^2	Test 2.C3 *P*-value
30 Mar–5 Apr	6.52	0.259	5.22	0.156	1.22	0.543	4.00	**0.045**
6 Apr–12 Apr	3.74	0.712	3.44	0.329	1.34	0.513	2.10	0.147
13 Apr–19 Apr	12.80	**0.046**	9.67	**0.022**	4.37	0.112	5.30	**0.021**
20 Apr–26 Apr	48.26	**<0.001**	46.88	**<0.001**	40.04	**<0.001**	6.84	**0.009**
27 Apr–3 May	11.90	0.064	10.04	**0.018**	7.96	**0.019**	2.08	0.149
4 May–10 May	43.40	**<0.001**	33.96	**<0.001**	21.86	**<0.001**	12.10	**0.001**
11 May–17 May	7.79	0.254	6.05	0.109	3.42	0.181	2.63	0.105
18 May–24 May	20.69	**0.002**	19.44	**<0.001**	17.14	**<0.001**	2.30	0.130
Total (df)	155.11 (47)	**<0.001**	134.69 (24)	**<0.001**	97.35 (16)	**<0.001**	37.34 (8)	**<0.001**

Release period	Test 3 χ^2	Test 3 *P*-value	Test 3.SR3 χ^2	Test 3.SR3 *P*-value	Test 3.Sm3 χ^2	Test 3.Sm3 *P*-value	Test 3.SR4 χ^2	Test 3.SR4 *P*-value
30 Mar–5 Apr	1.30	0.522	0.00	1.000	.	.	1.30	0.254
6 Apr–12 Apr	0.30	0.960	0.06	0.808	0.18	0.675	0.07	0.799
13 Apr–19 Apr	3.14	0.371	0.18	0.669	0.42	0.518	2.54	0.111
20 Apr–26 Apr	1.39	0.709	0.47	0.491	0.40	0.528	0.52	0.473
27 Apr–3 May	1.86	0.602	0.38	0.538	1.34	0.247	0.14	0.709
4 May–10 May	9.44	**0.024**	6.68	**0.010**	0.58	0.446	2.19	0.139
11 May–17 May	1.75	0.627	0.83	0.362	0.28	0.595	0.63	0.426
18 May–24 May	1.25	0.740	0.03	0.861	0.73	0.394	0.50	0.480
Total (df)	20.43 (23)	0.616	8.63 (8)	0.374	3.92 (7)	0.790	7.88 (8)	0.445

Appendix Table A4. Number of tests of goodness of fit to the single release model conducted for weekly release groups of yearling Chinook salmon and steelhead (hatchery and wild combined) from McNary Dam, and number of significant ($\alpha = 0.05$) test results, 2016.

	Test 2.C2		Test 3.SR3		Test 2 + 3	
Species	No.	sig.	No.	sig.	No.	sig.
Chinook	6	0	6	0	6	0
Steelhead	3	2	2	0	3	1
Total	9	2	8	0	9	1

Appendix Table A5. Results of tests of goodness of fit to the single release model for release groups of yearling Chinook salmon (hatchery and wild) from McNary to Bonneville Dam in 2016.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
13 Apr–19 Apr	0.95	0.621	0.55	0.457	0.40	0.528
20 Apr–26 Apr	2.91	0.233	2.58	0.108	0.34	0.561
27 Apr–3 May	0.55	0.759	0.00	0.956	0.55	0.459
4 May–10 May	2.30	0.317	1.80	0.180	0.50	0.478
11 May–17 May	0.47	0.792	0.34	0.561	0.13	0.721
18 May–24 May	0.59	0.744	0.58	0.445	0.01	0.924
25 May–31 May						
Total (df)	7.77 (12)	0.803	5.85 (6)	0.440	1.92 (6)	0.927

Appendix Table A6. Results of tests of goodness of fit to the single release model for release groups of steelhead (hatchery and wild) from McNary to Bonneville Dam in 2016.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
6 Apr–19 Apr						
20 Apr–3 May	0.86	0.651	0.72	0.396	0.14	0.712
4 May–17 May	4.51	0.105	4.28	**0.039**	0.23	0.631
18 May–31 May	3.98	**0.046**	3.98	**0.046**		
1 Jun–14 Jun						
Total (df)	9.35 (5)	0.096	8.98 (3)	**0.030**	0.37 (2)	0.831

Appendix B: Survival and Detection from Individual Hatcheries and Traps

Appendix Table B1. Estimated survival probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2016. Estimates based on the single-release model. Standard errors in parentheses.

	Yearling Chinook salmon					
Release site	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Release to McNary Dam
			Clearwater Hatchery			
Clear Creek	9,488	0.904 (0.010)	0.976 (0.023)	0.937 (0.038)	0.908 (0.046)	0.750 (0.029)
N Fork Clearwater R	17,081	0.925 (0.008)	0.998 (0.019)	0.919 (0.029)	0.883 (0.033)	0.749 (0.022)
Mill Creek	1,000	0.586 (0.035)	0.914 (0.080)	0.914 (0.111)	1.089 (0.194)	0.533 (0.081)
Powell Pond	25,468	0.686 (0.006)	0.994 (0.015)	0.890 (0.024)	0.909 (0.030)	0.552 (0.014)
Red River Pond	17,070	0.602 (0.010)	1.020 (0.044)	0.857 (0.057)	0.792 (0.057)	0.418 (0.020)
Selway River	14,363	0.711 (0.013)	0.993 (0.032)	0.858 (0.040)	1.032 (0.054)	0.625 (0.026)
			Dworshak Hatchery			
N Fork Clearwater R	40,876	0.714 (0.007)	0.941 (0.016)	0.859 (0.024)	0.931 (0.031)	0.538 (0.014)
			Kooskia Hatchery			
Kooskia	7,941	0.684 (0.012)	0.922 (0.030)	0.834 (0.045)	0.949 (0.067)	0.499 (0.029)
			Lookingglass Hatchery			
Catherine Creek Pond	20,947	0.371 (0.005)	1.018 (0.030)	0.820 (0.041)	0.971 (0.062)	0.300 (0.016)
Grande Ronde Pond	1,997	0.429 (0.016)	1.012 (0.059)	0.859 (0.083)	0.873 (0.119)	0.326 (0.037)
Imnaha Weir	20,950	0.704 (0.007)	0.950 (0.020)	0.850 (0.034)	0.925 (0.050)	0.526 (0.022)
Lookingglass Hatchery	4,999	0.759 (0.012)	0.993 (0.027)	0.809 (0.035)	0.899 (0.057)	0.548 (0.029)
Lostine Pond	2,403	0.586 (0.017)	0.963 (0.046)	0.933 (0.078)	0.795 (0.093)	0.419 (0.039)
			McCall Hatchery			
Knox Bridge	51,888	0.654 (0.006)	1.023 (0.022)	0.813 (0.029)	0.944 (0.037)	0.514 (0.014)
			Pahsimeroi Hatchery			
Pahsimeroi Pond	22,325	0.772 (0.008)	1.028 (0.031)	0.813 (0.042)	0.793 (0.054)	0.512 (0.026)
			Rapid River Hatchery			
Rapid River Hatchery	51,900	0.815 (0.005)	1.006 (0.017)	0.855 (0.024)	0.903 (0.029)	0.632 (0.015)
			Sawtooth Hatchery			
Sawtooth Hatchery	19,842	0.676 (0.006)	0.997 (0.022)	0.814 (0.030)	0.864 (0.036)	0.474 (0.015)
Yankee Fork	2,494	0.629 (0.025)	1.023 (0.094)	0.840 (0.150)	0.768 (0.156)	0.415 (0.049)

Appendix Table B2. Estimated survival probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2016. Estimates based on the single-release model. Standard errors in parentheses.

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	10,661	0.848 (0.012)	0.984 (0.029)	0.902 (0.046)	0.859 (0.059)	0.646 (0.035)
Newsome Creek	5,980	0.791 (0.014)	1.030 (0.041)	0.893 (0.058)	0.785 (0.065)	0.571 (0.038)
S Fork Clearwater R	4,795	0.846 (0.016)	1.010 (0.044)	0.946 (0.067)	0.814 (0.077)	0.658 (0.051)
			Dworshak Hatchery			
Clearwater R	18,145	0.794 (0.010)	0.885 (0.019)	1.041 (0.037)	0.874 (0.038)	0.639 (0.021)
Lolo Creek	3,468	0.654 (0.022)	0.923 (0.066)	0.987 (0.118)	0.710 (0.103)	0.423 (0.045)
S Fork Clearwater R	10,598	0.782 (0.009)	1.018 (0.028)	0.759 (0.031)	0.946 (0.056)	0.572 (0.030)
			Hagerman Hatchery			
East Fork Salmon R	8,401	0.640 (0.020)	0.895 (0.059)	1.055 (0.135)	0.620 (0.093)	0.375 (0.033)
Sawtooth Hatchery	25,778	0.638 (0.006)	1.031 (0.022)	0.867 (0.031)	0.842 (0.041)	0.480 (0.020)
			Irrigon Hatchery			
Big Canyon Facility	6,787	0.762 (0.016)	1.071 (0.054)	0.934 (0.079)	0.838 (0.088)	0.639 (0.050)
Cottonwood Pond	4,000	0.910 (0.014)	0.986 (0.118)	1.001 (0.174)	0.989 (0.116)	0.888 (0.091)
Little Sheep Facility	14,878	0.787 (0.009)	1.015 (0.025)	0.820 (0.033)	0.929 (0.053)	0.609 (0.029)
Wallowa Hatchery	9,165	0.855 (0.012)	0.983 (0.031)	0.917 (0.046)	0.834 (0.055)	0.643 (0.034)
			Lyons Ferry Hatchery			
Cottonwood Pond	5,992	0.831 (0.012)	0.992 (0.028)	0.877 (0.039)	1.154 (0.092)	0.834 (0.057)
Wallowa Hatchery	3,982	0.768 (0.017)	0.966 (0.036)	0.975 (0.076)	0.790 (0.087)	0.571 (0.043)

Appendix Table B2. Continued.

Release site	Number released	Juvenile steelhead Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Release to McNary Dam
Magic Valley Hatchery						
Little Salmon R	4,385	0.954 (0.015)	0.981 (0.039)	0.923 (0.062)	0.820 (0.068)	0.708 (0.046)
Pahsimeroi R Trap	11,370	0.932 (0.021)	0.875 (0.038)	0.907 (0.061)	0.644 (0.051)	0.477 (0.024)
Salmon R (rkm 347)	1,899	0.813 (0.022)	1.211 (0.103)	0.672 (0.085)	1.235 (0.209)	0.817 (0.121)
Salmon R (rkm 385)	1,898	0.865 (0.023)	0.942 (0.060)	1.007 (0.123)	0.791 (0.129)	0.649 (0.081)
Salmon R (rkm 476)	1,894	0.814 (0.027)	0.978 (0.077)	1.036 (0.143)	0.815 (0.134)	0.672 (0.079)
Yankee Fork	11,306	0.699 (0.014)	1.012 (0.054)	0.855 (0.093)	0.647 (0.076)	0.391 (0.025)
Niagara Springs Hatchery						
Hells Canyon Dam	8,572	0.754 (0.013)	1.083 (0.043)	0.912 (0.062)	0.982 (0.080)	0.732 (0.043)
Little Salmon R	5,084	0.942 (0.022)	0.993 (0.059)	0.926 (0.093)	0.683 (0.082)	0.591 (0.047)
Pahsimeroi R Trap	8,973	0.845 (0.010)	1.022 (0.034)	0.868 (0.047)	0.903 (0.061)	0.676 (0.036)

Appendix Table B3. Estimated survival probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2016. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile sockeye salmon							
Release site	Release date	Number released	Release to Lower Granite Dam	Lower Granite to Little Goose Dam	Little Goose to Lower Monumental Dam	Lower Monumental to McNary Dam	Lower Granite to McNary Dam	Release to McNary Dam
				Oxbow Hatchery				
Redfish Lake Cr Trap	10 May 16	2,033	0.543 (0.076)	0.658 (0.123)	1.476 (0.424)	0.590 (0.179)	0.572 (0.120)	0.311 (0.049)
				Springfield Hatchery				
Redfish Lake Cr Trap	9-19 May 16	50,656	0.321 (0.022)	0.588 (0.072)	0.579 (0.119)	0.806 (0.175)	0.274 (0.039)	0.088 (0.011)

Appendix Table B4. Estimated detection probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2016. Estimates based on the single-release model. Standard errors in parentheses.

	Yearling Chinook salmon				
Release site	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Clearwater Hatchery		
Clear Creek	9,488	0.318 (0.006)	0.352 (0.009)	0.231 (0.009)	0.241 (0.011)
N Fork Clearwater R	17,081	0.299 (0.004)	0.333 (0.007)	0.243 (0.007)	0.252 (0.008)
Mill Creek	1,000	0.301 (0.025)	0.273 (0.027)	0.216 (0.028)	0.221 (0.038)
Powell Pond	25,468	0.330 (0.004)	0.361 (0.006)	0.246 (0.006)	0.261 (0.008)
Red River Pond	17,070	0.301 (0.007)	0.214 (0.009)	0.198 (0.011)	0.244 (0.013)
Selway River	14,363	0.186 (0.005)	0.261 (0.008)	0.220 (0.008)	0.210 (0.010)
			Dworshak Hatchery		
N Fork Clearwater R	40,876	0.233 (0.003)	0.335 (0.006)	0.212 (0.005)	0.242 (0.007)
			Kooskia Hatchery		
Kooskia	7,941	0.332 (0.008)	0.371 (0.012)	0.275 (0.013)	0.260 (0.017)
			Lookingglass Hatchery		
Catherine Cr Pond	20,947	0.418 (0.007)	0.334 (0.011)	0.257 (0.011)	0.278 (0.016)
Grande Ronde Pond	1,997	0.465 (0.021)	0.332 (0.023)	0.240 (0.025)	0.282 (0.036)
Imnaha Weir	20,950	0.417 (0.005)	0.355 (0.008)	0.242 (0.009)	0.280 (0.012)
Lookingglass Hatch	4,999	0.409 (0.010)	0.368 (0.012)	0.261 (0.012)	0.324 (0.019)
Lostine Pond	2,403	0.455 (0.017)	0.331 (0.019)	0.217 (0.020)	0.305 (0.031)
			McCall Hatchery		
Knox Bridge	51,888	0.367 (0.004)	0.233 (0.005)	0.172 (0.005)	0.270 (0.008)
			Pahsimeroi Hatchery		
Pahsimeroi Pond	22,325	0.451 (0.006)	0.249 (0.008)	0.240 (0.010)	0.189 (0.011)
			Rapid River Hatchery		
Rapid River Hatch	51,900	0.408 (0.003)	0.263 (0.005)	0.213 (0.005)	0.246 (0.006)
			Sawtooth Hatchery		
Sawtooth Hatchery	19,842	0.409 (0.005)	0.318 (0.008)	0.261 (0.008)	0.342 (0.012)
Yankee Fork	2,494	0.430 (0.020)	0.303 (0.027)	0.166 (0.029)	0.340 (0.043)

Appendix Table B5. Estimated detection probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2016. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile steelhead				
Release site	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
Clearwater Hatchery					
Meadow Creek	10,661	0.307 (0.006)	0.303 (0.009)	0.206 (0.010)	0.136 (0.009)
Newsome Creek	5,980	0.326 (0.009)	0.293 (0.013)	0.270 (0.015)	0.171 (0.013)
S.F. Clearwater R	4,795	0.307 (0.009)	0.294 (0.014)	0.253 (0.015)	0.142 (0.013)
Dworshak Hatchery					
Clearwater R (April)	18,145	0.264 (0.005)	0.324 (0.007)	0.204 (0.007)	0.183 (0.007)
Lolo Creek	3,468	0.312 (0.014)	0.294 (0.021)	0.227 (0.023)	0.211 (0.025)
S.F. Clearwater R	10,598	0.414 (0.007)	0.311 (0.010)	0.379 (0.012)	0.146 (0.009)
Hagerman Hatchery					
East Fork Salmon R	8,401	0.341 (0.012)	0.262 (0.015)	0.150 (0.018)	0.203 (0.019)
Sawtooth Hatchery	25,778	0.402 (0.005)	0.307 (0.007)	0.280 (0.008)	0.158 (0.007)
Irrigon Hatchery					
Big Canyon Facility	6,787	0.362 (0.010)	0.233 (0.012)	0.164 (0.012)	0.144 (0.013)
Cottonwood Pond	4,000	0.429 (0.010)	0.279 (0.034)	0.273 (0.019)	0.130 (0.014)
Little Sheep Facility	14,878	0.385 (0.006)	0.304 (0.008)	0.249 (0.009)	0.154 (0.008)
Wallowa Hatchery	9,165	0.347 (0.007)	0.269 (0.009)	0.221 (0.010)	0.143 (0.009)
Lyons Ferry Hatchery					
Cottonwood Pond	5,992	0.389 (0.009)	0.256 (0.009)	0.274 (0.012)	0.118 (0.009)
Wallowa Hatchery	3,982	0.350 (0.011)	0.272 (0.012)	0.215 (0.017)	0.149 (0.014)
Magic Valley Hatchery					
Little Salmon R	4,385	0.385 (0.010)	0.314 (0.014)	0.266 (0.016)	0.210 (0.016)
Pahsimeroi R Trap	11,370	0.316 (0.008)	0.271 (0.010)	0.221 (0.013)	0.236 (0.014)
Salmon R (rkm 347)	1,899	0.374 (0.015)	0.260 (0.024)	0.291 (0.026)	0.132 (0.022)
Salmon R (rkm 385)	1,898	0.404 (0.016)	0.348 (0.023)	0.228 (0.026)	0.163 (0.024)
Salmon R (rkm 476)	1,894	0.337 (0.016)	0.272 (0.023)	0.189 (0.023)	0.163 (0.022)
Yankee Fork	11,306	0.439 (0.010)	0.260 (0.013)	0.123 (0.013)	0.244 (0.017)
Niagara Springs Hatchery					
Hells Canyon Dam	8,572	0.337 (0.008)	0.236 (0.010)	0.140 (0.009)	0.114 (0.008)
Little Salmon R	5,084	0.411 (0.012)	0.266 (0.015)	0.209 (0.019)	0.222 (0.020)
Pahsimeroi Trap	8,973	0.408 (0.007)	0.297 (0.011)	0.255 (0.012)	0.172 (0.011)

Appendix Table B6. Estimated detection probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2016. Estimates based on the single-release model. Standard errors in parentheses.

Juvenile sockeye salmon released at Redfish Lake Creek Trap					
Release date	Number released	Lower Granite	Little Goose	Lower Monumental	McNary
Oxbow Hatchery					
10 May 16	2,033	0.096 (0.016)	0.146 (0.022)	0.050 (0.015)	0.225 (0.039)
Springfield Hatchery					
9-19 May 16	50,656	0.155 (0.011)	0.157 (0.016)	0.070 (0.013)	0.208 (0.026)

Appendix Table B7. Estimated survival probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2016. Estimates based on the single-release model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Trap	Release dates	Number released	Release to LGR	LGR to LGO	LGO to LMO	LMO to MCN	Release to MCN
			Wild Chinook Salmon				
Catherine Creek	01 Mar-27 May	410	0.170 (0.037)	0.741 (0.211)	1.270 (0.555)	NA	NA
Elgin (G. Ronde)	27 Feb-29 May	793	0.563 (0.025)	0.885 (0.070)	0.921 (0.135)	0.974 (0.252)	0.447 (0.101)
Grande Ronde	09 Mar-28 May	2,868	0.876 (0.014)	0.999 (0.037)	0.789 (0.054)	1.122 (0.118)	0.775 (0.070)
Imnaha	07 Feb-31 May	3,600	0.775 (0.012)	0.952 (0.027)	0.891 (0.049)	0.840 (0.064)	0.552 (0.033)
Johnson Creek	01 Mar-31 May	707	0.417 (0.026)	0.894 (0.072)	0.806 (0.101)	0.825 (0.151)	0.248 (0.040)
Lemhi Weir	04 Mar-31 May	1,427	0.702 (0.022)	1.096 (0.093)	0.826 (0.124)	0.705 (0.106)	0.447 (0.043)
Lookingglass Cr	01 Feb-25 May	360	0.494 (0.044)	0.959 (0.148)	0.612 (0.136)	1.023 (0.294)	0.297 (0.074)
Lostine	01 Feb-23 May	866	0.519 (0.024)	1.064 (0.094)	0.720 (0.114)	0.793 (0.153)	0.316 (0.048)
Marsh Creek	23 Mar-20 Apr	227	0.328 (0.035)	1.029 (0.157)	0.917 (0.318)	NA	NA
Minam	03 Mar-27 May	747	0.462 (0.023)	1.127 (0.107)	0.692 (0.115)	0.932 (0.175)	0.337 (0.050)
Pahsimeroi	04 Mar-31 May	1,353	0.287 (0.018)	1.064 (0.130)	0.672 (0.140)	1.192 (0.262)	0.245 (0.042)
Salmon	07 Mar-21 Apr	4,538	0.845 (0.009)	0.964 (0.023)	0.945 (0.048)	0.767 (0.048)	0.591 (0.028)
Sawtooth	23 Mar-31 May	931	0.574 (0.025)	0.932 (0.083)	0.746 (0.113)	1.048 (0.208)	0.418 (0.073)
Snake	23 Mar-19 May	1,541	0.957 (0.019)	0.964 (0.047)	0.819 (0.072)	0.841 (0.093)	0.635 (0.057)
U. Grande Ronde	28 Feb-09 Apr	600	0.234 (0.024)	0.942 (0.170)	0.823 (0.295)	1.190 (0.663)	0.216 (0.102)
			Wild Sockeye Salmon				
Redfish Lake Cr	09 Apr-26 May	3,925	0.461 (0.014)	0.844 (0.038)	0.883 (0.072)	0.691 (0.097)	0.237 (0.029)

Appendix Table B7. Continued.

Trap	Release dates	Number released	Rel to LGR	LGR to LGO	LGO to LMO	LMO to MCN	Rel to MCN
			Wild Steelhead				
Asotin Creek	04 Feb-16 May	3,832	0.611 (0.016)	0.940 (0.045)	0.905 (0.082)	0.838 (0.119)	0.436 (0.051)
Elgin (G. Ronde)	27 Feb-29 May	784	0.600 (0.047)	0.896 (0.141)	1.283 (0.572)	0.494 (0.248)	0.341 (0.086)
Grande Ronde	09 Apr-26 May	713	0.938 (0.057)	1.176 (0.201)	0.613 (0.164)	0.935 (0.325)	0.631 (0.177)
Imnaha	13 Feb-31 May	4,492	0.845 (0.018)	0.920 (0.043)	0.844 (0.073)	0.750 (0.087)	0.492 (0.043)
Minam	07 Mar-27 May	328	0.599 (0.049)	0.987 (0.173)	1.122 (0.480)	0.605 (0.321)	0.401 (0.138)
Salmon	07 Mar-21 Apr	138	0.858 (0.056)	1.066 (0.161)	0.874 (0.308)	0.825 (0.342)	0.659 (0.189)
Sawtooth	23 Mar-31 May	363	0.132 (0.029)	0.846 (0.342)	0.661 (0.386)	NA	NA
Snake	25 Mar-23 May	741	0.958 (0.037)	0.907 (0.080)	0.910 (0.163)	0.631 (0.143)	0.499 (0.080)
Upper Grande Ronde	28 Feb-09 May	499	0.302 (0.035)	1.107 (0.266)	0.889 (0.405)	0.800 (0.488)	0.238 (0.112)
			Hatchery Chinook Salmon				
Grande Ronde	11 Mar-26 May	1,382	0.831 (0.025)	0.955 (0.050)	0.826 (0.069)	0.886 (0.113)	0.580 (0.063)
Salmon	15 Mar-21 Apr	3,050	0.838 (0.018)	1.022 (0.041)	0.962 (0.064)	0.760 (0.064)	0.627 (0.039)
Snake	17 Mar-17 May	1,862	0.921 (0.022)	1.002 (0.046)	0.942 (0.075)	0.736 (0.077)	0.640 (0.050)
			Hatchery Steelhead				
Grande Ronde	07 Apr-24 May	2,532	0.968 (0.021)	0.998 (0.046)	0.801 (0.052)	0.842 (0.078)	0.651 (0.051)
Salmon	05 Apr-21 Apr	565	0.988 (0.049)	0.944 (0.081)	0.936 (0.114)	0.799 (0.135)	0.698 (0.096)
Snake	25 Mar-23 May	3,209	1.008 (0.018)	0.995 (0.036)	0.869 (0.050)	0.929 (0.085)	0.809 (0.063)

Appendix Table B8. Estimated detection probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2016. Estimates based on the single-release model. Standard errors in parentheses.

Trap	Release dates	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
			Wild Chinook Salmon			
Catherine Creek	01 Mar-27 May	410	0.272 (0.074)	0.312 (0.088)	0.169 (0.084)	0.111 (0.105)
Elgin (G. Ronde)	27 Feb-29 May	793	0.560 (0.030)	0.439 (0.040)	0.341 (0.051)	0.255 (0.064)
Grande Ronde	09 Mar-28 May	2,868	0.501 (0.012)	0.433 (0.018)	0.304 (0.020)	0.255 (0.026)
Imnaha	07 Feb-31 May	3,600	0.483 (0.011)	0.446 (0.015)	0.289 (0.017)	0.305 (0.022)
Johnson Creek	01 Mar-31 May	707	0.492 (0.036)	0.453 (0.042)	0.343 (0.048)	0.370 (0.066)
Lemhi Weir	04 Mar-31 May	1,427	0.445 (0.020)	0.329 (0.030)	0.226 (0.030)	0.411 (0.043)
Lookingglass Cr	01 Feb-25 May	360	0.444 (0.049)	0.383 (0.064)	0.328 (0.072)	0.421 (0.113)
Lostine	01 Feb-23 May	866	0.507 (0.029)	0.410 (0.041)	0.276 (0.044)	0.349 (0.060)
Marsh Creek	23 Mar-20 Apr	227	0.631 (0.064)	0.500 (0.096)	0.291 (0.113)	NA
Minam	03 Mar-27 May	747	0.547 (0.032)	0.394 (0.045)	0.262 (0.046)	0.438 (0.072)
Pahsimeroi	04 Mar-31 May	1,353	0.389 (0.030)	0.355 (0.047)	0.198 (0.040)	0.306 (0.058)
Salmon	07 Mar-21 Apr	4,538	0.531 (0.009)	0.465 (0.013)	0.302 (0.015)	0.302 (0.018)
Sawtooth	23 Mar-31 May	931	0.492 (0.027)	0.436 (0.042)	0.357 (0.048)	0.333 (0.064)
Snake	23 Mar-19 May	1,541	0.459 (0.016)	0.427 (0.023)	0.347 (0.027)	0.295 (0.031)
U. Grande Ronde	28 Feb-09 Apr	600	0.541 (0.056)	0.421 (0.082)	0.202 (0.078)	0.188 (0.098)
			Wild Sockeye Salmon			
Redfish Lake Cr	09 Apr-26 May	3,925	0.433 (0.016)	0.399 (0.019)	0.278 (0.024)	0.268 (0.035)

Appendix Table B8. Continued.

Trap	Release dates	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
Wild Steelhead						
Asotin Creek	04 Feb-16 May	3,832	0.410 (0.014)	0.374 (0.018)	0.226 (0.020)	0.212 (0.027)
Elgin (Grande Ronde)	27 Feb-29 May	784	0.353 (0.034)	0.313 (0.048)	0.091 (0.040)	0.213 (0.060)
Grande Ronde	09 Apr-26 May	713	0.349 (0.028)	0.231 (0.040)	0.201 (0.044)	0.170 (0.052)
Imnaha	13 Feb-31 May	4,492	0.408 (0.012)	0.336 (0.016)	0.212 (0.018)	0.248 (0.024)
Minam	07 Mar-27 May	328	0.468 (0.048)	0.339 (0.064)	0.137 (0.060)	0.161 (0.066)
Salmon	07 Mar-21 Apr	138	0.482 (0.053)	0.432 (0.076)	0.170 (0.065)	0.214 (0.078)
Sawtooth	23 Mar-31 May	363	0.377 (0.096)	0.351 (0.146)	0.270 (0.136)	NA
Snake	23 Mar-31 May	363	0.454 (0.025)	0.376 (0.035)	0.212 (0.038)	0.247 (0.046)
Upper Grande Ronde	25 Mar-23 May	741	0.385 (0.053)	0.302 (0.076)	0.173 (0.074)	0.143 (0.076)
Hatchery Chinook Salmon						
Grande Ronde	11 Mar-26 May	1,382	0.417 (0.018)	0.352 (0.021)	0.274 (0.024)	0.297 (0.036)
Salmon	15 Mar-21 Apr	3,050	0.389 (0.012)	0.270 (0.013)	0.183 (0.013)	0.300 (0.021)
Snake	17 Mar-17 May	1,862	0.396 (0.015)	0.314 (0.017)	0.200 (0.017)	0.305 (0.027)
Hatchery Steelhead						
Grande Ronde	07 Apr-24 May	2,532	0.392 (0.013)	0.254 (0.014)	0.264 (0.017)	0.186 (0.017)
Salmon	05 Apr-21 Apr	565	0.317 (0.025)	0.286 (0.028)	0.244 (0.031)	0.196 (0.033)
Snake	25 Mar-23 May	3,209	0.397 (0.011)	0.288 (0.012)	0.232 (0.014)	0.153 (0.014)

Appendix Table B9. Estimated survival probabilities for PIT-tagged yearling Chinook, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2016. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Yearling Chinook Salmon			
Chelan						
Chelan River	9,813	0.644 (0.034)	0.975 (0.110)	0.758 (0.224)	0.739 (0.209)	0.476 (0.132)
Chiwawa Pond	10,179	0.633 (0.031)	0.914 (0.101)	0.929 (0.239)	0.849 (0.205)	0.537 (0.127)
Dryden Pond	20,786	0.796 (0.032)	0.815 (0.065)	1.126 (0.200)	0.917 (0.155)	0.730 (0.120)
Nason Creek	5,007	0.579 (0.040)	0.736 (0.091)	1.823 (1.013)	1.341 (0.738)	0.776 (0.424)
Cle Elum						
Clark Flat Pond	15,998	0.422 (0.014)	0.906 (0.061)	0.439 (0.091)	0.397 (0.080)	0.168 (0.033)
Easton Pond	12,000	0.319 (0.014)	0.833 (0.071)	1.687 (0.939)	1.406 (0.777)	0.448 (0.247)
Jack Creek Pond	12,000	0.273 (0.012)	0.850 (0.075)	1.386 (0.768)	1.179 (0.649)	0.322 (0.177)
Entiat						
Entiat Hatchery	19,919	0.631 (0.024)	0.841 (0.064)	0.879 (0.132)	0.739 (0.103)	0.466 (0.063)
Leavenworth						
Leavenworth NFH	19,216	0.501 (0.016)	0.901 (0.071)	1.046 (0.241)	0.943 (0.208)	0.473 (0.103)
Methow						
Chewuch Pond	4,984	0.545 (0.039)	0.982 (0.179)	1.382 (0.629)	1.357 (0.581)	0.739 (0.313)
Methow Hatchery	4,998	0.540 (0.046)	0.590 (0.103)	1.034 (0.297)	0.610 (0.157)	0.330 (0.080)
Twisp Pond	4,990	0.500 (0.036)	0.790 (0.117)	1.059 (0.346)	0.837 (0.258)	0.418 (0.125)
Winthrop						
Winthrop NFH	17,361	0.577 (0.022)	0.810 (0.065)	0.772 (0.124)	0.625 (0.093)	0.361 (0.052)

Appendix Table B9. Continued.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Steelhead			
East Bank						
Chiwawa River	4,366	0.426 (0.042)	0.654 (0.128)	0.793 (0.222)	0.519 (0.126)	0.221 (0.049)
Nason Creek	7,246	0.317 (0.030)	0.633 (0.108)	0.616 (0.140)	0.390 (0.078)	0.123 (0.022)
Wenatchee River	10,114	0.364 (0.022)	0.826 (0.093)	0.413 (0.060)	0.341 (0.042)	0.124 (0.014)
Wells						
Methow River	3,989	0.691 (0.063)	0.865 (0.157)	0.572 (0.151)	0.495 (0.114)	0.342 (0.072)
Omak Acclimation Pond	14,996	0.486 (0.026)	0.716 (0.068)	0.620 (0.089)	0.443 (0.058)	0.215 (0.026)
Twisp Acclimation Pond	4,958	0.210 (0.024)	0.800 (0.176)	0.533 (0.174)	0.426 (0.122)	0.090 (0.024)
Wells Hatchery	4,892	0.613 (0.043)	0.799 (0.116)	0.930 (0.235)	0.743 (0.171)	0.456 (0.100)
Winthrop						
Winthrop NFH	19,901	0.418 (0.021)	0.831 (0.071)	0.855 (0.130)	0.711 (0.102)	0.297 (0.040)
			Coho Salmon			
Cascade						
Leavenworth NFH	11,939	0.376 (0.016)	0.790 (0.072)	1.127 (0.223)	0.890 (0.165)	0.335 (0.061)
Eagle						
Clear Creek	4,509	0.231 (0.025)	0.902 (0.208)	0.516 (0.181)	0.465 (0.142)	0.107 (0.031)
Lapwai Creek	4,219	0.308 (0.028)	0.891 (0.203)	1.496 (0.751)	1.333 (0.619)	0.411 (0.188)
Natches River	3,756	0.241 (0.022)	0.756 (0.143)	1.599 (0.867)	1.209 (0.633)	0.291 (0.151)
Yakima R (rkm 256)	5,050	0.189 (0.017)	0.764 (0.136)	1.516 (0.981)	1.158 (0.734)	0.218 (0.137)
Yakima R (rkm 325)	5,098	0.124 (0.016)	0.646 (0.177)	1.034 (0.674)	0.667 (0.412)	0.083 (0.050)
Prosser						
Natches River	5,003	0.113 (0.014)	0.852 (0.230)	0.750 (0.502)	0.639 (0.406)	0.072 (0.045)
Roza Dam	2,500	0.157 (0.024)	0.869 (0.271)	0.722 (0.650)	0.627 (0.545)	0.099 (0.084)
Yakima R (rkm 76)	2,501	0.244 (0.026)	0.904 (0.174)	0.271 (0.091)	0.245 (0.076)	0.060 (0.018)
Willard						
Beaver Creek Pond	5,970	0.264 (0.023)	0.800 (0.189)	1.425 (0.721)	1.140 (0.529)	0.300 (0.137)
Coulter Pond	5,973	0.358 (0.023)	0.697 (0.097)	1.216 (0.349)	0.848 (0.227)	0.304 (0.079)
Rolfing Pond	5,966	0.280 (0.020)	0.843 (0.148)	0.615 (0.198)	0.518 (0.149)	0.145 (0.041)
Winthrop						
Winthrop NFH	5,963	0.453 (0.022)	1.104 (0.154)	1.013 (0.234)	1.118 (0.219)	0.507 (0.097)

Appendix Table B10. Estimated detection probabilities for PIT-tagged yearling Chinook salmon, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2016. Estimates based on the single-release model. Standard errors in parentheses.

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Yearling Chinook Salmon		
Chelan				
Chelan River	9,813	0.176 (0.010)	0.114 (0.012)	0.136 (0.038)
Chiwawa Pond	10,179	0.205 (0.011)	0.091 (0.010)	0.143 (0.034)
Dryden Pond	20,786	0.144 (0.006)	0.082 (0.006)	0.119 (0.020)
Nason Creek	5,007	0.195 (0.015)	0.159 (0.018)	0.097 (0.053)
Cle Elum				
Clark Flat Pond	15,998	0.261 (0.010)	0.238 (0.015)	0.278 (0.056)
Easton Pond	12,000	0.274 (0.013)	0.248 (0.020)	0.081 (0.045)
Jack Creek Pond	12,000	0.268 (0.014)	0.281 (0.023)	0.089 (0.049)
Entiat				
Entiat Hatchery	19,919	0.188 (0.008)	0.105 (0.008)	0.144 (0.020)
Leavenworth				
Leavenworth NFH	19,216	0.264 (0.010)	0.118 (0.009)	0.124 (0.028)
Methow				
Chewuch Pond	4,984	0.227 (0.018)	0.073 (0.013)	0.091 (0.039)
Methow Hatchery	4,998	0.195 (0.018)	0.078 (0.014)	0.200 (0.050)
Twisp Pond	4,990	0.211 (0.017)	0.107 (0.016)	0.171 (0.052)
Winthrop				
Winthrop NFH	17,361	0.217 (0.009)	0.104 (0.008)	0.205 (0.030)
		Steelhead		
East Bank				
Chiwawa River	4,366	0.170 (0.019)	0.067 (0.013)	0.335 (0.076)
Nason Creek	7,246	0.164 (0.017)	0.094 (0.015)	0.373 (0.068)
Wenatchee River	10,114	0.186 (0.012)	0.099 (0.011)	0.572 (0.062)
Wells				
Methow River	3,989	0.131 (0.014)	0.059 (0.010)	0.359 (0.077)
Omak Acclimation Pond	14,996	0.145 (0.009)	0.085 (0.008)	0.391 (0.048)
Twisp Acclimation Pond	4,958	0.194 (0.025)	0.099 (0.021)	0.421 (0.113)
Wells Hatchery	4,892	0.175 (0.014)	0.069 (0.010)	0.259 (0.058)
Winthrop				
Winthrop NFH	19,901	0.124 (0.007)	0.083 (0.007)	0.273 (0.037)

Appendix Table B10. Continued

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Coho Salmon		
Cascade				
Leavenworth NFH	11,939	0.241 (0.012)	0.085 (0.008)	0.269 (0.049)
Eagle				
Clear Creek	4,509	0.201 (0.024)	0.081 (0.019)	0.413 (0.120)
Lapwai Creek	4,219	0.215 (0.022)	0.057 (0.014)	0.154 (0.071)
Natches River	3,756	0.257 (0.027)	0.101 (0.020)	0.188 (0.098)
Yakima R (rkm 256)	5,050	0.256 (0.026)	0.110 (0.021)	0.202 (0.127)
Yakima R (rkm 325)	5,098	0.271 (0.037)	0.098 (0.028)	0.252 (0.154)
Prosser				
Natches River	5,003	0.280 (0.038)	0.150 (0.040)	0.200 (0.126)
Roza Dam	2,500	0.257 (0.043)	0.144 (0.044)	0.253 (0.218)
Yakima R (rkm 76)	2,501	0.236 (0.030)	0.212 (0.038)	0.750 (0.216)
Willard				
Beaver Creek Pond	5,970	0.233 (0.023)	0.052 (0.013)	0.155 (0.071)
Coulter Pond	5,973	0.249 (0.018)	0.089 (0.013)	0.240 (0.063)
Rolfing Pond	5,966	0.279 (0.022)	0.082 (0.015)	0.366 (0.103)
Winthrop				
Winthrop NFH	5,963	0.236 (0.014)	0.048 (0.007)	0.257 (0.050)

Appendix C: Environmental Conditions and Salmonid Passage Timing

Methods

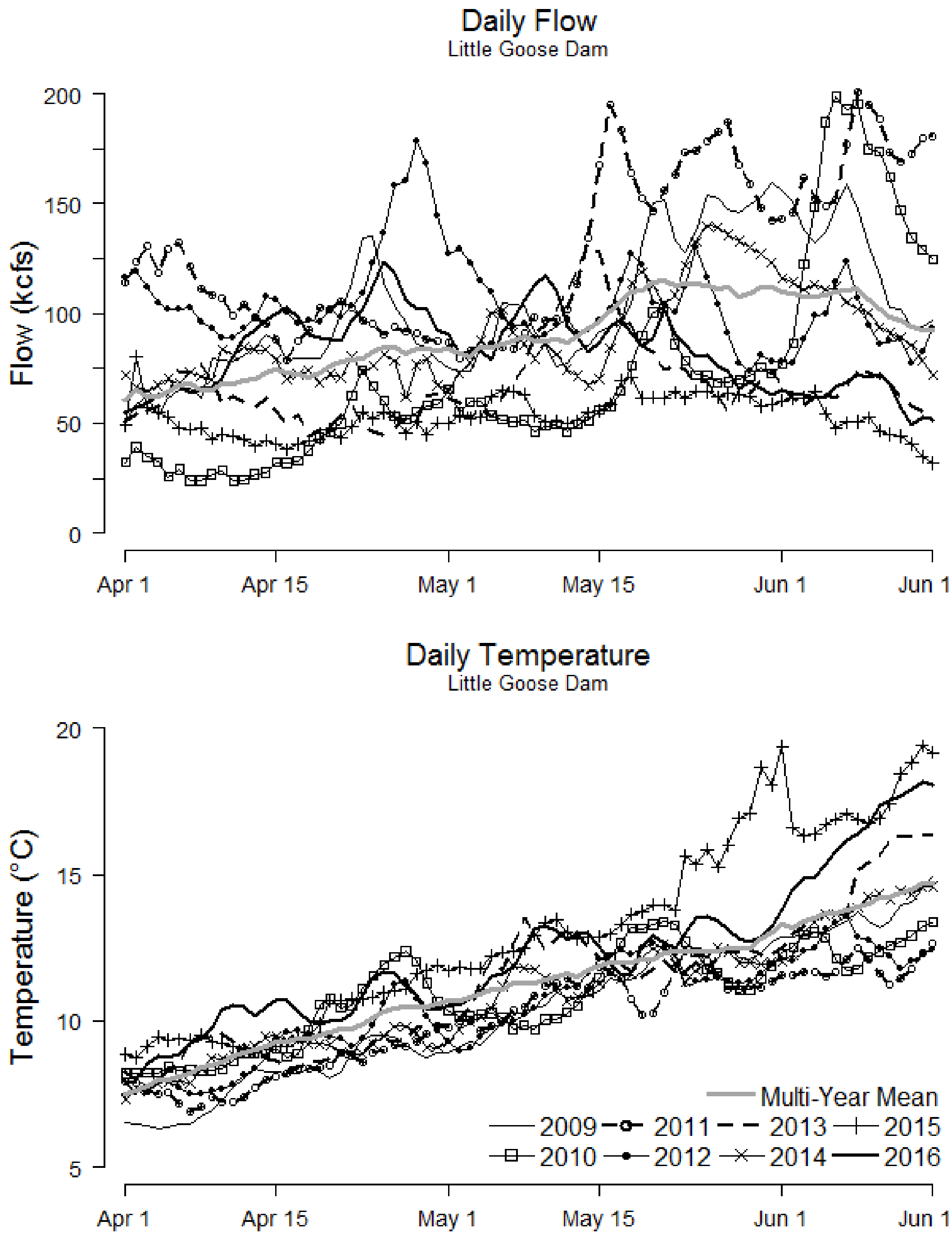
We obtained data on daily flow, temperature, and spill at Snake River dams and daily smolt passage index at Lower Granite Dam (yearling Chinook salmon and steelhead; hatchery and wild combined) in 2016 from the Columbia River DART website[1] on 23 August, 2016. We created plots to compare daily measures of flow, temperature, and spill at Little Goose Dam from 2016 to those from 2009-2015. We calculated long-term daily averages for flow, temperature, and spill as the mean daily value for 1993-2016. We created plots and calculated passage proportions to compare daily estimates of proportion of smolts passing Lower Granite Dam in 2016 to those of 2013-2015.

In addition, for each daily group of PIT-tagged yearling Chinook salmon and steelhead from Lower Granite Dam we calculated an index of Snake River flow exposure. For each daily group, the index was equal to the average daily flow at Lower Monumental Dam during the period between the 25th and 75th percentiles of PIT-tag detection at Lower Monumental Dam for the daily group. We then investigated the relationship between this index and estimates of travel time from Lower Granite Dam tailrace to McNary Dam tailrace (results shown in Figure 5 of the main text).

Results

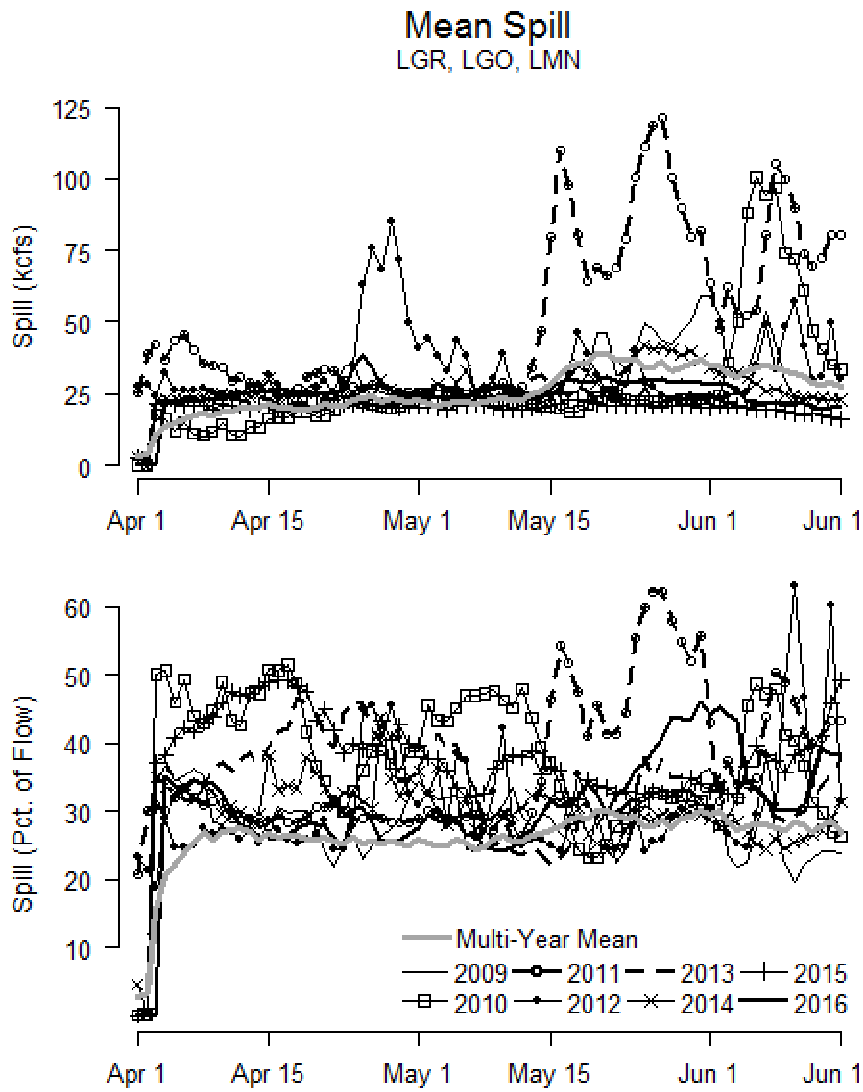
In general, environmental conditions were close to average in 2016, with the exception of water temperature later in the season. Mean flow at Little Goose Dam in 2016 during the main migration period (1 April-15 June) was 82.4 kcfs, which was a little below the long-term mean of 89.9 kcfs for 1993-2016. Daily flow values were above long-term daily means for the first part of the migration period, and then fell below the means in the second week of May (Appendix Figure C1).

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



Appendix Figure C1. Daily Snake River flow (kcfs) and temperature (°C) measured at Little Goose Dam from April through mid-June, 2009-2016, including daily long-term means (1993-2016).

Mean water temperature at Little Goose Dam in 2016 during the migration period was 12.3°C, which was higer than the long-term mean of 11.2°C. Thus 2016 was the third warmest year in our time series, behind 2001 and 2015. Daily water temperatures were above the long-term daily mean on most days, with differences becoming greatest in late May and early June (Appendix Figure C1).

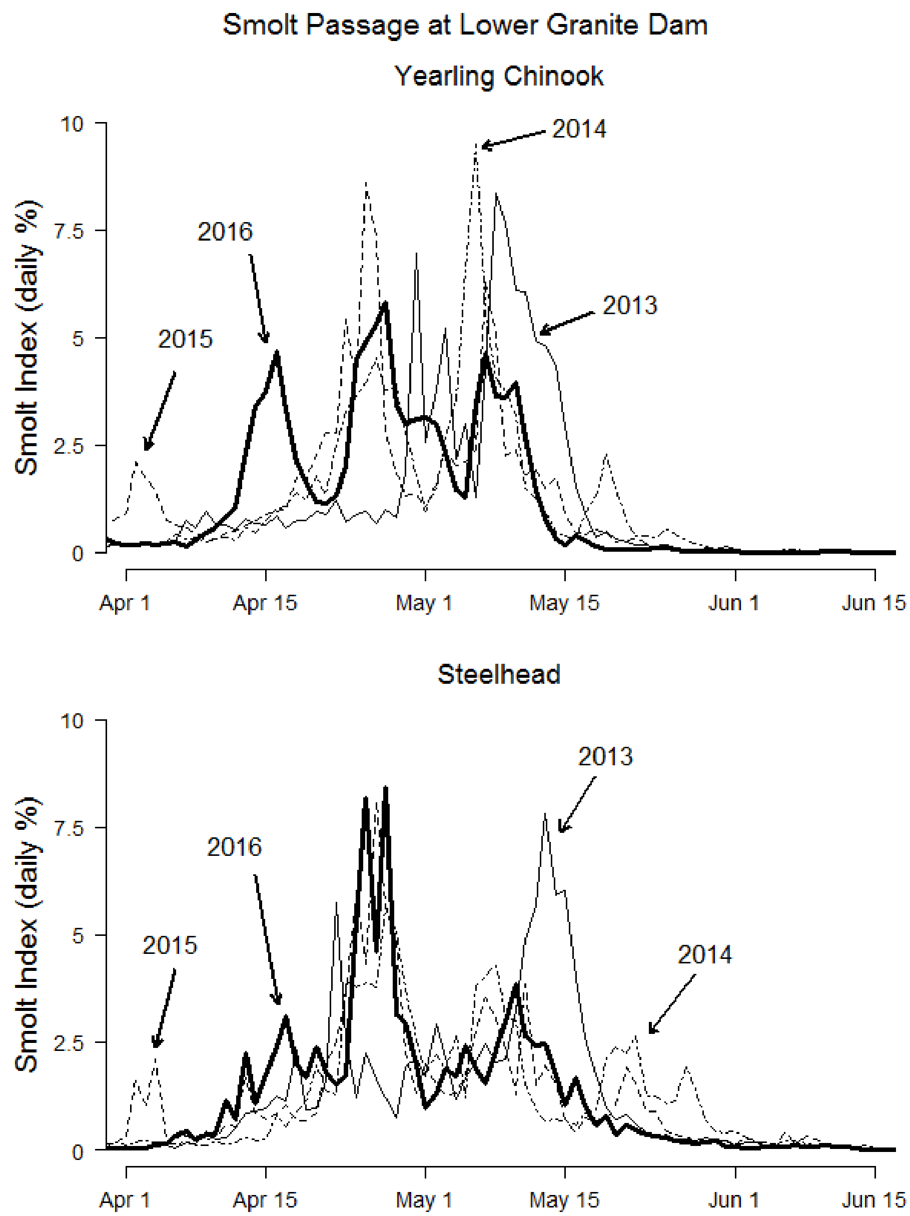


Appendix Figure C2. Daily mean spill (top = kcfs; bottom = percentage of total flow) averaged across Lower Granite, Little Goose and Lower Monumental dams from April through mid-June, 2009-2016, including daily long-term means (1993-2016).

During the 2016 migration season, mean spill discharge at Snake River dams was 24.9 kcfs, which was below the long-term mean of 25.7 kcfs during 1993-2016. Daily spill rates were above the long-term daily mean earlier in the season, but fell below the daily mean in the second week of May and stayed below the mean for the remainder of the migration period (Appendix Figure C2).

Spill as a percentage of flow at Snake River dams averaged 30.6% in 2016, which was above the long-term (1993-2016) mean of 26.1%, but was among the lower average spill percentages since 2007. Daily mean spill percentages in 2016 were above the long-term daily means for almost the entire migration period (Appendix Figure C2).

Pulses in flow that occurred around 15 and 25 April and 10 May (Appendix Figure C1) corresponded with peaks in smolt arrival at Lower Granite Dam for both Chinook and steelhead in 2016 (Appendix Figure C3).



Appendix Figure C3. Daily smolt passage index of yearling Chinook salmon and steelhead passing Lower Granite Dam, 2013-2016.

Appendix D: List of Tables and Figures

Tables

Figures