Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2015

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Executive Summary

In 2015, we completed the 23rd 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 19,085 hatchery steelhead *O. mykiss*, 10,835 wild steelhead, and 5,368 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 2015 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 2015, 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 63% hatchery and 37% wild for yearling Chinook and 66% hatchery and 34% 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 92.2% of the overall yearling Chinook salmon run in 2015 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 2015 (standard errors in parentheses).

	Yearling Chinook salmon (SE)	Steelhead (SE)
Snake River Trap to Lower Granite Dam	0.909 (0.103)	0.874 (0.046)
Lower Granite to Little Goose Dam	0.857 (0.036)	0.848 (0.039)
Little Goose to Lower Monumental Dam	0.964 (0.057)	0.834 (0.060)
Lower Monumental to McNary Dam[a]	0.802 (0.033)	0.939 (0.073)
Lower Monumental to Ice Harbor	0.867 (0.062)	1.118 (0.073)
Ice Harbor to McNary	0.990 (0.122)	0.783 (0.049)
McNary to John Day Dam	0.724 (0.069)	0.792 (0.066)
John Day to Bonneville Dam[b]	0.937 (0.160)	0.842 (0.050)
Snake River Trap to Bonneville Dam[c]	0.389 (0.055)	0.364 (0.034)

[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 0.389 (95% CI 0.281-0.497) for yearling Chinook and 0.364 (0.297-0.431) for steelhead.

For upper Columbia River hatchery yearling Chinook, we estimated survival from multiple release sites to McNary Dam tailrace. For Eastbank Hatchery fish released to the Wenatchee River, estimated survival ranged from 0.760 (0.052) for Dryden Pond releases to 0.346 (0.030) for Nason Creek releases. For Upper Columbia River steelhead from Wells Hatchery, estimated survival ranged from 0.547 (0.065) for releases from the hatchery to 0.248 (0.081) for releases to Twisp Acclimation Pond on the Wenatchee River.

Estimates of survival from Snake River hatcheries to Lower Granite Dam suggested substantial mortality upstream from the Snake and Clearwater River confluence. Continued development of instream PIT-detection systems for use in tributaries will be necessary if the sources of mortality in these upstream areas are to be identified.

For smolts that arrived at Lower Granite Dam, we estimated that 13% of yearling Chinook (wild and hatchery combined) and 13% of steelhead were transported from a Snake River collector dam. These estimates were considerably lower than in any other year in the record (1993-2015).

Low estimated proportions of transported smolts resulted in part from timing of the transportation program in 2015. We estimated that 58% of the yearling Chinook and 48% of the steelhead populations had already passed Lower Granite Dam by the time transportation began on 1 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). Despite low flow levels throughout the migration period, travel times through the entire hydropower system were shorter than the long-term average for most of the season.

In the past, some low-flow years have seen periods where no water was spilled at Snake River dams, and surface-passage structures were not yet present. During the low-flow year of 2015, surface-passage structures and provision of large spill proportions contributed to shorter travel times.

In 2015, the estimated proportion of PIT-tagged fish detected as they passed monitoring sites at dams was the lowest we have ever recorded at all sites except Bonneville Dam. This was mostly due to low flows in combination with high rates of spill used for surface passage at dams. The quality of information from mark-recapture models is proportional to sample size, which in turn depends on the number of tagged fish that are detected. The consequence of lower detection probabilities in 2015 was severely impaired precision in the estimates from which they are derived.

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 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.

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Introduction

Accurate and precise estimates of survival are needed for recovery of depressed stocks of Pacific salmon *Oncorhynchus* spp. These 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 2015, 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. 2007-2015). These annual survival estimates aer 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 2015, the 23rd year of the study. Research objectives in 2015 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 2015 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 2015, 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.

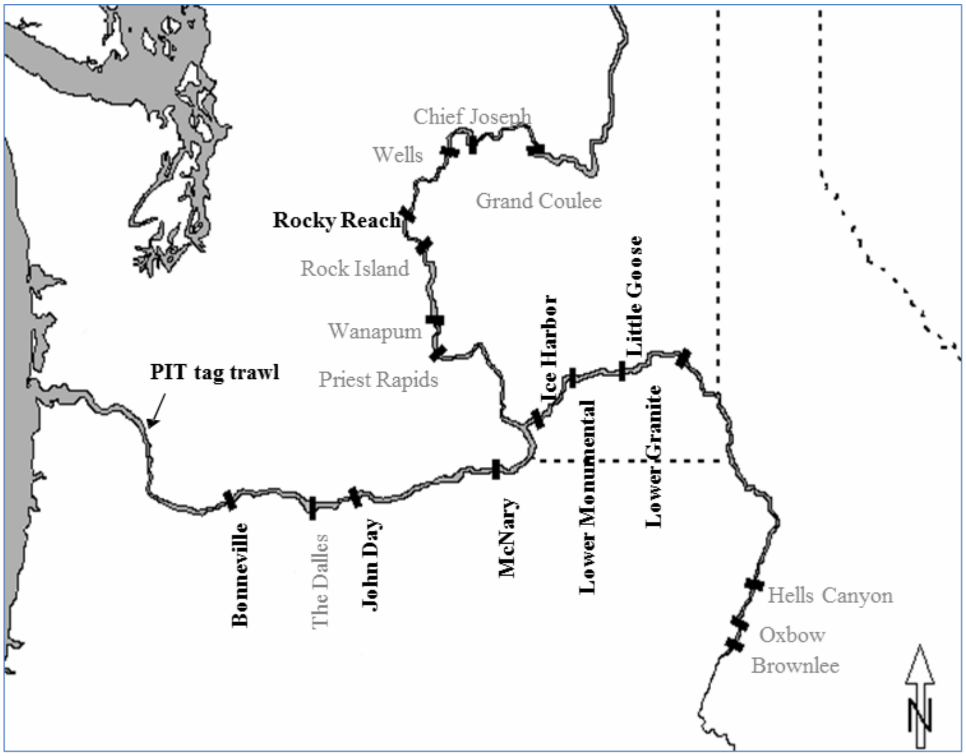

Figure 1. Study area showing the eight sites with PIT-tag detection capability in boldface, including seven dams and the PIT-tag trawl in the Columbia River estuary. Dams with names in gray do not have detection facilities.

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 especially low in 2015. 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 2015, 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 2015, 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 19,085 hatchery steelhead, 10,835 wild steelhead, and 5,368 wild yearling Chinook salmon from 15 April through

13 June 2015 (Table 1). From these numbers, total mortalities were 30, 18, and 16 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 2015. 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
15-Apr	917	-	1	102	-	2	359	2	1
16-Apr	879	1	1	175	-	2	457	-	1
22-Apr	1,849	-	-	201	-	1	405	-	2
23-Apr	1,728	-	1	167	-	-	402	1	-
1-May	2,441	3	-	225	-	-	124	1	-
2-May	1,266	1	-	292	-	-	137	-	-
5-May	679	3	-	426	1	-	200	1	-
6-May	673	4	2	221	-	1	132	-	-
7-May	666	3	1	407	3	1	312	-	-
8-May	661	2	5	487	1	1	283	-	-
9-May	641	1	-	750	1	3	332	-	-
12-May	630	1	-	966	-	3	194	1	-
13-May	480	-	-	542	2	6	236	-	-
14-May	530	1	-	439	-	2	325	-	-
15-May	458	1	-	467	3	-	550	-	-
16-May	348	-	-	438	-	-	203	1	1
19-May	425	-	-	182	-	2	146	3	-
20-May	335	-	-	629	1	-	215	1	-
21-May	335	-	1	545	-	1	97	-	-
22-May	337	1	1	1,183	3	-	146	3	-
23-May	318	-	3	1,038	-	3	113	2	-
27-May	297	-	-	284	2	1	-	-	-
28-May	311	2	-	101	-	2	-	-	-
29-May	149	-	-	74	1	-	-	-	-
30-May	296	-	-	61	-	-	-	-	-
2-Jun	197	2	-	60	-	-	-	-	-
3-Jun	92	-	-	32	-	-	-	-	-
4-Jun	82	2	-	22	-	-	-	-	-
5-Jun	72	-	-	19	-	-			
6-Jun	9	-	-	4	-	-			
9-Jun	497	1	-	84	-	-			
10-Jun	218	1	3	81	-	1			
11-Jun	102	-	1	53	-	-			
12-Jun	110	-	-	48	-	-			
13-Jun	57	-	-	30	-	-			
	19,085	30	20	10,835	18	32	5,368	16	5

A total of 29,198 yearling Chinook salmon (18,261 hatchery origin, 10,937 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 52,872 steelhead (34,967 hatchery origin and 17,905 wild) were similarly tagged and released or detected and returned to the tailrace of Lower Granite Dam.

We estimated that 92.2% of the overall run of yearling Chinook salmon in 2015 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 tag groups used to estimate survival, estimated proportions of hatchery fish were 63% for yearling Chinook salmon and 66% 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 2015 were too sparse to estimate survival for daily groups.

Releases from Hatcheries and Smolt Traps—In 2015, 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 for fish originating in the Snake River Basin and from release to McNary Dam for fish originating in the Upper Columbia River Basin, as well as estimtaes to points downstream from McNary for fish from both basins.

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 2015 from the Columbia Basin PIT Tag Information System (PTAGIS), a regional database maintained by the Pacific States Marine Fisheries Commission (PTAGIS 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 2015. 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. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities 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 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, which results in disproportionate influence from these lower estimates. 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 to Bonneville Dam for fish released from the Snake River trap 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 to Bonneville covers essentially the entire eight-project hydropower system negotiated by juvenile salmonids from the Snake River Basin. For yearling Chinook salmon and steelhead (hatchery and wild combined), 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 weekly estimates 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 9 consecutive weeks during 23 March-24 May. Mean estimated survival was 0.857 (SE 0.036) from Lower Granite to Little Goose, 0.964 (0.057) from Little Goose to Lower Monumental, and 0.802 (0.033) from Lower Monumental to McNary Dam (Tables 2 and 5). For the combined reach from Lower Granite to McNary Dam, mean estimated survival was 0.680 (0.035).

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 2015. 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	1,211	0.814 (0.043)	1.157 (0.342)	0.647 (0.222)	0.609 (0.110)
30 Mar–5 Apr	2,941	1.015 (0.057)	1.068 (0.269)	0.594 (0.158)	0.644 (0.067)
6–12 Apr	1,066	0.930 (0.108)	1.085 (0.442)	0.670 (0.288)	0.676 (0.119)
13–19 Apr	2,960	1.021 (0.099)	0.798 (0.137)	0.756 (0.131)	0.616 (0.062)
20–26 Apr	8,437	0.798 (0.042)	1.261 (0.216)	0.920 (0.164)	0.925 (0.066)
27 Apr–3 May	2,676	0.986 (0.123)	0.903 (0.189)	0.772 (0.161)	0.687 (0.082)
4 –10 May	4,901	0.824 (0.045)	0.863 (0.112)	0.882 (0.126)	0.627 (0.052)
11–17 May	3,051	0.771 (0.049)	0.920 (0.132)	0.702 (0.110)	0.498 (0.044)
18–24 May	1,767	0.659 (0.110)	0.862 (0.344)	0.894 (0.411)	0.508 (0.144)
Weighted mean[a]		**0.857 (0.036)**	**0.964 (0.057)**	**0.802 (0.033)**	**0.680 (0.035)**

a Weighted mean estimates for daily groups (24 Mar–25 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 six consecutive weeks during 20 April-31 May. Overall weighted mean survival was 0.724 (SE0.069) from McNary to John Day, 0.937 (0.160) from John Day to Bonneville, and 0.629 (0.043) for the combined reach from McNary to Bonneville Dam (Table 3).

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 2015. 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
20–26 Apr	1,839	0.943 (0.356)	0.713 (0.422)	0.672 (0.307)
27 Apr–3 May	6,921	0.881 (0.209)	0.672 (0.191)	0.593 (0.092)
4–10 May	11,869	0.528 (0.059)	1.443 (0.267)	0.762 (0.113)
11–17 May	6,976	0.817 (0.095)	0.753 (0.139)	0.615 (0.089)
18–24 May	3,446	0.830 (0.136)	0.602 (0.157)	0.499 (0.102)
25–31 May	481	1.229 (1.153)	0.319 (0.336)	0.392 (0.187)
Weighted mean		**0.724 (0.069)**	**0.937 (0.160)**	**0.629 (0.043)**

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 0.428 (SE 0.037) from Lower Granite to Bonneville Dam. For wild and hatchery yearling Chinook salmon released from the Snake River trap, estimated survival was 0.909 (0.103) 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 0.389 (SE0.055).

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. Meaningful comparisons among shorter reaches were not feasible because SEs from individual estimates for these reaches were high as a result of poor detection rates at Little Goose and Lower Monumental 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 2015. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

		Estimated survival of pooled 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	1,091	0.830 (0.046)	1.266 (0.402)	0.568 (0.206)	0.597 (0.110)
30 Mar–5 Apr	2,652	1.008 (0.061)	1.146 (0.316)	0.560 (0.163)	0.648 (0.071)
6–12 Apr	856	0.857 (0.110)	1.109 (0.449)	0.791 (0.345)	0.752 (0.153)
13–19 Apr	1,673	1.203 (0.184)	1.249 (0.471)	0.396 (0.144)	0.595 (0.070)
20–26 Apr	6,280	0.857 (0.063)	1.827 (0.544)	0.717 (0.218)	1.123 (0.104)
27 Apr–3 May	2,079	1.048 (0.167)	1.105 (0.332)	0.534 (0.154)	0.618 (0.079)
4–10 May	2,595	0.877 (0.064)	0.807 (0.145)	1.207 (0.248)	0.855 (0.107)
11–17 May	759	0.857 (0.129)	0.866 (0.323)	0.712 (0.277)	0.529 (0.100)
Weighted mean		**0.908 (0.035)**	**1.108 (0.118)**	**0.768 (0.109)**	**0.775 (0.082)**
		Wild yearling Chinook			
13–19 Apr	1,287	0.878 (0.109)	0.692 (0.134)	1.112 (0.265)	0.676 (0.128)
20–26 Apr	2,157	0.714 (0.053)	0.944 (0.190)	0.836 (0.180)	0.563 (0.060)
27 Apr–3 May	597	0.889 (0.177)	0.723 (0.211)	1.655 (0.660)	1.064 (0.359)
4–10 May	2,306	0.763 (0.063)	0.891 (0.165)	0.639 (0.126)	0.434 (0.046)
11–17 May	2,292	0.752 (0.052)	0.936 (0.145)	0.688 (0.118)	0.484 (0.048)
18–24 May	1,591	0.655 (0.122)	0.831 (0.365)	0.890 (0.441)	0.484 (0.144)
Weighted mean		**0.758 (0.025)**	**0.859 (0.045)**	**0.837 (0.116)**	**0.524 (0.051)**

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 the entire season in order to create sufficient sample sizes for survival probability estimates.

Nevertheless, variation in the resulting seasonal estimates was high—so high that any patterns in survival through Snake River reaches were difficult to distinguish from statistical sampling error (Table 5; Figure 2). However, it appeared that during the 2015 migration season, estimated survival between Lower Granite and McNary Dam increased in late April and then declined throughout 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 2015. 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 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
24–27 Mar	529	0.764 (0.058)	1.489 (0.779)	0.613 (0.375)	0.697 (0.225)
28–30 Mar	907	0.910 (0.067)	1.009 (0.400)	0.590 (0.254)	0.542 (0.098)
31 Mar–2 Apr	1,995	1.022 (0.068)	0.959 (0.271)	0.650 (0.195)	0.637 (0.076)
3–5 Apr	656	1.044 (0.147)	1.656 (1.116)	0.409 (0.289)	0.707 (0.181)
6–10 Apr	707	0.954 (0.132)	0.789 (0.311)	0.905 (0.386)	0.682 (0.146)
11–15 Apr	1,435	1.309 (0.188)	0.793 (0.230)	0.629 (0.183)	0.653 (0.096)
16–18 Apr	1,568	0.782 (0.098)	0.929 (0.200)	0.888 (0.207)	0.645 (0.100)
19–21 Apr	1,675	0.727 (0.084)	1.906 (0.801)	0.562 (0.242)	0.778 (0.114)
22–24 Apr	4,262	0.775 (0.054)	1.129 (0.240)	0.932 (0.209)	0.816 (0.081)
25–27 Apr	3,324	0.895 (0.089)	1.307 (0.485)	0.843 (0.316)	0.987 (0.108)
28–30 Apr	1,078	1.784 (0.805)	0.617 (0.371)	0.551 (0.247)	0.606 (0.120)
1–3 May	1,090	0.897 (0.121)	0.858 (0.193)	0.981 (0.261)	0.755 (0.147)
4–6 May	1,968	0.745 (0.075)	0.973 (0.200)	0.894 (0.202)	0.648 (0.089)
7–9 May	2,720	0.856 (0.058)	0.833 (0.146)	0.844 (0.163)	0.602 (0.064)
10–12 May	905	0.938 (0.134)	1.440 (0.684)	0.432 (0.210)	0.584 (0.100)
13–15 May	1,972	0.692 (0.049)	0.878 (0.138)	0.801 (0.142)	0.487 (0.054)
16–19 May	888	1.048 (0.193)	0.577 (0.193)	0.836 (0.307)	0.505 (0.122)
20–25 May	1,271	0.498 (0.087)	1.118 (0.536)	0.665 (0.353)	0.371 (0.107)
Weighted mean		**0.857 (0.036)**	**0.964 (0.057)**	**0.802 (0.033)**	**0.680 (0.035)**

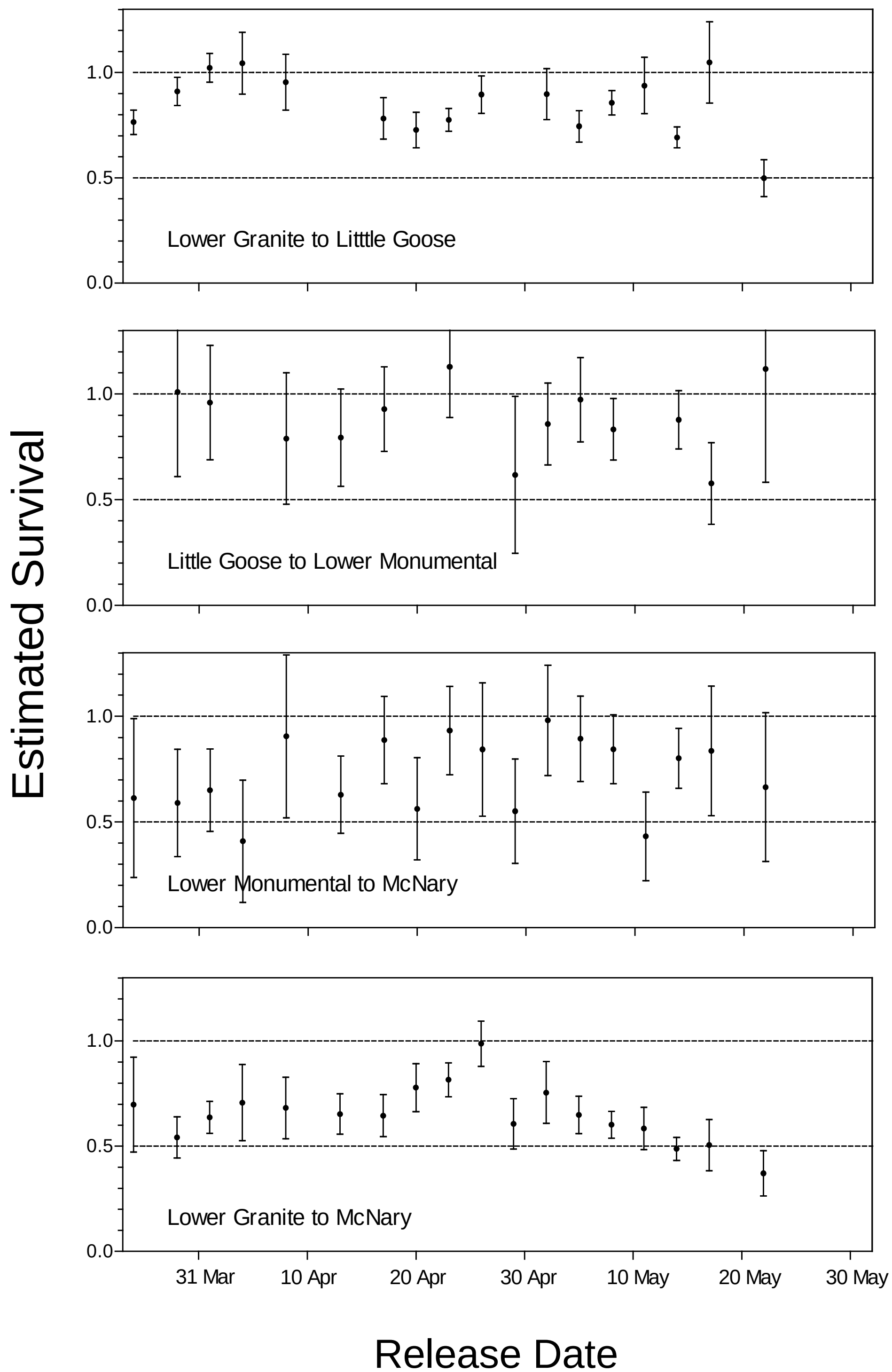

Figure 2. Estimated survival probabilities through various reaches by release date at Lower Granite Dam for daily groups of Snake River yearling Chinook salmon (hatchery and wild combined), 2015. Whiskers extend one standard error above and below point estimates.

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 readinesss in fish (Tables 6-8). Detection probability estimates were generally highest at McNary and Bonneville and lowest at Lower Monumental and John Day Dam. 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 2015. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon from Lower Granite Dam release groups (SE)			
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
23–29 Mar	1,211	0.516 (0.031)	0.039 (0.013)	0.190 (0.037)
30 Mar–5 Apr	2,941	0.265 (0.017)	0.021 (0.006)	0.211 (0.024)
6–12 Apr	1,066	0.180 (0.024)	0.023 (0.010)	0.208 (0.039)
13–19 Apr	2,960	0.100 (0.011)	0.055 (0.009)	0.222 (0.024)
20–26 Apr	8,437	0.106 (0.007)	0.016 (0.003)	0.168 (0.013)
27 Apr–3 May	2,676	0.080 (0.011)	0.069 (0.013)	0.165 (0.022)
4–10 May	4,901	0.180 (0.012)	0.050 (0.007)	0.175 (0.016)
11–17 May	3,051	0.199 (0.015)	0.066 (0.010)	0.241 (0.024)
18–24 May	1,767	0.125 (0.023)	0.034 (0.014)	0.097 (0.029)

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 2015. Daily groups were pooled for weekly estimates. Standard errors in parentheses.

	Estimated detection probability of yearling Chinook salmon from McNary Dam release groups (SE)		
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
20–26 Apr	1,839	0.029 (0.012)	0.146 (0.067)
27 Apr–3 May	6,921	0.018 (0.005)	0.166 (0.026)
4 –10 May	11,869	0.047 (0.006)	0.114 (0.017)
11–17 May	6,976	0.049 (0.006)	0.248 (0.036)
18–24 May	3,446	0.059 (0.011)	0.264 (0.055)
25–31 May	481	0.019 (0.018)	0.266 (0.130)

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 2015. Daily groups were pooled to form weekly estimates. Standard errors in parentheses.

		Estimated detection probability for Lower Granite Dam release groups (SE)		
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery Yearling Chinook		
23–29 Mar	1,091	0.505 (0.032)	0.038 (0.013)	0.196 (0.039)
30 Mar–5 Apr	2,652	0.257 (0.018)	0.020 (0.006)	0.203 (0.024)
6–12 Apr	856	0.172 (0.026)	0.028 (0.012)	0.181 (0.040)
13–19 Apr	1,673	0.075 (0.013)	0.018 (0.007)	0.238 (0.031)
20–26 Apr	6,280	0.078 (0.007)	0.008 (0.002)	0.133 (0.013)
27 Apr–3 May	2,079	0.071 (0.013)	0.050 (0.013)	0.188 (0.026)
4–10 May	2,595	0.176 (0.015)	0.042 (0.008)	0.132 (0.018)
11–17 May	759	0.168 (0.029)	0.041 (0.016)	0.192 (0.041)
		Wild Yearling Chinook		
13–19 Apr	1,287	0.135 (0.020)	0.112 (0.020)	0.191 (0.038)
20–26 Apr	2,157	0.189 (0.017)	0.037 (0.009)	0.308 (0.035)
27 Apr–3 May	597	0.104 (0.024)	0.115 (0.029)	0.096 (0.034)
4–10 May	2,306	0.186 (0.018)	0.061 (0.012)	0.246 (0.029)
11–17 May	2,292	0.208 (0.017)	0.074 (0.012)	0.260 (0.029)
18–24 May	1,591	0.117 (0.024)	0.031 (0.014)	0.100 (0.032)

Snake River Steelhead

Survival Probabilities—For weekly groups of steelhead, we estimated probabilities of survival from Lower Granite Dam to multiple downstream dams for 9 consecutive weeks during 30 March-31 May. Average estimated survival was 0.848 (SE 0.039) from Lower Granite to Little Goose, 0.834 (0.060) from Little Goose to Lower Monumental, and 0.939 (0.073) from Lower Monumental to McNary Dam (Table 9). For the combined reach from Lower Granite to McNary Dam, estimated survival averaged 0.628 (0.033).

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 2015. 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	1,197	1.080 (0.096)	1.338 (0.628)	0.459 (0.232)	0.664 (0.136)
6–12 Apr	778	1.157 (0.164)	0.413 (0.178)	1.841 (0.881)	0.880 (0.226)
13–19 Apr	3,589	0.904 (0.101)	1.012 (0.242)	0.673 (0.161)	0.616 (0.070)
20–26 Apr	7,976	0.984 (0.056)	0.706 (0.070)	1.164 (0.136)	0.809 (0.068)
27 Apr–3 May	6,953	0.906 (0.061)	0.799 (0.097)	0.886 (0.109)	0.641 (0.045)
4–10 May	8,790	0.796 (0.035)	0.934 (0.106)	0.683 (0.086)	0.508 (0.035)
11–17 May	8,978	0.744 (0.043)	1.031 (0.148)	0.707 (0.111)	0.543 (0.046)
18–24 May	8,813	0.672 (0.042)	0.816 (0.139)	1.050 (0.203)	0.576 (0.064)
25–31 May	2,742	0.712 (0.090)	0.841 (0.287)	1.873 (0.999)	1.123 (0.480)
Weighted mean*		**0.848 (0.039)**	**0.834 (0.060)**	**0.939 (0.073)**	**0.628 (0.033)**

* Weighted mean of estimates for daily groups (24 Mar–31 May; see Table 12)

For steelhead detected and returned to the tailrace of McNary Dam, we estimated probabilities of survival to multiple dams downstream for 6 consecutive weeks during 20 April-31 May. Detection rates were very low at John Day and Bonneville Dam and in the pair trawl detection system; thus, precision of these estimates was low. We pooled the weekly groups into bi-weekly groups to help increase precision. Mean estimated survival from the pooled weekly groups was 0.792 (SE 0.066) from McNary to John Day, 0.842 (SE 0.050) from John Day to Bonneville, and 0.663 (SE 0.039) for the entire reach from McNary to Bonneville Dam (Table 10).

Table 10. Estimated survival probabilities for bi-weekly groups of juvenile Snake River steelhead (hatchery and wild combined) from McNary Dam in 2015. 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 from McNary Dam (SE)			
Date at McNary Dam	Number released	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam
20 Apr–3 May	2,032	0.704 (0.151)	1.010 (0.312)	0.711 (0.159)
4–17 May	5,835	0.883 (0.110)	0.796 (0.123)	0.702 (0.064)
18–31 May	3,526	0.693 (0.110)	0.848 (0.166)	0.588 (0.068)
Weighted mean		**0.792 (0.066)**	**0.842 (0.050)**	**0.663 (0.039)**

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 0.416 (SE 0.033) 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 0.874 (0.046). Thus, estimated survival probability through all eight hydropower projects encountered by Snake River steelhead was 0.364 (0.034).

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. However, many of the differences were likely due to sampling variation. Average estimated survival was higher for hatchery than for wild steelhead over the combined reach between Lower Granite Dam and McNary Dam.

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, 2015. Daily groups were pooled for weekly estimates, and weighted means are of independent estimates for weekly groups. Standard errors in parentheses.

	Estimated survival for Lower Granite Dam releases (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	1,145	1.098 (0.100)	1.189 (0.554)	0.508 (0.256)	0.664 (0.140)
6–12 Apr	751	1.169 (0.169)	0.417 (0.180)	1.811 (0.865)	0.882 (0.226)
13–19 Apr	3,212	0.920 (0.112)	0.902 (0.221)	0.721 (0.174)	0.598 (0.068)
20–26 Apr	7,332	0.990 (0.058)	0.704 (0.072)	1.147 (0.137)	0.800 (0.068)
27 Apr–3 May	6,059	0.927 (0.064)	0.790 (0.100)	0.904 (0.116)	0.662 (0.048)
4–10 May	5,245	0.868 (0.048)	0.864 (0.112)	0.685 (0.098)	0.514 (0.042)
11–17 May	4,001	0.887 (0.070)	1.164 (0.249)	0.497 (0.111)	0.514 (0.052)
18–24 May	3,259	0.694 (0.061)	0.810 (0.192)	1.038 (0.276)	0.584 (0.086)
25–31 May	1,657	0.855 (0.135)	0.780 (0.339)	1.191 (0.692)	0.794 (0.331)
Weighted mean		**0.921 (0.038)**	**0.813 (0.049)**	**0.904 (0.088)**	**0.633 (0.039)**
	Wild steelhead				
20–26 Apr	644	0.914 (0.212)	0.722 (0.297)	1.622 (0.920)	1.071 (0.488)
27 Apr–3 May	894	0.803 (0.218)	0.740 (0.297)	0.909 (0.386)	0.540 (0.164)
4–10 May	3,545	0.686 (0.050)	1.191 (0.288)	0.607 (0.160)	0.496 (0.064)
11–17 May	4,977	0.629 (0.054)	0.921 (0.178)	1.053 (0.238)	0.610 (0.088)
18–24 May	5,554	0.665 (0.058)	0.823 (0.199)	1.077 (0.300)	0.590 (0.097)
Weighted mean		**0.677 (0.029)**	**0.930 (0.079)**	**0.961 (0.126)**	**0.572 (0.050)**

We estimated survival for daily release groups of combined hatchery and wild steelhead either detected and returned to the tailarace or released to the tailrace of Lower Granite Dam on the same day. However, even after pooling of multiple daily groups, these estimates were highly variable with relatively poor precision. The most notable pattern was a relative 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 2015. 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 steelhead daily 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 Mar–5 Apr	1,229	1.025 (0.084)	1.133 (0.426)	0.518 (0.213)	0.602 (0.111)
6–10 Apr	539	1.258 (0.218)	0.302 (0.122)	2.046 (0.950)	0.778 (0.231)
11–15 Apr	1,669	0.977 (0.128)	1.372 (0.467)	0.648 (0.228)	0.868 (0.137)
16–19 Apr	2,159	0.835 (0.135)	0.802 (0.263)	0.713 (0.231)	0.477 (0.073)
20–22 Apr	2,870	1.071 (0.088)	0.761 (0.111)	1.061 (0.195)	0.864 (0.119)
23–25 Apr	4,574	0.969 (0.087)	0.610 (0.088)	1.265 (0.201)	0.748 (0.084)
26–28 Apr	1,650	1.039 (0.113)	0.648 (0.184)	1.252 (0.379)	0.844 (0.122)
29 Apr–1 May	3,145	0.996 (0.094)	0.864 (0.150)	0.783 (0.135)	0.673 (0.062)
2–4 May	2,759	0.715 (0.087)	0.780 (0.154)	1.016 (0.215)	0.567 (0.082)
5–7 May	4,714	0.914 (0.062)	0.725 (0.096)	0.770 (0.110)	0.509 (0.044)
8–10 May	4,007	0.677 (0.039)	1.574 (0.381)	0.479 (0.126)	0.511 (0.060)
11–13 May	4,487	0.811 (0.102)	1.312 (0.480)	0.469 (0.170)	0.499 (0.055)
14–16 May	4,430	0.723 (0.046)	0.959 (0.150)	0.858 (0.167)	0.595 (0.079)
17–19 May	1,227	0.759 (0.094)	0.752 (0.237)	0.993 (0.375)	0.567 (0.138)
20–22 May	5,616	0.664 (0.055)	0.893 (0.237)	0.958 (0.276)	0.569 (0.080)
23–25 May	2,056	0.674 (0.091)	0.724 (0.218)	1.204 (0.439)	0.588 (0.146)
26–31 May	2,717	0.724 (0.094)	0.809 (0.277)	1.901 (1.013)	1.114 (0.476)
Weighted mean		**0.848 (0.039)**	**0.834 (0.060)**	**0.939 (0.073)**	**0.628 (0.033)**

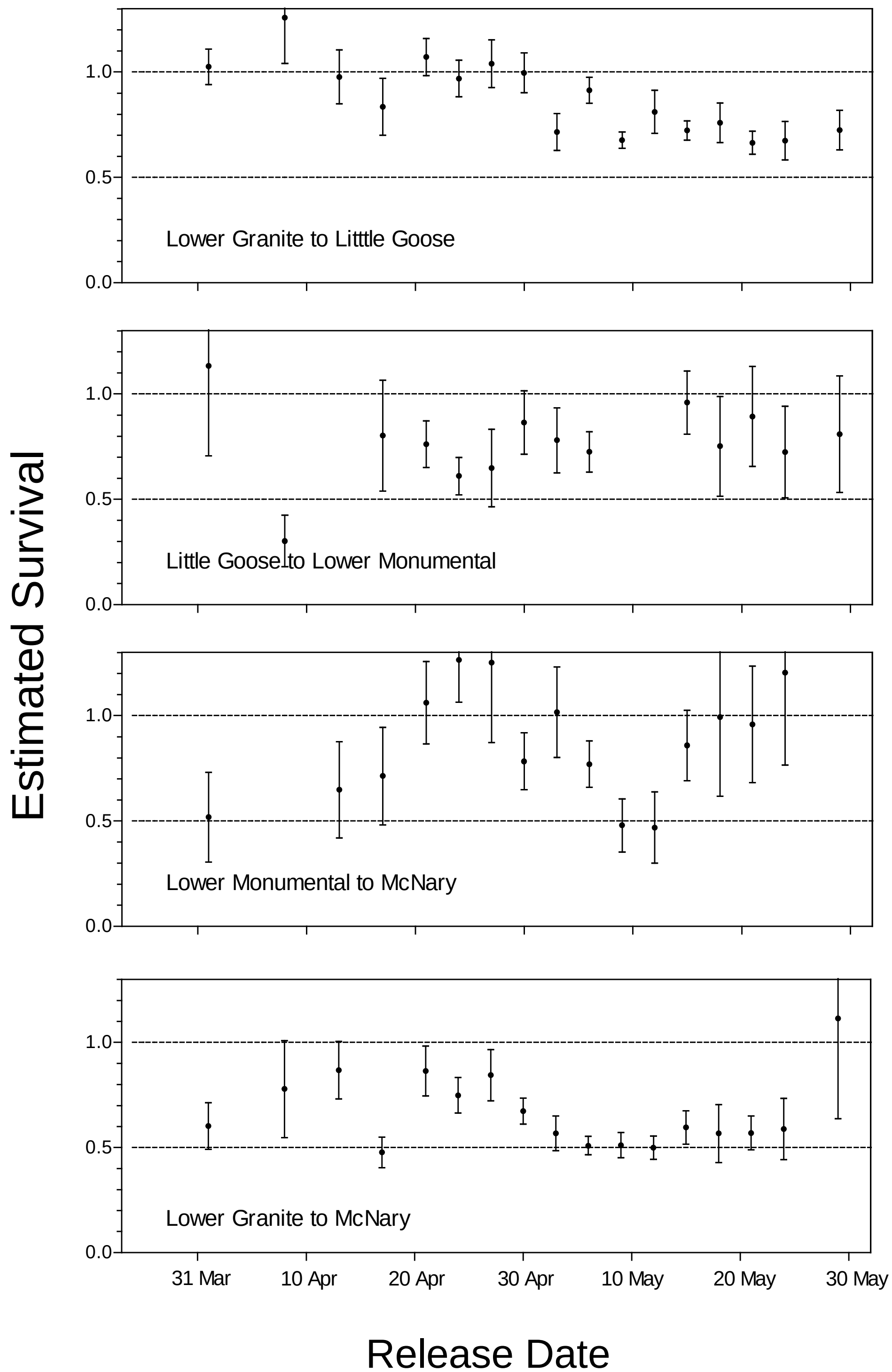

Figure 3. Estimated survival probabilities through various reaches versus release date at Lower Granite Dam for daily release groups of Snake River steelhead (hatchery and wild combined), 2015. Whiskers extend one standard error above and below point estimates.

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 Lower Monumental and John Day Dam. Detection probability estimates were often higher for hatchery fish than for wild fish released in the same week, although patterns were not consistent among weeks or across dams (Table 15).

Table 13. Estimated detection probability for juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of Lower Granite Dam, 2015. Weekly estimates from pooled daily groups. Standard errors in parentheses.

Estimated detection probability of steelhead from Lower Granite Dam (SE)				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
30 Mar–5 Apr	1,197	0.285 (0.028)	0.019 (0.009)	0.113 (0.026)
6–12 Apr	778	0.171 (0.028)	0.019 (0.010)	0.081 (0.023)
13–19 Apr	3,589	0.072 (0.009)	0.023 (0.006)	0.091 (0.012)
20–26 Apr	7,976	0.100 (0.007)	0.051 (0.005)	0.064 (0.006)
27 Apr–3 May	6,953	0.089 (0.007)	0.048 (0.006)	0.112 (0.009)
4–10 May	8,790	0.182 (0.009)	0.046 (0.006)	0.129 (0.010)
11–17 May	8,978	0.121 (0.008)	0.031 (0.004)	0.084 (0.008)
18–24 May	8,813	0.140 (0.010)	0.026 (0.005)	0.070 (0.009)
25–31 May	2,742	0.150 (0.020)	0.036 (0.012)	0.028 (0.012)

Table 14. Estimated detection probability for bi-weekly groups of juvenile Snake River steelhead (hatchery and wild combined) from the tailrace of McNary Dam, 2015. Standard errors in parentheses.

Estimated detection probability of steelhead from McNary Dam (SE)			
Date at McNary Dam	Number released	John Day Dam	Bonneville Dam
20 Apr–3 May	2,032	0.030 (0.008)	0.317 (0.072)
4–17 May	5,835	0.028 (0.004)	0.352 (0.033)
18–31 May	3,526	0.028 (0.006)	0.413 (0.049)

Table 15. Estimated detection probabilities for juvenile Snake River hatchery and wild steelhead from the tailrace at Lower Granite Dam, 2015. Daily groups pooled weekly. Standard errors in parentheses.

Estimated detection probability of steelhead from Lower Granite Dam				
Date at Lower Granite Dam	Number released	Little Goose Dam	Lower Monumental Dam	McNary Dam
		Hatchery steelhead		
	1,145	0.282 (0.029)	0.020 (0.010)	0.109 (0.026)
30 Mar–5 Apr	751	0.169 (0.028)	0.019 (0.011)	0.082 (0.024)
6–12 Apr	3,212	0.067 (0.009)	0.024 (0.006)	0.094 (0.012)
13–19 Apr	7,332	0.100 (0.007)	0.051 (0.005)	0.066 (0.006)
20–26 Apr	6,059	0.092 (0.007)	0.047 (0.006)	0.115 (0.010)
27 Apr–3 May	5,245	0.174 (0.011)	0.054 (0.007)	0.128 (0.012)
4–10 May	4,001	0.125 (0.011)	0.026 (0.006)	0.095 (0.012)
11–17 May	3,259	0.146 (0.015)	0.029 (0.008)	0.077 (0.013)
18–24 May	1,657	0.150 (0.026)	0.032 (0.014)	0.041 (0.018)
		Wild steelhead		
20–26 Apr	644	0.098 (0.026)	0.052 (0.021)	0.045 (0.022)
27 Apr–3 May	894	0.064 (0.020)	0.068 (0.023)	0.083 (0.028)
4–10 May	3,545	0.199 (0.016)	0.030 (0.008)	0.132 (0.019)
11–17 May	4,977	0.117 (0.012)	0.036 (0.007)	0.070 (0.011)
18–24 May	5,554	0.135 (0.013)	0.024 (0.006)	0.065 (0.011)

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 0.811 (SE0.024) for Rapid River Hatchery releases to 0.266 (0.016) for Lookingglass Hatchery fish released to Catherine Creek Pond (Appendix Table B1).

For steelhead, estimated survival to Lower Granite Dam ranged from 1.069 (0.128) for Niagara Springs Hatchery releases to the Little Salmon River to 0.630 (0.067) for Hagerman Hatchery releases to the East Fork Salmon River (Appendix Table B2). For sockeye salmon released at Redfish Lake Creek Trap in spring, estimated survival to Lower Granite Dam ranged from 0.483 (0.042) for Sawtooth Hatchery fish to 0.304 (0.027) 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 generally low and similar among release groups of the same species and rearing type from different traps (Appendix Table B8).

For wild steelhead, estimated detection probabilities at Snake River dams were consistently lower than those of hatchery conspecifics released from the same location (i.e., Grande Ronde, Salmon, and Snake River traps). These lower detection probabilities could be due to fish size (Zabel et al. 2005) but could also be partly due to differences in migration timing. Wild yearling Chinook salmon did not display a consistent difference in detectability compared to hatchery fish released from the same traps.

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 Eastbank Hatchery yearling Chinook released into the Wenatchee River, estimated survival to McNary Dam ranged from 0.760 (0.052) for releases to Dryden Pond to 0.346 (0.030) for releases to Nason Creek. For Upper Columbia River steelhead from Wells Hatchery, estimated survival to McNary Dam ranged from 0.547 (0.065) for releases from the hatchery to 0.248 (0.081) for releases to Twisp Acclimation Pond on the Methow River. For coho salmon, estimated survival to McNary Dam ranged from 0.533 (0.166) for Willard Hatchery fish released from Winthrop Hatchery, to 0.222 (0.046) for Cascade Hatchery fish released to Butcher 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. However, detection rates in 2015 were too low for acceptable accuracy, even in pooled estimates of survival (Table 16).

For yearling Chinook salmon in 2015, mean estimated survival was 0.867 (SE 0.062) from Lower Monumental to Ice Harbor Dam and 0.990 (0.122) from Ice Harbor to McNary Dam. For steelhead, estimated mean survival through these same respective reaches was 1.118 (0.073) and 0.783 (0.049).

Table 16. Estimated survival and detection probabilities from Lower Granite to Ice Harbor Dam for Snake River yearling Chinook salmon and steelhead (hatchery and wild combined), 2015. Accuracy of the estimates was unacceptable, even for pooled weekly release groups, as indicated by the standard errors shown in parentheses.

		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	1,211	1.088 (0.465)	0.730 (0.290)	0.026 (0.010)
30 Mar–5 Apr	2,941	1.031 (0.423)	0.594 (0.209)	0.011 (0.004)
6–12 Apr	1,066	0.325 (0.184)	2.054 (0.906)	0.009 (0.006)
13–19 Apr	2,960	0.780 (0.336)	0.958 (0.401)	0.006 (0.003)
20–26 Apr	8,437	0.753 (0.282)	1.214 (0.418)	0.003 (0.001)
27 Apr–3 May	2,676	1.087 (0.460)	0.744 (0.304)	0.009 (0.004)
4–10 May	4,901	0.786 (0.156)	1.099 (0.198)	0.024 (0.005)
11–17 May	3,051	1.007 (0.225)	0.692 (0.142)	0.032 (0.007)
18–24 May	1,767	0.652 (0.280)	1.427 (0.560)	0.050 (0.016)
Weighted mean		**0.867 (0.062)**	**0.990 (0.122)**	**0.006 (0.002)**
		Hatchery and wild steelhead		
30 Mar–5 Apr	1,197	0.522 (0.289)	0.788 (0.289)	0.035 (0.012)
6–12 Apr	778	1.298 (0.788)	1.381 (0.718)	0.016 (0.009)
13–19 Apr	3,589	1.147 (0.478)	0.602 (0.229)	0.008 (0.003)
20–26 Apr	7,976	1.235 (0.297)	0.935 (0.226)	0.007 (0.002)
27 Apr–3 May	6,953	1.138 (0.192)	0.854 (0.135)	0.022 (0.004)
4–10 May	8,790	1.019 (0.143)	0.679 (0.085)	0.045 (0.005)
11–17 May	8,978	0.896 (0.165)	0.854 (0.139)	0.025 (0.004)
18–24 May	8,813	1.494 (0.310)	0.659 (0.120)	0.033 (0.005)
25–31 May	2,742	1.483 (0.762)	1.220 (0.730)	0.019 (0.008)
Weighted mean		**1.118 (0.073)**	**0.783 (0.049)**	**0.016 (0.004)**

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 was calculated only for fish detected at both the upstream and downstream dam. We defined travel time as the number of days between last detection at the upstream dam and first detection at the downstream dam. Generally, the last detection at an upstream dam was on a monitor near the 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. For both species, travel time between Lower Granite and Bonneville Dam was longer than in recent years (2008-2014) but shorter than the long-term average (1998-2015) and shorter than most other low-flow years (Figure 4).

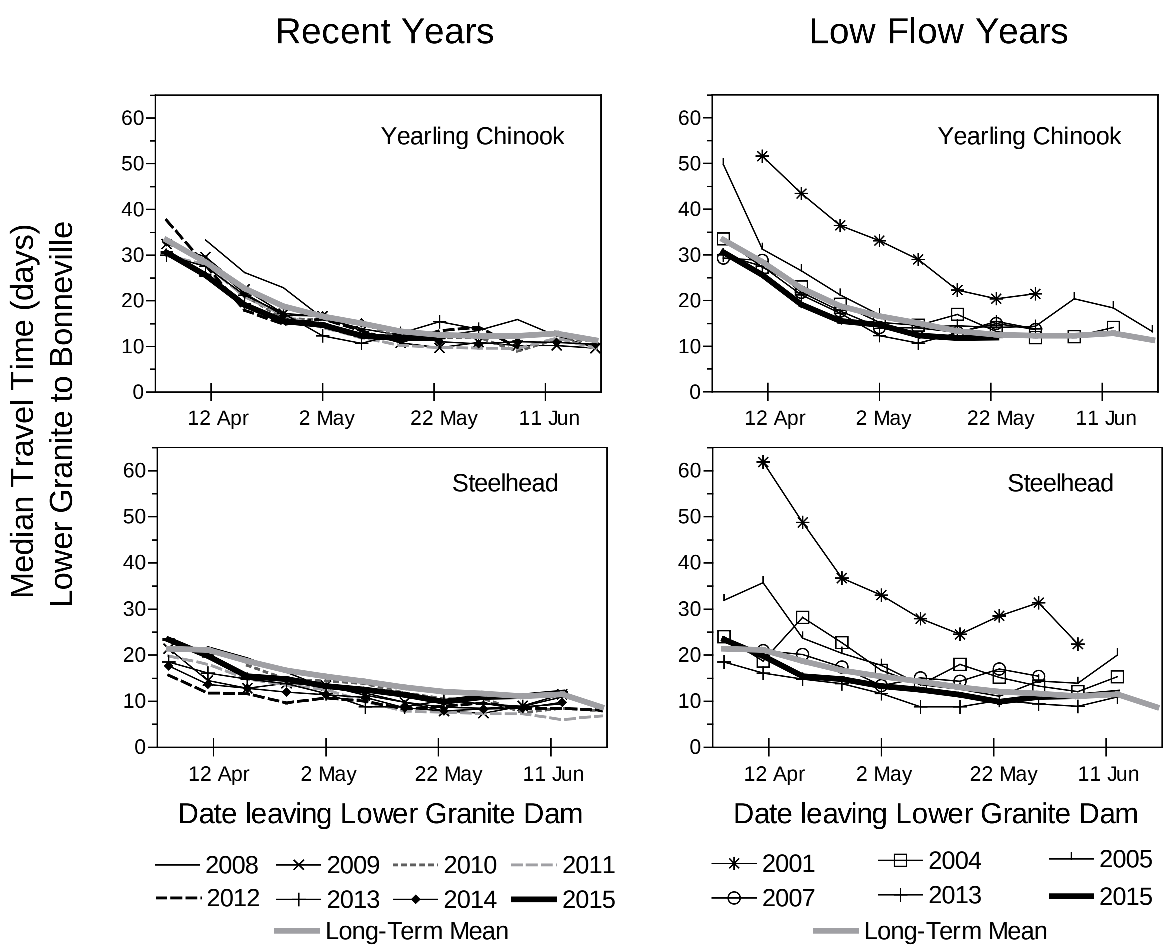

Figure 4. Median travel time (d) from Lower Granite Dam to Bonneville Dam for yearling Chinook salmon and steelhead for the most recent eight years (left) and for the six lowest flow years (right) in the period 1998-2015, with long-term mean for 1998-2015.

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

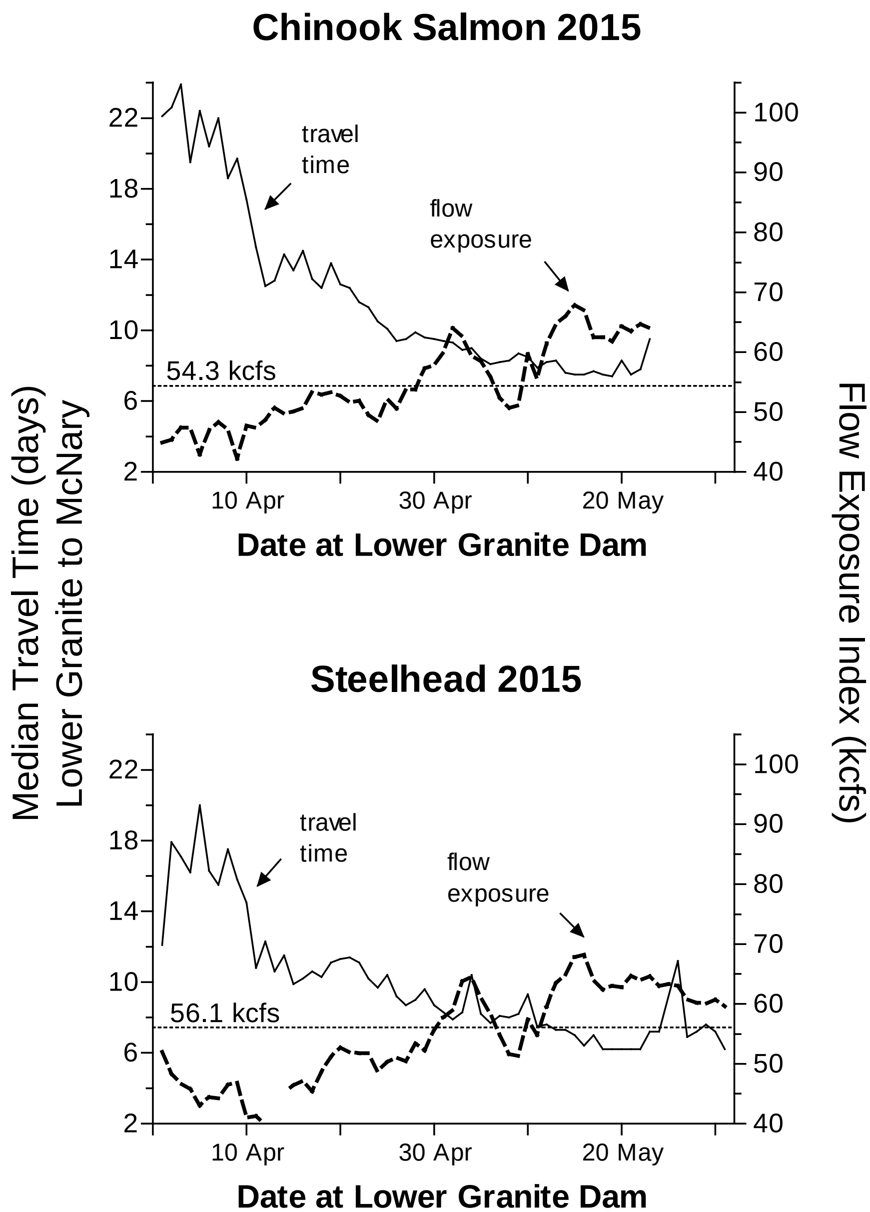

Figure 5. Travel time (d) for yearling Chinook salmon and steelhead from Lower Granite to McNary Dam and index of flow exposure at Lower Monumental Dam (kcfs) for daily groups of PIT-tagged fish during 2015 (see Appendix C). Dashed horizontal lines represent the annual average flow exposure index, weighted 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, 2015.

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

Date at Lower Granite Dam	Lower Granite to Little Goose Dam				Little Goose to Lower Monumental				Lower Monumental to McNary Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
24–30 Mar	472	5.5	8.4	12.8	20	2.5	3.3	4.7	4	4.5	4.9	5.6
31 Mar–6 Apr	790	6.2	8.8	13.5	21	3.2	4.4	5.8	9	5.1	5.4	5.8
7–13 Apr	178	5.7	8.3	12.9	7	3.1	4.2	4.5	3	4.9	5.9	6.3
14–20 Apr	303	4.5	5.9	7.8	13	2.2	2.6	3.2	21	4.4	5.1	7.3
21–27 Apr	711	3.0	3.9	5.0	17	2.0	2.4	3.2	19	3.7	4.3	5.1
28 Apr–4 May	210	3.0	3.5	4.4	13	1.8	2.0	2.8	13	3.7	4.2	4.7
5–11 May	729	2.4	2.7	3.3	36	1.9	2.2	3.1	33	3.4	4.1	4.7
12–18 May	468	2.3	2.6	3.1	27	1.4	1.8	2.2	24	3.1	3.6	4.2
19–25 May	146	2.1	2.6	2.9	5	1.6	2.3	2.5	4	3.3	3.7	4.2

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
24–30 Mar	135	19.5	25.6	30.7	52	29.2	34.8	39.1
31 Mar–6 Apr	397	18.1	22.6	27.5	185	26.2	30.4	33.7
7–13 Apr	149	14.1	19.4	22.8	73	22.2	25.8	28.7
14–20 Apr	403	11.4	13.6	18.0	202	17.1	19.2	23.2
21–27 Apr	1309	9.4	10.6	12.6	593	13.7	15.5	18.7
28 Apr–4 May	291	8.4	9.5	11.2	192	12.9	14.7	16.4
5–11 May	535	7.4	8.4	9.5	415	11.7	12.4	13.9
12–18 May	364	7.3	7.8	8.7	210	10.8	11.8	13.2
19–25 May	87	7.0	8.2	9.5	50	10.4	11.9	13.2

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, 2015.

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%
24–30 Mar	472	4.7	7.1	10.9	20	9.8	14.0	18.6	4	21.1	24.4	26.3
31 Mar–6 Apr	790	4.4	6.8	9.8	21	7.9	10.4	14.4	9	20.5	22.0	23.5
7–13 Apr	178	4.7	7.2	10.5	7	10.2	10.9	14.7	3	18.9	20.3	24.3
14–20 Apr	303	7.7	10.2	13.2	13	14.4	17.9	21.2	21	16.3	23.3	26.8
21–27 Apr	711	12.1	15.5	19.7	17	14.4	19.2	23.1	19	23.5	27.7	32.3
28 Apr–4 May	210	13.5	16.9	20.3	13	16.4	23.4	25.7	13	25.4	28.5	32.1
5–11 May	729	18.2	22.1	24.7	36	14.7	20.8	24.5	33	25.4	29.2	35.3
12–18 May	468	19.4	23.2	26.1	27	21.0	24.9	31.9	24	28.3	32.6	38.0
19–25 May	146	20.4	23.4	28.3	5	18.5	20.2	28.4	4	28.5	32.0	35.8

Date at Lower Granite Dam	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
24–30 Mar	135	7.3	8.8	11.5	52	11.8	13.3	15.8
31 Mar–6 Apr	397	8.2	10.0	12.5	185	13.7	15.2	17.6
7–13 Apr	149	9.9	11.6	15.9	73	16.0	17.9	20.7
14–20 Apr	403	12.5	16.5	19.7	202	19.8	24.0	27.0
21–27 Apr	1309	17.9	21.2	23.9	593	24.7	29.7	33.7
28 Apr–4 May	291	20.0	23.7	26.8	192	28.2	31.4	35.6
5–11 May	535	23.7	26.8	30.4	415	33.2	37.0	39.6
12–18 May	364	25.9	29.0	30.9	210	34.9	38.9	42.6
19–25 May	87	23.6	27.6	32.0	50	34.9	38.7	44.1

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, 2015.

Date at McNary Dam	Hatchery and wild yearling Chinook salmon from McNary Dam											
	McNary to John Day Dam				John Day to Bonneville Dam				McNary to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%	N	20%	Median	80%
	Travel time (d)											
7–13 Apr	9	4.3	5.8	7.6	1	3.3	3.3	3.3	3	7.0	7.1	9
14–20 Apr	11	4.9	5.5	7.0	3	2.5	3.0	3.1	16	7.2	8.6	11.2
21–27 Apr	51	4.8	6.3	7.2	5	2.1	2.2	2.4	180	6.2	7.1	8.2
28 Apr–4 May	110	3.9	4.6	5.7	9	1.8	2.0	2.1	679	5.0	5.7	6.5
5–11 May	294	3.6	4.5	5.5	47	1.7	1.8	1.9	1,029	4.9	5.7	6.6
12–18 May	277	3.4	4.0	4.7	52	1.6	1.8	1.9	1,064	4.5	4.9	5.7
19–25 May	169	3.3	3.7	4.3	24	1.4	1.6	1.8	453	4.1	4.5	5.2
26 May–1 Jun	11	3.5	3.7	5.4	1	1.8	1.8	1.8	50	3.9	4.2	5
2–8 Jun	10	3.6	4.2	5.3	1	1.4	1.4	1.4	12	4.1	4.5	5
	Migration rate (km/d)											
13–19 Apr	9	16.2	21.1	28.3	1	34.3	34.3	34.3	3	26.3	33.2	33.5
20–26 Apr	11	17.6	22.5	25.2	3	36.9	38.3	45.9	16	21.1	27.3	33.0
27 Apr–3 May	51	17.0	19.5	25.9	5	47.3	50.2	53.8	180	29.0	33.4	38.1
4–10 May	110	21.5	26.9	31.7	9	54.3	57.9	61.1	679	36.5	41.5	47.0
11–17 May	294	22.3	27.4	34.4	47	58.2	62.4	66.9	1,029	35.8	41.6	48.2
18–24 May	277	26.1	30.9	36.3	52	60.1	64.2	68.9	1,064	41.1	48.0	52.3
25–31 May	169	28.5	33.2	37.6	24	63.1	69.8	77.9	453	45.6	51.9	57.1
1–7 Jun	11	22.9	33.0	35.4	1	64.2	64.2	64.2	50	47.4	55.5	60.4
8–14 Jun	10	23.0	29.6	33.7	1	79.0	79.0	79.0	12	46.9	52.2	57.1
15–21 Jun	9	16.2	21.1	28.3	1	34.3	34.3	34.3	3	26.3	33.2	33.5

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, 2015.

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%
24–30 Mar	17	3.3	3.8	4.2	6	1.8	2.0	2.2	1	4.7	4.7	4.7
31 Mar–6 Apr	368	3.1	3.9	5.9	10	1.9	2.3	2.8	1	5.2	5.2	5.2
7–13 Apr	154	3.2	4.2	6.6	1	7.7	7.7	7.7	1	4.6	4.6	4.6
14–20 Apr	232	3.0	3.5	4.9	3	3.5	4.5	6.4	3	5.4	5.5	5.9
21–27 Apr	782	2.9	3.5	4.5	23	2.2	2.8	3.5	36	3.9	4.6	5.7
28 Apr–4 May	561	2.1	2.8	3.2	19	1.6	2.0	2.7	30	3.6	4.5	5.2
5–11 May	1277	1.9	2.0	2.2	42	1.7	2.3	3.0	27	3.7	4.2	5.4
12–18 May	811	2.0	2.1	2.8	25	1.1	1.6	2.0	22	2.8	3.1	3.9
19–25 May	828	1.9	2.0	2.2	12	1.4	1.7	2.4	14	2.7	3.0	3.5
26 May–1 Jun	292	1.9	2.0	2.3	9	1.3	2.1	2.4	2	2.9	3.3	3.7
2–8 Jun	82	1.9	2.1	3.0	1	3.0	3.0	3.0	0	NA	NA	NA
9–15 Jun	63	2.0	2.1	2.9	1	2.0	2.0	2.0	0	NA	NA	NA

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
24–30 Mar	5	10.8	11.9	13.7	4	16.8	20.4	24.2
31 Mar–6 Apr	89	10.8	16.2	20.5	125	19.9	23.5	30.8
7–13 Apr	55	12.0	15.2	20.1	118	16.8	20.2	25.5
14–20 Apr	202	8.5	10.2	12.6	505	13.2	15.4	17.9
21–27 Apr	414	9.2	10.4	12.0	1329	13.3	14.8	16.8
28 Apr–4 May	494	7.5	8.3	9.5	965	12.0	13.3	14.7
5–11 May	574	7.2	8.1	9.2	842	11.3	12.5	13.8
12–18 May	407	6.6	7.2	8.2	916	10.5	11.4	12.7
19–25 May	356	6.0	6.3	7.2	692	9.3	9.9	10.9
26 May–1 Jun	86	6.2	7.2	8.2	100	9.8	10.9	12.4
2–8 Jun	49	6.2	7.2	8.7	18	9.6	11.1	14.9
9–15 Jun	26	7.0	8.1	12.2	122	10.8	11.9	13.3

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, 2015.

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%
24–30 Mar	17	14.3	16.0	18.0	6	21.1	23.4	25.7	1	25.1	25.1	25.1
31 Mar–6 Apr	368	10.1	15.5	19.5	10	16.2	20.1	23.7	1	22.9	22.9	22.9
7–13 Apr	154	9.1	14.4	18.6	1	6.0	6.0	6.0	1	25.9	25.9	25.9
14–20 Apr	232	12.2	17.1	20.1	3	7.2	10.3	13.2	3	20.1	21.6	22.1
21–27 Apr	782	13.2	17.3	20.4	23	13.0	16.7	20.6	36	20.9	25.8	30.2
28 Apr–4 May	561	19.0	21.7	28.6	19	17.1	22.5	27.9	30	22.7	26.5	32.9
5–11 May	1277	26.7	29.3	31.2	42	15.5	20.1	26.4	27	22.0	28.1	31.8
12–18 May	811	21.1	28.3	30.8	25	23.0	28.4	40.0	22	30.6	38.8	41.8
19–25 May	828	27.1	29.4	30.9	12	19.2	27.4	33.6	14	33.5	39.3	44.7
26 May–1 Jun	292	26.2	29.3	31.2	9	19.0	22.3	35.9	2	32.3	36.3	41.3
2–8 Jun	82	19.7	28.2	31.4	1	15.1	15.1	15.1	0	NA	NA	NA
9–15 Jun	63	20.9	28.4	30.8	1	22.7	22.7	22.7	0	NA	NA	NA

	Lower Granite to McNary Dam				Lower Granite to Bonneville Dam			
	N	20%	Median	80%	N	20%	Median	80%
24–30 Mar	5	16.4	18.9	20.8	4	19.1	22.6	27.4
31 Mar–6 Apr	89	11.0	13.9	20.8	125	15.0	19.6	23.2
7–13 Apr	55	11.2	14.8	18.7	118	18.1	22.8	27.4
14–20 Apr	202	17.9	22.0	26.5	505	25.8	29.8	34.8
21–27 Apr	414	18.8	21.7	24.5	1329	27.4	31.1	34.6
28 Apr–4 May	494	23.6	27.0	30.2	965	31.4	34.7	38.4
5–11 May	574	24.5	27.8	31.4	842	33.4	36.9	40.7
12–18 May	407	27.4	31.2	33.9	916	36.3	40.4	44.0
19–25 May	356	31.3	35.9	37.4	692	42.1	46.6	49.5
26 May–1 Jun	86	27.4	31.3	36.2	100	37.3	42.3	47.1
2–8 Jun	49	26.0	31.1	36.2	18	30.8	41.5	47.8
9–15 Jun	26	18.4	28.0	32.3	122	34.6	38.7	42.7

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, 2015.

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)												
7 Apr–13 Apr	4	3.9	4.1	4.7	0	NA	NA	NA	6	5.6	6.9	7.5
14 Apr–20 Apr	7	4.2	4.8	5.8	3	2.2	2.2	2.5	19	6.6	7.4	8.1
21 Apr–27 Apr	15	3.6	4.6	6.3	6	2.0	2.3	2.5	144	5.5	5.9	6.9
28 Apr–4 May	28	3.1	3.7	4.7	8	1.8	2.0	2.2	314	4.8	5.2	5.8
5 May–11 May	49	3.3	3.9	4.6	10	1.9	2.1	2.8	650	4.9	5.4	5.9
12 May–18 May	97	3.3	3.5	4.3	32	1.6	1.7	1.9	790	4.4	4.8	5.3
19 May–25 May	55	3.1	3.5	4.0	19	1.6	1.7	1.9	636	4.0	4.6	5.2
26 May–1 Jun	14	2.6	3.2	3.5	5	1.4	1.6	1.8	218	3.9	4.4	4.9
2 Jun–8 Jun	3	3.5	4.4	5.0	0	NA	NA	NA	33	3.9	4.3	5.3
9 Jun–15 Jun	1	3.3	3.3	3.3	0	NA	NA	NA	16	4.3	4.9	5.5
16 Jun–22 Jun	0	NA	NA	NA	0	NA	NA	NA	19	4.4	4.8	5.9
Migration rate (km/d)												
7 Apr–13 Apr	4	26.0	30.1	31.2	0	NA	NA	NA	6	31.5	34.3	42.3
14 Apr–20 Apr	7	21.1	25.6	29.1	3	45.6	51.8	52.3	19	29.0	32.1	35.9
21 Apr–27 Apr	15	19.6	26.9	33.9	6	46.1	48.9	55.7	144	34.4	40.3	43.2
28 Apr–4 May	28	26.3	33.6	39.5	8	51.8	56.8	64.2	314	40.3	45.2	48.8
5 May–11 May	49	26.5	31.9	36.8	10	40.9	52.8	60.8	650	39.7	43.5	48.5
12 May–18 May	97	28.5	35.1	37.4	32	59.8	65.7	72.4	790	44.5	49.4	54.0
19 May–25 May	55	30.5	35.4	39.2	19	60.4	67.7	72.4	636	45.8	51.4	59.4
26 May–1 Jun	14	35.2	38.3	46.8	5	62.8	69.3	79.0	218	48.3	53.3	60.8
2 Jun–8 Jun	3	24.7	28.0	34.7	0	NA	NA	NA	33	44.5	54.5	60.4
9 Jun–15 Jun	1	37.6	37.6	37.6	0	NA	NA	NA	16	42.8	48.0	54.8
16 Jun–22 Jun	0	NA	NA	NA	0	NA	NA	NA	19	40.1	48.8	53.5

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 percentage transported for the season.

Results

In 2015, collection for transportation began on 1 May at Lower Granite, Little Goose, and Lower Monumental Dams, and the first barge operated on 2 May at each of those 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 2015 season were 11.4% for wild and 13.6% for hatchery smolts. For non-tagged steelhead, estimated percentages transported were 12.4% for wild and 13.9% for hatchery smolts.

These estimates were by far the lowest recorded in our time series of estimates (1993-2015; Figure 6; Table 23). 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.

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 2015.

By the time collection for transportation began at Lower Granite Dam on 1 May 2015, about 58% of wild yearling Chinook, 58% of hatchery yearling Chinook, 48% of steelhead (hatchery and wild combined) had already passed the dam. During general transportation operations, we estimated that approximately 25% of wild yearling Chinook, 30% of hatchery Chinook smolts that arrived at Lower Granite Dam were transported, either from Lower Granite or from a downstream collector dam.

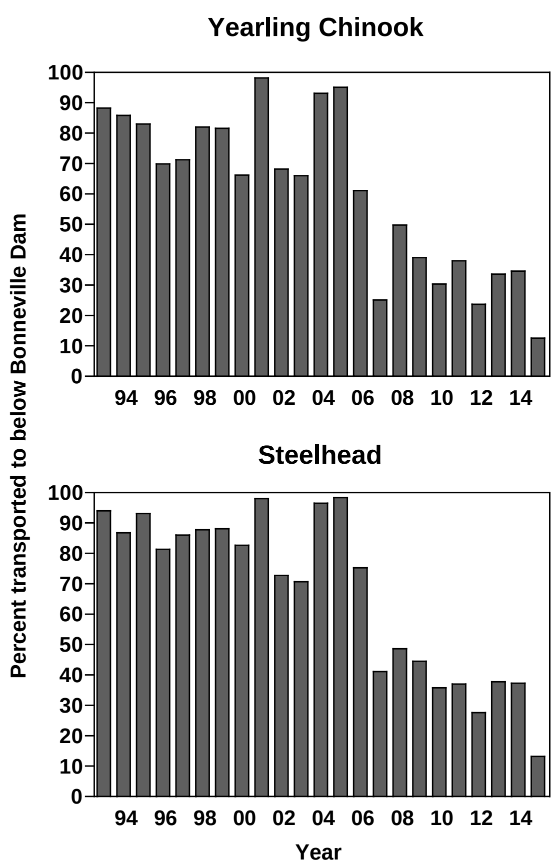

Figure 6. Estimated percent of yearling Chinook salmon and steelhead (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2015).

Table 23. Annual estimated percentages of migrating Snake River yearling Chinook salmon and steelhead that were transported (1993-2015). 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
Mean 1993-2015	**59.4**	**62.1**	**60.7**	**66.1**	**67.2**	**66.7**
Mean 1993-2006	**77.6**	**80.9**	**79.3**	**85.9**	**87.1**	**86.5**
Mean 2007-2015	**31.1**	**32.7**	**31.9**	**35.4**	**36.3**	**35.8**

For steelhead, we did not have sufficient data to estimate separate percentages of transported hatchery vs. wild fish. For hatchery and wild steelhead combined, we estimated that 24% of fish passing after 1 May were transported.

For both yearling Chinook salmon and steelhead, a smaller percentage of the total run passed before transportation began in 2015 than in 2014. Nevertheless, a lower percentage was transported after the program began in 2015 than in 2014. Resulting overall percentages transported in 2015 were much lower than those in 2014.

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.

Therefore, when considering the implications of in-river survival probability for populations of Snake River salmonids, it is important to remember that a significant proportion of fish may have been transported. In each year from 1993 to 2006, well over one-half the population at large was typically transported. In recent years, with the exception of 2015, the transported percentage has been closer to 30-40%. Our estimates of reach survival probability pertain *only* to fish that remained in the river during their entire migration through that reach; survival of transported fish is affected by entirely different factors.

Comparisons of Annual Survival Estimates

Comparison Among Years

We made two types of comparisons among annual survival estimates from 2015 and those obtained during the previous 22 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 esimtates of overall seasonal survival through specific reaches during 2015 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 2015 was similar to esimates from recent years. Mean survival was higher than the long-term mean for fish from some hatcheries and lower for fish from others (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 relationhip is illustrated for hatchery yearling Chinook salmon in Figure 7 (R^2 = 0.818, P = 0.005).

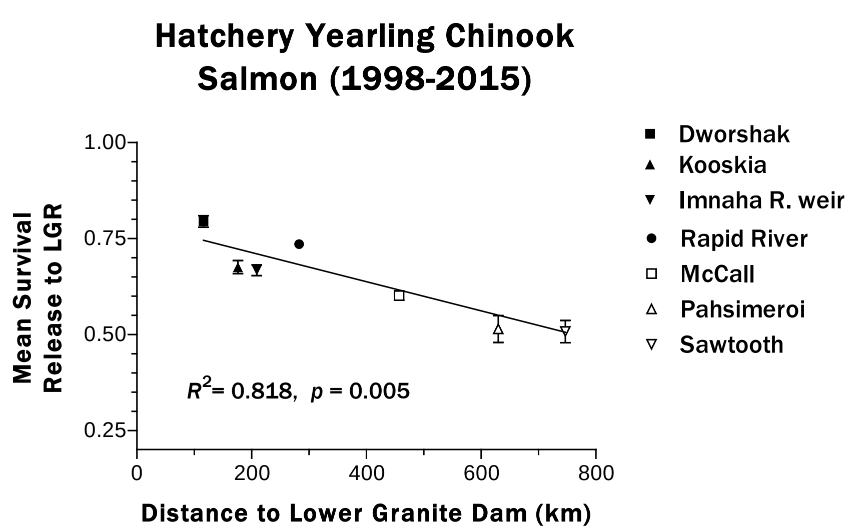

Figure 7. Estimated survival from release at Snake River Basin hatcheries to Lower Granite Dam tailrace, 1998-2015 vs. distance (km) to Lower Granite Dam. The squared correlation between survival and migration distance is also shown, along with a P-value for a test of the null hypothesis of zero correlation. Whiskers show standard errors.

Table 24. Estimated survival for yearling Chinook salmon from selected Snake River Basin hatcheries to the tailrace of Lower Granite Dam, 1993-2015. 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)
Mean	**0.778 (0.015)**	**0.667 (0.018)**	**0.659 (0.011)**	**0.705 (0.020)**	**0.591 (0.015)**	**0.518 (0.033)**	**0.455 (0.034)**	**0.625 (0.012)**

***** Released at Imnaha River Weir.

For combined wild and hatchery yearling Chinook salmon in 2015, mean estimated survival was 0.680 (95% CI 0.611-0.749) from Lower Granite to McNary Dam and 0.629 (0.545-0.713) from McNary to Bonneville Dam (Tables 25-26; Figures 8-9). For both reaches, the 2015 estimates were most similar to those in 2004.

For these fish, mean estimated survival through the entire hydrosystem from the Snake River Trap to Bonneville Dam was 0.389 (0.281-0.497) in 2015 (Table 26). This estimate was lower than either the 18-year mean from 1997 to 2015 (0.494) or the mean estimate from 2014 (0.497). However, the difference between estimates in 2014 and 2105 was not significant ($P = 0.25$).

For wild yearling Chinook salmon in 2015, mean estimated survival was below the long-term average (0.721) from Lower Granite to McNary Dam, at 0.524 (95% CI 0.424-0.624), but was above the long-term average (0.672) from McNary to Bonneville Dam, at 0.843 (0.635-1.051; Table 27). For these wild fish, mean estimated survival through the entire hydrosystem was below the long-term average of 0.446 and was among the lowest of our time series, at 0.383 (0.179-0.587).

Steelhead—For combined wild and hatchery steelhead, mean estimated survival was 0.628 (95% CI 0.563-0.693) from Lower Granite to McNary Dam and 0.663 (0.587-0.739) from McNary to Bonneville Dam in 2015 (Tables 28-29; Figures 8-9). These estimates were both lower than the respective long-term average for each reach and lower than the corresponding estimate for each reach in 2014. Estimated survival through the entire hydrosystem was also lower than either the long-term average (0.448) or corresponding estimate in 2014 (0.771) for these steelhead, at 0.364 (0.297-0.431; Table 29). The difference between estimates in 2014 and 2015 was statistically significant ($P < 0.001$).

For wild steelhead, mean estimated survival from Lower Granite to McNary Dam was below the long-term average (0.634) in 2015, at 0.572 (0.474-0.670; Table 30). Estimated survival from McNary to Bonneville Dam was also below the long-term average for these fish (0.637), at 0.608 (0.508-0.708). For these wild steelhead, mean estimated survival through the entire hydrosystem was 0.383 (0.179-0.587), which was also below the long-term average of 0.412 at 0.301 (0.182-0.420).

Table 25. Annual weighted mean survival probability estimates for yearling Chinook salmon (hatchery and wild combined), 1995–2015 with standard errors. Shaded columns are reaches that comprise two dams and reservoirs (i.e., two projects) for which 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 (1993-2015).

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			
1996	0.977 (0.025)	0.926 (0.006)	0.929 (0.011)	0.756 (0.033)	0.870			
1997	NA	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.893			
1998	0.924 (0.009)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)		
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
Mean	**0.932 (0.009)**	**0.924 (0.008)**	**0.923 (0.010)**	**0.861 (0.013)**	**0.927 (0.007)**	**0.876 (0.019)**	**0.802 (0.027)**	**0.893 (0.016)**

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), 1997–2015. Standard errors in parentheses. Simple arithmetic means are given.

	Annual survival estimates for hatchery and wild yearling Chinook (SE)				
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
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)
Mean	**0.931 (0.009)**	**0.735 (0.013)**	**0.705 (0.022)**	**0.528 (0.023)**	**0.494 (0.021)**

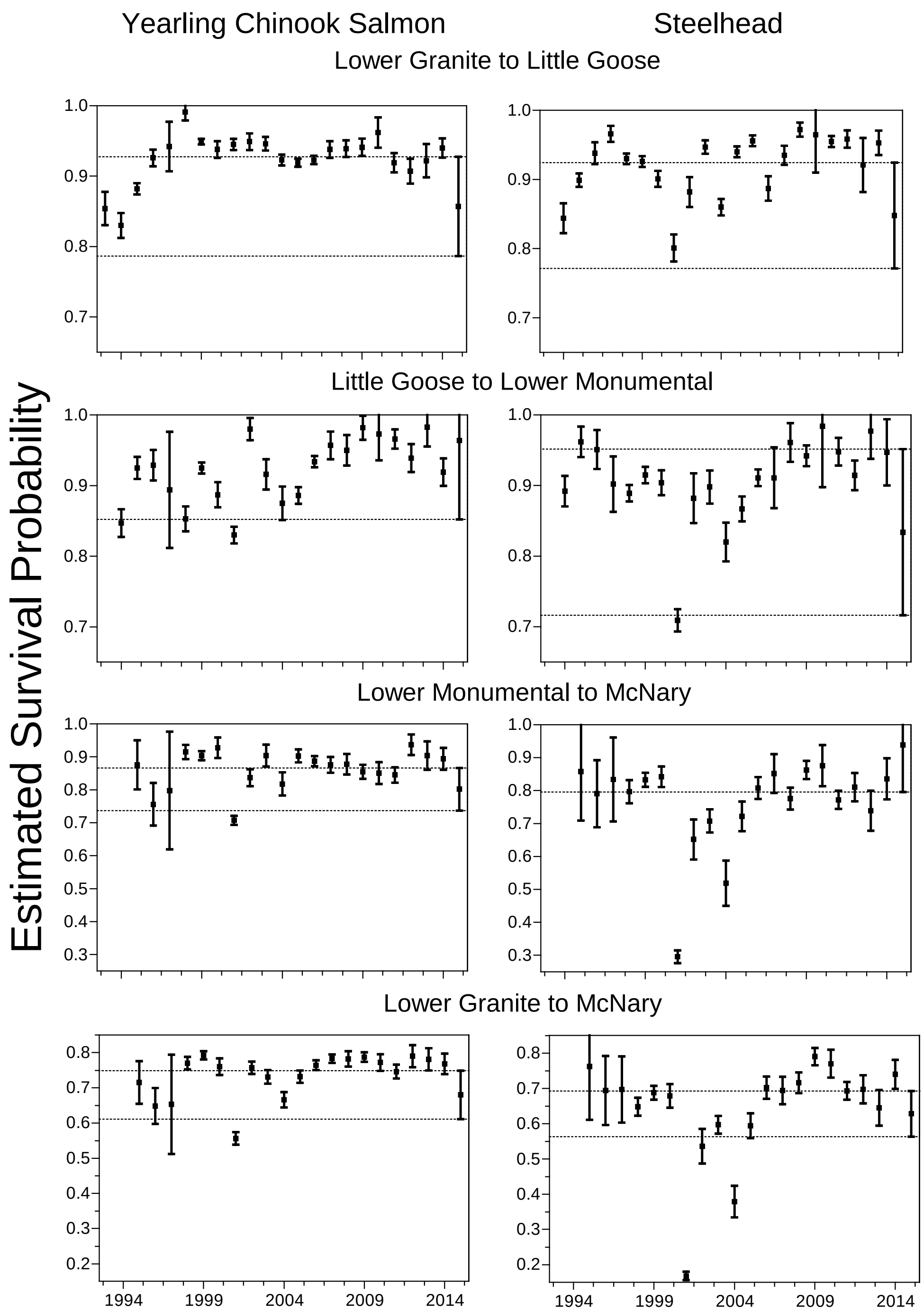

Figure 8. Annual average survival estimates for PIT-tagged yearling Chinook salmon and steelhead (hatchery and wild combined) through Snake River reaches, 1993-2015. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2015 estimates.

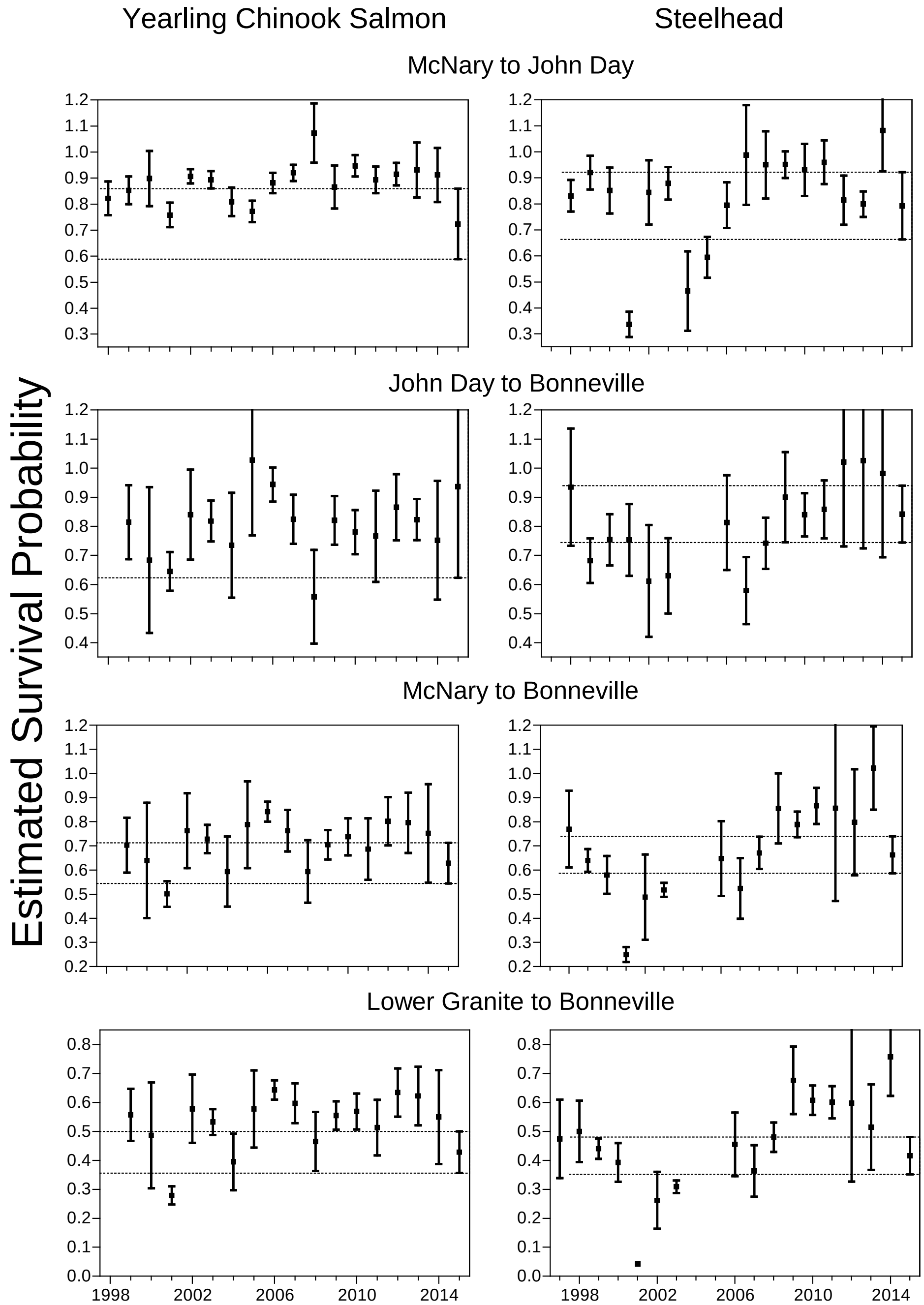

Figure 9. Annual average survival estimates for PIT-tagged Snake River yearling Chinook salmon and steelhead (hatchery and wild combined) through Columbia River reaches and from Lower Granite Dam to Bonneville Dam, 1993-2015. Estimates are from tailrace to tailrace. Whiskers represent 95% CIs. Horizontal dashed lines are 95% CI endpoints for 2015 estimates.

Table 27. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling Chinook salmon (wild only) 1999–2015. Standard errors in parentheses. Simple arithmetic means are given.

	Annual survival estimates for wild yearling Chinook				
Year	Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
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)
Mean	**0.916 (0.013)**	**0.721 (0.021)**	**0.672 (0.034)**	**0.487 (0.029)**	**0.446 (0.028)**

Table 28. Annual weighted means of survival probability estimates for steelhead (hatchery and wild combined), 1995–2015. 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 (1993–2015) 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			
1996	0.951 (0.015)	0.938 (0.008)	0.951 (0.014)	0.791 (0.052)	0.889			
1997	0.964 (0.015)	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.913			
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
Mean	**0.948 (0.011)**	**0.917 (0.010)**	**0.905 (0.013)**	**0.768 (0.030)**	**0.872 (0.020)**	**0.821 (0.044)**	**0.811 (0.035)**	**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), 1997–2015. Standard errors in parentheses; simple arithmetic means are given.

	Annual survival estimates for hatchery and wild steelhead				
Year	Snake River Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
1997	1.020 (0.023)	0.728 (0.053)	0.651 (0.082)	0.474 (0.069)	0.484 (0.072)
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)
Mean	**0.951 (0.012)**	**0.644 (0.031)**	**0.682 (0.044)**	**0.464 (0.041)**	**0.451 (0.043)**

Table 30. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River steelhead (wild only), 1999–2015. Standard errors in parentheses; simple arithmetic means are given.

	Annual survival estimates for wild steelhead				
Year	Snake River Trap to Lower Granite Dam	Lower Granite to McNary Dam	McNary to Bonneville Dam	Lower Granite to Bonneville Dam	Trap to Bonneville Dam
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)
Mean	**0.963 (0.014)**	**0.630 (0.038)**	**0.637 (0.051)**	**0.428 (0.041)**	**0.412 (0.042)**

Sockeye Salmon—For pooled groups of wild and hatchery sockeye salmon, estimated survival from Lower Granite to McNary Dam was 0.702 in 2015 (95% CI 0.604-0.816; Table 31). This estimate was lower than in 2014 but higher than the average of 0.635 for 1996-2015. For these fish, estimated survival from Lower Granite to Bonneville Dam was 0.373 (0.307-0.453) in 2015. This estimate was among the lowest of our time series through this reach, and was below the 1996-2015 average of 0.424.

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, 1996–2015. 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)
Mean	**0.635 (0.039)**	**0.580 (0.075)**	**0.424 (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)
Mean	**0.663 (0.034)**	**0.741 (0.087)**	**0.506 (0.062)**

Upper Columbia River Stocks

Sockeye Salmon—For Upper Columbia River sockeye salmon captured, tagged, and released to the tailrace of Rock Island Dam in 2015, estimated survival to McNary tailrace was 0.763 (95% CI 0.481-1.210; Table 31). This estimate was higher than both the long-term average of 0.663 and the 2014 estimate of 0.428. Estimated survival of sockeye from Rock Island to Bonneville Dam was 0.340 (0.165-0.701). This estimate was among the lowest we have seen for these fish and was well below the mean of 0.506.

Yearling Chinook Salmon—For pooled groups of yearling Chinook from Upper Columbia River hatcheries, estimated survival from McNary tailrace to Bonneville tailrace was 0.870 (0.757-1.000). This estimate was higher the 1999-2015 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 2015 was 0.570 (0.492-0.661). This estimate was again imprecise due to low and variable detection rates at Lower Columbia River dams (Table 32).

Table 32. Mean estimated survival and standard error (SE) through the lower Columbia River for hatchery yearling Chinook salmon (1999–2015) and steelhead (2003–2015) 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)
Mean	**0.552 (0.012)**	**0.904 (0.026)**	**0.887 (0.048)**	**0.809 (0.036)**
		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)
Mean	**0.418 (0.017)**	**0.905 (0.035)**	**0.843 (0.057)**	**0.750 (0.043)**

Comparison Among Snake and Columbia River Stocks

In 2015, estimated survival from McNary to Bonneville tailrace was lower for hatchery and wild spring/summer Chinook originating in the Snake River (0.629; 95% CI 0.555-0.713) than for those originating in the Upper Columbia River Basin (0.816; 0.722-0.922; Table 33), and the difference was statistically significant ($P = 0.005$).

In contrast, for hatchery and wild steelhead migrating in this same reach during 2015, estimated survival was higher for Snake (0.663; 0.587-0.739) than for Upper Columbia River fish (0.548; 0.484-0.621), and the difference was statistically significant ($P = 0.03$).

For hatchery and wild sockeye salmon, estimated survival from McNary to Bonneville tailrace was lower for stocks originating in the Snake (0.531; 0.349-0.808) than in the Upper Columbia River Basin (0.699; 0.482-1.014). However, estimates for fish from both basins were very imprecise, and the difference was not statistically significant ($P = 0.41$).

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 2015. 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	32,129	0.724 (0.069)	0.937 (0.160)	0.629 (0.043)
Upper Columbia Chinook	Upper Columbia sites[a]	198,380	0.857 (0.040)	0.952 (0.067)	0.816 (0.051)
Upper Columbia Chinook	Yakima River sites[b]	57,445	0.850 (0.081)	0.572 (0.096)	0.486 (0.073)
Upper Columbia Coho	Upper Columbia sites	60,831	0.746 (0.064)	0.902 (0.102)	0.673 (0.068)
Upper Columbia Coho	Yakima River sites	16,271	1.023 (0.219)	.	.
Snake River Sockeye	Snake River sites[c]	103,189	0.701 (0.056)	0.757 (0.078)	0.531 (0.151)
Upper Columbia Sockeye	Upper Columbia sites	12,889	0.840 (0.138)	0.832 (0.184)	0.699 (0.134)
Snake River Steelhead	McNary Dam Tailrace	12,301	0.792 (0.066)	0.842 (0.050)	0.663 (0.039)
Upper Columbia Steelhead	Upper Columbia sites	74,084	0.720 (0.058)	0.761 (0.063)	0.548 (0.035)

[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, estimated survival through the entire hydrosystem from the Snake River Trap to Bonneville tailrace was 38.9%, in 2015. This estimate was the third lowest among 17 years of observations (1999-2015) and was below the long-term average of 49.4%. The 2015 estimate was also lower than the 2014 estimate of 49.7%, but the difference was not significant ($P = 0.29$; Table 27).

For these combined groups of yearling Chinook, estimated survival in 2105 was below average, both from Lower Granite to McNary and from McNary to Bonneville. Survival through the hydropower system has remained relatively stable for these fish since 1999, with the exception of lower estimates in 2001, 2004, and 2015, which were all low-flow years.

For combined hatchery and wild Snake River steelhead, estimated survival through the entire hydropower system was 36.4% in 2015. This estimate was below the long-term mean of 45.1% and was the fourth lowest estimate in our time series (1997-2015; Table 29). For these combined steelhead stocks, estimated survival was significantly different between 2014 and 2015 (77.1 vs. 36.4%), with the latter estimate less than half of the former ($P < 0.001$; Table 29). Estimated survival for steelhead was below average both from Lower Granite to McNary and from McNary to Bonneville.

For Snake River sockeye salmon, estimated survival from Lower Granite to Bonneville tailrace was 37.3% in 2015. This estimate was lower than average, but there have been five lower estimates over our time series for sockeye through that reach. For sockeye originating in the Upper Columbia Basin, estimated survival between Rock Island and Bonneville Dam was 34.0%. For stocks from both basins, estimated survival from McNary to Bonneville was below average and contributed most to the low combined survival from respective upstream sites.

Lower survival estimates for yearling Chinook, steelhead, and sockeye occurred in the context of extreme environmental conditions and unusual operating conditions in 2015. Conditions in the Snake River during spring 2015 were unlike those of any other year in our time series.

Water temperatures and spill percentages reached record highs, while flows remained at near-record lows. By comparison, 2015 was most like 1994, 2001, and 2007 in terms of flow and most like 2008 and 2010 in terms of spill. In terms of water temperature, there was no year comparable to 2015 in our time series. Water was extremely warm in May, with temperatures exceeding the average by 2°C in the third week and by 4°C at the end of the month (see Appendix Figure C1).

For both yearling Chinook salmon and steelhead, travel times between Lower Granite and Bonneville Dam were longer in 2015 than in 2008-2014, but still shorter than the long-term average (1998-2015) and shorter than in most other low-flow years. The main difference between conditions in 2015 and those in low-flow years such as 2001 and 2004 was that the earlier years had extended periods with no spill, and most dams had limited surface-passage structures or none at all.

During low-flow conditions, even small amounts of spill, especially near the surface, can be attractive to smolts looking for a passage route. Migrating smolts are naturally surface orientated, so passage routes that require sounding to a greater depth can be a behavioral barrier to passage. When spill is shut off completely, fish delay passage because the only route available is through powerhouse intake bays, and entrances to these bays are located at depths of 20 m or more. In contrast, entrances to normal spillways are situated at depths of only about 10 m. These entrances can also be accessed via spillway weirs, which entrain the top 1-2 m of surface flow.

With the addition of a temporary spillway weir (TSW) at Little Goose Dam in 2009, all eight mainstem dams encountered by migrating Snake River smolts have some form of surface-passage structure. These include removable spillway weirs (RSWs) at Lower Granite, Lower Monumental, and Ice Harbor Dam; TSWs at Little Goose, McNary, and John Day Dam, the ice-trash sluiceway at The Dalles Dam, and the corner collector at Bonneville Dam.

Operation of surface-passage structures can have direct positive effects on survival, as well as indirect positive effects associated with decreased travel times. Passage survival estimates through surface-passage structures have often been similar to those through juvenile bypass systems or unaltered spillways. However, surface-passage structures provide an advantage by reducing forebay delay. For migrating smolts, less time spent in the reservoir and forebay of a dam means decreased travel time and potentially reduced exposure to predators.

Decreased forebay delay and overall shortened travel times also 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.

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). Temperatures in May 2015 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 (about 500 breeding pairs annually on average in the last 10 years), as well as 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, active dissuasion measures were employed on the Crescent Island Caspian tern colony; these efforts resulted in no nesting pairs 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). Populations were not monitored at all of the relocation sites, so the degree to which the dissuation measures reduced overall predation pressure on salmonids is not known.

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.

We have complied an index of the percentages of PIT-tags detected at Lower Monumental Dam and subsequently detected on bird colonies (Table 34). Based on this index, the estimated proportion 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, expanded use of surface passage at Snake River dams (all 4 dams since 2009), and delayed initiation of the smolt transportation program.

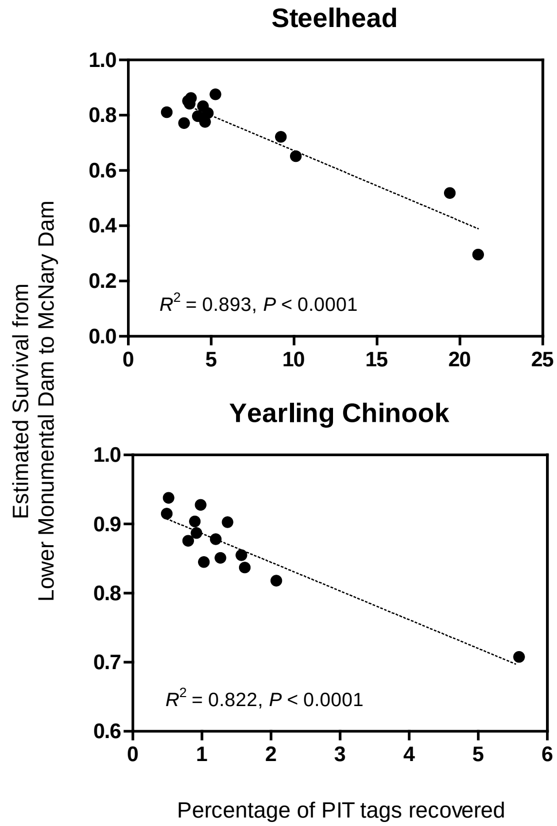

Figure 10. Estimated survival between Lower Monumental and McNary Dams vs. percentage of Lower Monumental Dam-detected PIT tags recovered on bird colonies, 1998-2012 (excluding 2003, which had incomplete recovery effort).

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2015 were by far the lowest of our 23-year time series. This was due to the earlier run timing of both species in relation to transportation start dates and partly due to the very low collection probabilities at collector dams during transportation operations.

Approximately 60% of yearling Chinook and 50% of steelhead had passed Lower Granite Dam before collection started on 1 May. Among fish that passed during transport operations, approximately 25% of each species was transported. For both species, a larger proportion of the total run passed before transportation began in 2014 than in 2015, but in 2015, a smaller proportion was transported after the program began. As a result, the overall percentages transported in 2015 were much lower than those in 2014.

An extremely low percentage of PIT-tagged fish entered juvenile bypass systems at several dams in 2015, resulting in very low detection probabilities. In fact, mean detection probabilities in 2015 were the lowest we have ever recorded at all detection sites except Bonneville Dam (Figures 11 and 12).

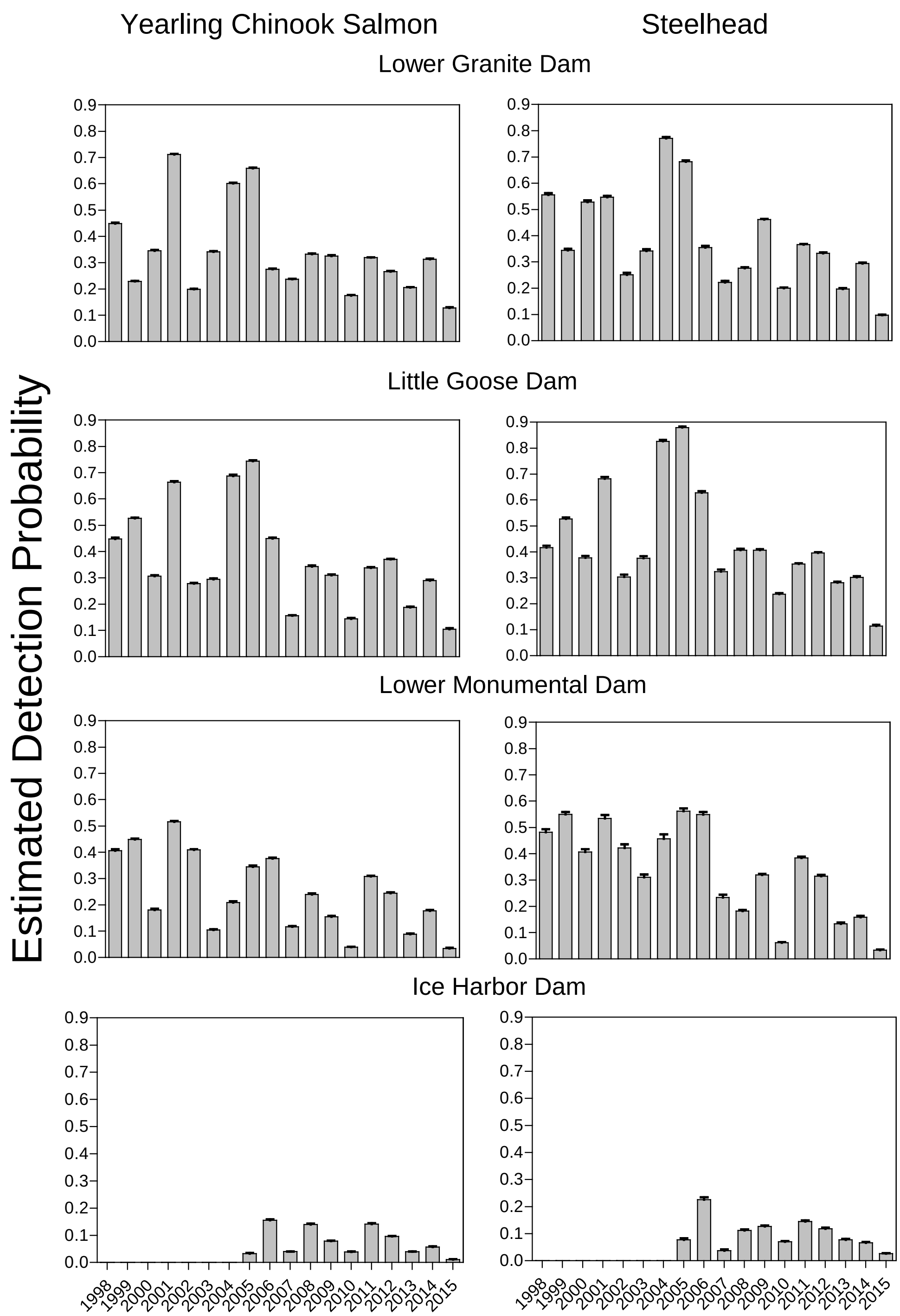

Figure 11. Annual average detection probability estimates at Snake River dams for PIT-tagged yearling Chinook salmon and steelhead, hatchery and wild fish combined. Whiskers represent 95% confidence intervals.

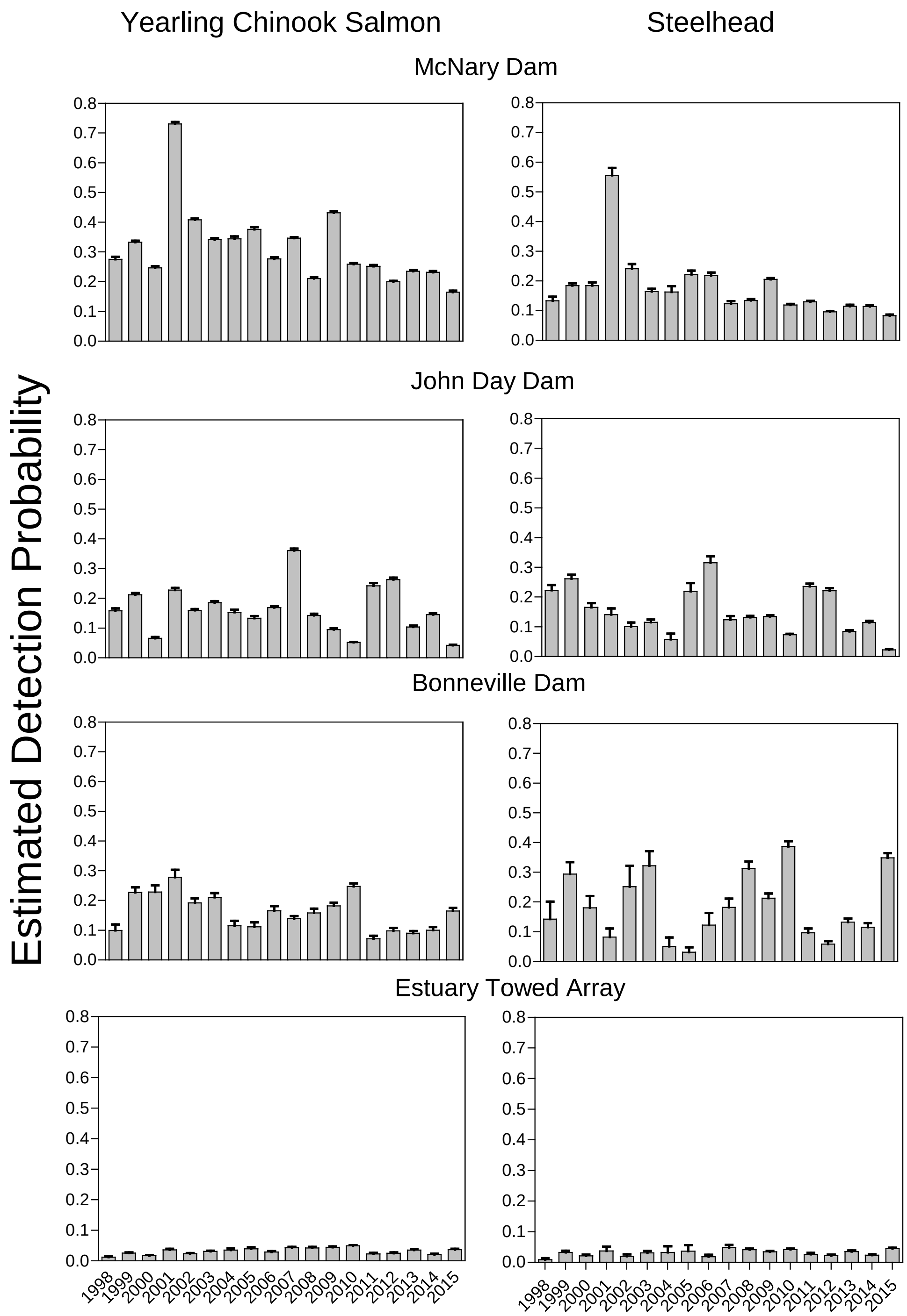

Figure 12. Annual average detection probability estimates at Columbia River dams and the towed estuary array for PIT-tagged yearling Chinook salmon and steelhead, hatchery and wild fish combined. Whiskers represent 95% confidence intervals.

Detection probabilities at dams have been lower in general since programs were instituted in 2007 to encourage spillway passage using increased spill and surface-passage structures at most dams. 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 very few fish 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, for which 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.

At a fixed detection rate, precision in survival estimates can be increased only by increasing the number of tagged fish released 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 increased spill for surface 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 when 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 and not likely to be increased substantially in the future.

The ability to estimate survival to Bonneville Dam would be greatly improved if a detection method superior to the paired trawl could be developed for use in open water. 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 a valuable research tool that yields a great deal of important information that cannot be obtained by any other tagging method. For example, the PIT-tag allows continuous monitoring of large fish groups through both their juvenile and adult migrations. 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 in 2013 (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 df = 1	Detected at Trawl 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 2015 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 9 weekly groups of yearling Chinook salmon. For these, the overall sum of the χ^2 test statistics was significant 1 time (11%). For 9 steelhead groups, the overall test was significant 5 times (56%). Counting all individual component tests (i.e., 2.C2, 3.SR3, etc.), 3 tests of 39 (8%) were significant for yearling Chinook salmon and 10 of 39 (26%) were significant for steelhead (Appendix Tables A1-A3). There is a 31% chance of 3 or more tests out of 39 being significant if the true $\alpha = 0.05$, but there is just a 0.002% chance of 10 or more significant tests out of 39. This provides evidence that the results for Chinook are not unexpected, but those for steelhead indicate a significant number of assumption violations.

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, 11 of the 13 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, but the pattern was not consistent. For both species, half of their respective significant Test 2 results showed that detected fish were more likely to be detected again than their cohorts that were not previously detected, and the other half of tests showed detected fish were less likely to be detected again.

For weekly groups from McNary Dam, there was one significant contingency table test result for yearling Chinook and none for steelhead (Appendix Tables A4-A6). Low detection probabilities led to reduced power of these tests to detect significant differences when present. Therefore, a lack of significant results does 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 2015, 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 adjacent 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, 2015.

		Species		
Test		Chinook	Steelhead	Total
Test 2.C2	Tests (n)	9	9	18
	Significant tests (n)	1	5	6
Test 2.C3	Tests (n)	9	9	18
	Significant tests (n)	1	4	5
Test 3.SR3	Tests (n)	8	7	15
	Significant tests (n)	0	1	1
Test 3.Sm3	Tests (n)	4	5	9
	Significant tests (n)	0	0	0
Test 3.SR4	Tests (n)	9	9	18
	Significant tests (n)	1	0	1
Test 2 sum	Tests (n)	9	9	18
	Significant tests (n)	2	5	7
Test 3 sum	Tests (n)	9	9	18
	Significant tests (n)	1	1	2
Test 2 + 3	Tests (n)	9	9	18
	Significant tests (n)	1	5	6

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 2015.

	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	6.02	0.421	5.65	0.130	4.68	0.096	0.97	0.325
30 Mar–5 Apr	3.60	0.608	1.98	0.576	1.73	0.422	0.26	0.614
6 Apr–12 Apr	4.02	0.546	2.38	0.498	2.34	0.310	0.04	0.853
13 Apr–19 Apr	1.85	0.933	0.36	0.949	0.14	0.932	0.22	0.643
20 Apr–26 Apr	15.06	**0.010**	8.37	**0.039**	8.25	**0.016**	0.12	0.728
27 Apr–3 May	3.12	0.681	1.23	0.746	1.19	0.552	0.04	0.838
4 May–10 May	9.04	0.171	8.53	**0.036**	4.23	0.121	4.30	**0.038**
11 May–17 May	2.24	0.897	0.70	0.873	0.69	0.709	0.02	0.904
18 May–24 May	3.77	0.438	1.34	0.720	0.46	0.797	0.89	0.347
Total (df)	48.71 (48)	0.444	30.53 (27)	0.291	23.69 (18)	0.165	6.84 (9)	0.654

	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	0.37	0.947	0.13	0.714	0.23	0.635	0.01	0.932
30 Mar–5 Apr	1.62	0.445	0.63	0.426	.	.	0.99	0.320
6 Apr–12 Apr	1.65	0.439	0.64	0.423	.	.	1.00	0.316
13 Apr–19 Apr	1.49	0.684	0.08	0.780	0.97	0.324	0.44	0.507
20 Apr–26 Apr	6.69	**0.035**	2.82	0.093	.	.	3.88	**0.049**
27 Apr–3 May	1.89	0.389	1.75	0.186	.	.	0.14	0.704
4 May–10 May	0.51	0.917	0.39	0.535	0.00	0.954	0.12	0.727
11 May–17 May	1.54	0.674	0.02	0.892	0.94	0.333	0.58	0.446
18 May–24 May	2.43	0.119	.	.	.	.	2.43	0.119
Total (df)	18.18 (21)	0.638	6.45 (8)	0.597	2.14 (4)	0.710	9.59 (9)	0.385

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 2015.

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	3.55	0.615	1.82	0.610	1.49	0.474	0.33	0.566
6 Apr–12 Apr	0.91	0.823	0.04	0.978	0.04	0.978	.	.
13 Apr–19 Apr	2.29	0.683	2.10	0.552	1.25	0.535	0.85	0.356
20 Apr–26 Apr	19.21	**0.004**	18.37	**0.000**	2.19	0.334	16.18	**0.000**
27 Apr–3 May	13.30	**0.039**	11.55	**0.009**	5.38	**0.068**	6.17	**0.013**
4 May–10 May	16.46	**0.011**	8.64	**0.035**	8.47	**0.014**	0.16	0.687
11 May–17 May	24.99	**0.000**	22.36	**0.000**	10.83	**0.004**	11.54	**0.001**
18 May–24 May	18.84	**0.004**	16.57	**0.001**	11.77	**0.003**	4.79	**0.029**
25 May–31 May	1.67	0.893	1.58	0.664	1.34	0.513	0.24	0.622
Total (df)	101.21 (47)	**<0.001**	83.03 (26)	**<0.001**	42.77 (18)	**<0.001**	40.26 (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	1.73	0.421	1.68	0.195	.	.	0.05	0.816
6 Apr–12 Apr	0.87	0.352	.	.	.	.	0.87	0.352
13 Apr–19 Apr	0.19	0.666	.	.	.	.	0.19	0.666
20 Apr–26 Apr	0.84	0.839	0.73	0.392	0.08	0.780	0.03	0.859
27 Apr–3 May	1.74	0.627	0.29	0.592	0.03	0.873	1.43	0.232
4 May–10 May	7.82	**0.050**	4.89	**0.027**	0.41	0.520	2.52	0.112
11 May–17 May	2.63	0.453	0.39	0.534	1.10	0.294	1.14	0.286
18 May–24 May	2.27	0.518	0.52	0.469	1.33	0.249	0.42	0.517
25 May–31 May	0.09	0.958	0.09	0.768	.	.	0.00	1.000
Total (df)	18.18 (21)	0.638	8.58 (7)	0.284	2.94 (5)	0.709	6.64 (9)	0.675

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 (α = 0.05) test results, 2015.

	Test 2.C2		Test 3.SR3		Test 2 + 3	
Species	No.	sig.	No.	sig.	No.	sig.
Chinook	4	1	2	0	4	1
Steelhead	2	0	2	0	2	0
Total	6	1	6	0	6	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 2015.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
20 Apr–26 Apr						
27 Apr–3 May	3.91	**0.048**	3.91	**0.048**		
4 May–10 May	0.09	0.955	0.06	0.813	0.04	0.851
11 May–17 May	0.65	0.724	0.30	0.583	0.34	0.558
18 May–24 May	1.96	0.162	1.96	0.162		
25 May–31 May						
Total (df)	6.60 (6)	0.359	6.22 (4)	0.183	0.38 (2)	0.827

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 2015.

	Overall		Test 2.C2		Test 3.SR3	
Release	χ^2	*P*-value	χ^2	*P*-value	χ^2	*P*-value
20 Apr–3 May						
4 May–17 May	2.75	0.253	2.34	0.126	0.41	0.523
18 May–31 May	1.77	0.412	1.76	0.185	0.01	0.917
Total (df)	4.52 (4)	0.340	4.10 (2)	0.129	0.42 (2)	0.811

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 2015. 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	9,779	0.741 (0.019)	1.319 (0.084)	0.682 (0.090)	1.023 (0.139)	0.682 (0.046)
Powell Pond	25,478	0.768 (0.023)	1.054 (0.058)	1.169 (0.161)	0.757 (0.104)	0.717 (0.033)
Red River Pond	17,051	0.434 (0.017)	1.100 (0.086)	1.126 (0.228)	0.727 (0.148)	0.390 (0.026)
Selway River	17,088	0.541 (0.011)	1.375 (0.069)	0.916 (0.120)	0.768 (0.104)	0.523 (0.031)
			Dworshak Hatchery			
N Fork Clearwater R	41,774	0.768 (0.018)	1.001 (0.039)	1.043 (0.085)	0.760 (0.063)	0.610 (0.019)
			Kooskia Hatchery			
Kooskia	7,967	0.532 (0.027)	1.085 (0.106)	1.221 (0.295)	0.548 (0.138)	0.387 (0.042)
			Lookingglass Hatchery			
Catherine Creek Pond	20,854	0.266 (0.016)	1.025 (0.110)	1.065 (0.229)	0.830 (0.177)	0.241 (0.020)
Grande Ronde Pond	1,993	0.346 (0.050)	0.833 (0.168)	0.840 (0.217)	0.950 (0.272)	0.230 (0.044)
Imnaha River	8,275	0.734 (0.049)	0.970 (0.109)	0.717 (0.125)	0.876 (0.147)	0.447 (0.034)
Imnaha Weir	12,599	0.655 (0.035)	0.969 (0.090)	1.001 (0.164)	0.713 (0.116)	0.453 (0.031)
Lookingglass Hatchery	1,986	0.632 (0.076)	1.153 (0.218)	1.009 (0.319)	0.710 (0.237)	0.522 (0.096)
Lostine Pond	1,291	0.556 (0.078)	1.023 (0.244)	1.151 (0.510)	0.654 (0.307)	0.429 (0.106)
			McCall Hatchery			
Johnson Creek	1,936	0.413 (0.089)	0.739 (0.207)	0.963 (0.407)	0.628 (0.271)	0.185 (0.038)
Knox Bridge	51,906	0.729 (0.030)	0.955 (0.060)	0.872 (0.096)	0.897 (0.096)	0.544 (0.019)
			Pahsimeroi Hatchery			
Pahsimeroi Pond	22,367	0.771 (0.036)	0.926 (0.072)	0.804 (0.110)	0.948 (0.129)	0.544 (0.033)
			Rapid River Hatchery			
Rapid River Hatchery	51,931	0.811 (0.024)	1.093 (0.054)	0.843 (0.072)	0.953 (0.079)	0.712 (0.022)
			Sawtooth Hatchery			
Sawtooth Hatchery	19,862	0.696 (0.036)	1.055 (0.093)	0.918 (0.133)	0.763 (0.105)	0.515 (0.027)
Yankee Fork	2,496	0.428 (0.058)	1.000 (0.236)	0.971 (0.501)	0.992 (0.526)	0.412 (0.087)

Appendix Table B2. Estimated survival probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2015. Estimates based on the single-release model. Standard errors in parentheses.

	Juvenile steelhead					
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			
S Fork Clearwater R	2,594	0.696 (0.061)	1.142 (0.162)	0.656 (0.189)	1.041 (0.317)	0.543 (0.080)
Meadow Creek	13,983	0.756 (0.034)	1.032 (0.070)	1.363 (0.220)	0.578 (0.098)	0.615 (0.042)
Newsome Creek	1,501	0.844 (0.153)	1.169 (0.321)	0.689 (0.274)	0.731 (0.280)	0.497 (0.088)
			Dworshak Hatchery			
Clearwater R (April)	6,569	0.754 (0.038)	1.179 (0.107)	0.740 (0.132)	1.028 (0.187)	0.676 (0.056)
Clearwater R (January)	11,326	0.842 (0.037)	1.021 (0.074)	0.860 (0.133)	1.005 (0.164)	0.742 (0.054)
Lolo Creek	3,154	0.755 (0.078)	1.042 (0.178)	0.822 (0.241)	0.658 (0.189)	0.426 (0.046)
S Fork Clearwater R	9,765	0.766 (0.030)	1.002 (0.064)	1.223 (0.169)	0.683 (0.105)	0.642 (0.054)
			Hagerman Hatchery			
East Fork Salmon R	8,534	0.630 (0.067)	0.792 (0.111)	0.862 (0.165)	0.929 (0.178)	0.400 (0.033)
Sawtooth Hatchery	25,977	0.731 (0.035)	0.895 (0.061)	0.973 (0.101)	0.908 (0.096)	0.578 (0.029)
			Irrigon Hatchery			
Big Canyon Facility	9,163	1.066 (0.122)	0.663 (0.092)	0.980 (0.184)	0.846 (0.160)	0.586 (0.044)
Cottonwood Pond	4,001	0.855 (0.034)	1.404 (0.122)	0.971 (0.361)	0.514 (0.197)	0.600 (0.065)
Little Sheep Facility	14,901	0.844 (0.037)	1.093 (0.073)	1.049 (0.139)	0.709 (0.097)	0.686 (0.039)
Wallowa Hatchery	13,458	0.848 (0.069)	1.066 (0.122)	1.100 (0.243)	0.587 (0.128)	0.584 (0.037)
			Lyons Ferry Hatchery			
Cottonwood Pond	5,981	0.716 (0.028)	1.104 (0.081)	0.829 (0.176)	0.843 (0.194)	0.552 (0.058)
Wallowa Hatchery	3,998	0.646 (0.094)	1.260 (0.323)	0.802 (0.650)	0.899 (0.742)	0.587 (0.076)

Appendix Table B2. Continued.

Release site	Juvenile steelhead 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
Magic Valley Hatchery						
Little Salmon R	4,388	0.882 (0.052)	1.223 (0.126)	0.864 (0.151)	0.913 (0.160)	0.850 (0.072)
Pahsimeroi R Trap	11,367	0.664 (0.047)	1.154 (0.122)	1.017 (0.182)	0.734 (0.128)	0.573 (0.033)
Salmon R (rkm 347)	1,897	0.842 (0.133)	1.229 (0.305)	1.332 (0.896)	0.385 (0.257)	0.531 (0.083)
Salmon R (rkm 385)	1,898	0.886 (0.127)	0.833 (0.168)	1.138 (0.426)	0.798 (0.321)	0.671 (0.132)
Salmon R (rkm 476)	1,893	0.787 (0.088)	1.126 (0.209)	1.378 (0.578)	0.492 (0.204)	0.600 (0.074)
Yankee Fork	13,261	0.663 (0.066)	0.866 (0.115)	1.060 (0.230)	0.706 (0.152)	0.430 (0.031)
Niagara Springs Hatchery						
Hells Canyon Dam	8,553	0.701 (0.034)	1.411 (0.122)	1.104 (0.252)	0.641 (0.147)	0.701 (0.052)
Little Salmon R	5,074	1.069 (0.128)	0.870 (0.156)	0.962 (0.256)	0.550 (0.139)	0.492 (0.047)
Pahsimeroi R Trap	8,959	0.844 (0.047)	1.126 (0.103)	0.836 (0.131)	0.816 (0.130)	0.648 (0.049)

Appendix Table B3. Estimated survival probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2015. 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	24 March 15	2,010	0.417 (0.115)	2.208 (0.930)	0.562 (0.239)	0.828 (0.314)	1.027 (0.389)	0.429 (0.112)
Sawtooth Hatchery								
Redfish Lake Cr Trap	12-13 March 15	49,772	0.483 (0.042)	0.978 (0.131)	0.809 (0.136)	0.893 (0.131)	0.707 (0.075)	0.341 (0.019)
Springfield Hatchery								
Redfish Lake Cr Trap	21-22 January 15	49,307	0.304 (0.027)	0.846 (0.114)	0.578 (0.097)	0.875 (0.151)	0.428 (0.059)	0.130 (0.013)

Appendix Table B4. Estimated detection probabilities for PIT-tagged yearling Chinook salmon released from Snake River Basin hatcheries in 2015. 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	9,779	0.261 (0.008)	0.102 (0.007)	0.028 (0.004)	0.159 (0.012)
Powell Pond	25,478	0.114 (0.004)	0.070 (0.004)	0.012 (0.002)	0.144 (0.007)
Red River Pond	17,051	0.158 (0.007)	0.091 (0.007)	0.018 (0.004)	0.176 (0.012)
Selway River	17,088	0.289 (0.007)	0.118 (0.006)	0.022 (0.003)	0.168 (0.011)
		Dworshak Hatchery			
N Fork Clearwater R	41,774	0.112 (0.003)	0.097 (0.003)	0.030 (0.002)	0.216 (0.007)
		Kooskia Hatchery			
Kooskia	7,967	0.169 (0.010)	0.114 (0.011)	0.025 (0.006)	0.208 (0.024)
		Lookingglass Hatchery			
Catherine Cr Pond	20,854	0.124 (0.009)	0.114 (0.011)	0.032 (0.007)	0.159 (0.014)
Grande Ronde Pond	1,993	0.116 (0.020)	0.147 (0.026)	0.083 (0.022)	0.206 (0.043)
Imnaha River	8,275	0.149 (0.011)	0.156 (0.014)	0.061 (0.010)	0.204 (0.017)
Imnaha Weir	12,599	0.136 (0.008)	0.119 (0.010)	0.056 (0.008)	0.200 (0.014)
Lookingglass Hatch	1,986	0.098 (0.014)	0.100 (0.017)	0.036 (0.011)	0.154 (0.030)
Lostine Pond	1,291	0.134 (0.022)	0.103 (0.023)	0.033 (0.015)	0.150 (0.040)
		McCall Hatchery			
Johnson Creek	1,936	0.074 (0.018)	0.134 (0.028)	0.037 (0.016)	0.213 (0.047)
Knox Bridge	51,906	0.085 (0.004)	0.100 (0.005)	0.032 (0.003)	0.127 (0.005)
		Pahsimeroi Hatchery			
Pahsimeroi Pond	22,367	0.085 (0.004)	0.075 (0.005)	0.029 (0.004)	0.134 (0.009)
		Rapid River Hatchery			
Rapid River Hatch	51,931	0.098 (0.003)	0.098 (0.004)	0.036 (0.003)	0.151 (0.005)
		Sawtooth Hatchery			
Sawtooth Hatchery	19,862	0.098 (0.006)	0.092 (0.007)	0.038 (0.005)	0.162 (0.009)
Yankee Fork	2,496	0.179 (0.026)	0.167 (0.032)	0.044 (0.022)	0.145 (0.032)

Appendix Table B5. Estimated detection probabilities for PIT-tagged juvenile steelhead released from Snake River Basin hatcheries in 2015. 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	13,983	0.094 (0.005)	0.115 (0.006)	0.021 (0.003)	0.075 (0.006)
Newsome Creek	1,501	0.066 (0.014)	0.080 (0.018)	0.032 (0.012)	0.086 (0.018)
S.F. Clearwater R	2,594	0.120 (0.013)	0.123 (0.016)	0.027 (0.008)	0.086 (0.015)
		Dworshak Hatchery			
Clearwater R (April)	6,569	0.130 (0.008)	0.087 (0.008)	0.033 (0.006)	0.082 (0.008)
Clearwater R (January)	11,326	0.114 (0.006)	0.093 (0.006)	0.032 (0.005)	0.074 (0.006)
Lolo Creek	3,154	0.117 (0.014)	0.128 (0.018)	0.052 (0.014)	0.141 (0.018)
S.F. Clearwater R	9,765	0.149 (0.007)	0.136 (0.008)	0.038 (0.005)	0.080 (0.008)
		Hagerman Hatchery			
East Fork Salmon R	8,534	0.093 (0.011)	0.163 (0.015)	0.056 (0.010)	0.118 (0.011)
Sawtooth Hatchery	25,977	0.066 (0.004)	0.093 (0.005)	0.034 (0.003)	0.072 (0.004)
		Irrigon Hatchery			
Big Canyon Facility	9,163	0.055 (0.007)	0.134 (0.010)	0.034 (0.006)	0.072 (0.007)
Cottonwood Pond	4,001	0.208 (0.011)	0.158 (0.013)	0.018 (0.007)	0.082 (0.011)
Little Sheep Facility	14,901	0.097 (0.005)	0.123 (0.007)	0.031 (0.004)	0.087 (0.006)
Wallowa Hatchery	13,458	0.054 (0.005)	0.087 (0.007)	0.020 (0.004)	0.069 (0.005)
		Lyons Ferry Hatchery			
Cottonwood Pond	5,981	0.198 (0.010)	0.164 (0.012)	0.028 (0.006)	0.071 (0.009)
Wallowa Hatchery	3,998	0.072 (0.012)	0.093 (0.020)	0.046 (0.036)	0.067 (0.010)
		Magic Valley Hatchery			
Little Salmon R	4,388	0.113 (0.008)	0.104 (0.010)	0.042 (0.007)	0.099 (0.010)
Pahsimeroi R Trap	11,367	0.079 (0.006)	0.104 (0.008)	0.038 (0.006)	0.108 (0.007)
Salmon R (rkm 347)	1,897	0.064 (0.012)	0.064 (0.013)	0.011 (0.007)	0.073 (0.014)
Salmon R (rkm 385)	1,898	0.078 (0.013)	0.106 (0.017)	0.030 (0.011)	0.056 (0.013)
Salmon R (rkm 476)	1,893	0.091 (0.012)	0.090 (0.015)	0.022 (0.009)	0.103 (0.016)
Yankee Fork	13,261	0.071 (0.008)	0.139 (0.012)	0.037 (0.008)	0.106 (0.009)
		Niagara Springs Hatchery			
Hells Canyon Dam	8,553	0.092 (0.006)	0.111 (0.008)	0.016 (0.004)	0.065 (0.006)
Little Salmon R	5,074	0.078 (0.010)	0.118 (0.016)	0.046 (0.011)	0.102 (0.012)
Pahsimeroi Trap	8,959	0.090 (0.006)	0.081 (0.007)	0.035 (0.005)	0.074 (0.007)

Appendix Table B6. Estimated detection probabilities for PIT-tagged juvenile sockeye salmon from Snake River Basin hatcheries released for migration year 2015. 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					
24 March 15	2,010	0.030 (0.010)	0.040 (0.014)	0.047 (0.014)	0.065 (0.019)
Sawtooth Hatchery					
12-13 March 15	49,772	0.052 (0.005)	0.050 (0.005)	0.030 (0.004)	0.069 (0.004)
Springfield Hatchery					
21-22 January 15	49,307	0.094 (0.008)	0.115 (0.011)	0.094 (0.013)	0.101 (0.011)

Appendix Table B7. Estimated survival probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2015. 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			
American River	30 Mar-31 May	623	0.084 (0.011)	NA	NA	NA	NA
Catherine Creek	05 Mar-29 May	211	0.275 (0.217)	0.430 (0.371)	NA	NA	NA
Elgin (G. Ronde)	03 Mar-29 May	843	0.582 (0.110)	0.780 (0.201)	0.706 (0.234)	1.621 (0.654)	0.519 (0.148)
Grande Ronde	16 Mar-28 May	326	1.064 (0.243)	0.610 (0.190)	1.314 (0.834)	0.663 (0.446)	0.565 (0.170)
Imnaha	02 Feb-31 May	6,582	0.763 (0.030)	1.081 (0.074)	0.854 (0.100)	0.941 (0.119)	0.663 (0.049)
Lemhi River	27 Feb-31 May	1362	0.577 (0.108)	0.927 (0.288)	0.354 (0.113)	NA	NA
Lookingglass Cr	20 Feb-13 May	175	0.331 (0.135)	0.750 (0.393)	NA	NA	NA
Lostine River	02 Feb-30 May	670	0.525 (0.154)	0.894 (0.371)	0.440 (0.246)	1.690 (1.040)	0.349 (0.133)
Marsh Creek	21 Mar-31 May	487	0.250 (0.058)	1.726 (1.022)	0.468 (0.421)	NA	NA
Minam River	27 Mar-29 May	956	0.701 (0.184)	0.589 (0.206)	1.381 (0.898)	0.823 (0.566)	0.469 (0.143)
Pahsimeroi	24 Feb-31 May	2,818	0.239 (0.048)	1.530 (0.551)	1.302 (0.944)	0.412 (0.287)	0.196 (0.046)
Salmon	12 Mar-22 May	3,182	0.811 (0.045)	0.986 (0.088)	1.044 (0.217)	0.643 (0.140)	0.537 (0.048)
Sawtooth	22 Mar-31 May	777	0.714 (0.208)	0.823 (0.411)	1.264 (1.272)	0.464 (0.474)	0.345 (0.150)
Snake	16 Mar-17 May	103	0.866 (0.192)	0.904 (0.374)	0.637 (0.404)	1.529 (1.526)	0.764 (0.658)
U. Grande Ronde	10 Mar-29 May	797	0.312 (0.073)	0.901 (0.285)	0.924 (0.532)	1.680 (1.117)	0.437 (0.172)
				Wild Sockeye Salmon			
Redfish Lake Cr	09 Apr-31 May	2,083	0.391 (0.031)	0.795 (0.100)	0.848 (0.170)	0.944 (0.282)	0.249 (0.061)

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	30 Mar-31 May	783	0.536 (0.118)	1.238 (0.579)	1.002 (0.988)	1.048 (1.100)	0.697 (0.371)
Elgin (G. Ronde)	03 Mar-31 May	890	0.785 (0.321)	0.580 (0.270)	0.582 (0.217)	1.677 (0.771)	0.445 (0.149)
Grande Ronde	03 Apr-29 May	93	1.183 (1.004)	0.125 (0.117)	NA	NA	NA
Imnaha River	26 Feb-31 May	5,931	0.990 (0.084)	0.834 (0.111)	0.760 (0.156)	0.845 (0.172)	0.531 (0.051)
Minam River	28 Feb-30 May	596	0.824 (0.246)	1.170 (0.608)	0.920 (0.706)	0.503 (0.353)	0.446 (0.137)
Salmon River	20 Mar-22 May	279	1.505 (0.916)	0.551 (0.405)	0.914 (0.863)	NA	NA
Snake River	16 Mar-19 May	995	0.867 (0.139)	0.850 (0.198)	1.804 (1.202)	0.519 (0.362)	0.690 (0.170)
Upper Grande Ronde	10 Mar-29 May	971	0.306 (0.085)	1.028 (0.436)	1.255 (1.168)	1.090 (1.192)	0.431 (0.276)
			Hatchery Chinook Salmon				
Grande Ronde	24 Mar-28 May	1,064	0.878 (0.100)	1.173 (0.250)	1.083 (0.478)	0.593 (0.273)	0.661 (0.146)
Salmon	16 Mar-05 May	4,000	0.851 (0.060)	1.160 (0.137)	0.791 (0.150)	1.012 (0.198)	0.791 (0.084)
Snake	17 Mar-18 May	769	0.928 (0.119)	1.011 (0.231)	0.745 (0.273)	0.886 (0.340)	0.619 (0.138)
			Hatchery Steelhead				
Grande Ronde	30 Mar-29 May	551	1.013 (0.130)	0.948 (0.194)	1.004 (0.460)	0.903 (0.487)	0.870 (0.283)
Salmon	06 Apr-22 May	1,937	0.832 (0.073)	1.109 (0.147)	0.936 (0.202)	0.871 (0.210)	0.752 (0.110)
Snake	26 Mar-19 May	3,546	0.892 (0.049)	1.203 (0.110)	0.802 (0.133)	0.819 (0.148)	0.704 (0.072)

Appendix Table B8. Estimated detection probabilities for juvenile salmonids released from fish traps in Snake River Basin in 2015. 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			
American River	30 Mar-31 May	623	0.250 (0.060)	0.199 (0.092)	NA	NA
Catherine Creek	05 Mar-29 May	211	0.069 (0.063)	0.326 (0.136)	NA	NA
Elgin (G. Ronde)	03 Mar-29 May	843	0.124 (0.028)	0.188 (0.037)	0.090 (0.031)	0.170 (0.052)
Grande Ronde	16 Mar-28 May	326	0.141 (0.037)	0.216 (0.052)	0.036 (0.024)	0.215 (0.071)
Imnaha	02 Feb-31 May	6,582	0.171 (0.008)	0.146 (0.010)	0.063 (0.007)	0.225 (0.018)
Lemhi River	27 Feb-31 May	1362	0.111 (0.024)	0.149 (0.038)	0.103 (0.027)	0.156 (0.041)
Lookingglass Cr	20 Feb-13 May	175	0.155 (0.078)	0.286 (0.115)	NA	0.125 (0.117)
Lostine River	02 Feb-30 May	670	0.088 (0.030)	0.173 (0.054)	0.097 (0.052)	0.179 (0.072)
Marsh Creek	21 Mar-31 May	487	0.238 (0.065)	0.149 (0.084)	0.068 (0.054)	0.118 (0.078)
Minam River	27 Mar-29 May	956	0.103 (0.029)	0.182 (0.043)	0.034 (0.022)	0.151 (0.049)
Pahsimeroi	24 Feb-31 May	2,818	0.076 (0.018)	0.088 (0.028)	0.017 (0.012)	0.206 (0.051)
Salmon	12 Mar-22 May	3,182	0.158 (0.011)	0.182 (0.015)	0.049 (0.010)	0.298 (0.029)
Sawtooth	22 Mar-31 May	777	0.123 (0.038)	0.159 (0.064)	0.038 (0.036)	0.190 (0.086)
Snake	16 Mar-17 May	103	0.269 (0.075)	0.266 (0.104)	0.138 (0.087)	0.200 (0.179)
Upper Grande Ronde	10 Mar-29 May	797	0.116 (0.034)	0.176 (0.045)	0.042 (0.027)	0.143 (0.059)
			Wild Sockeye Salmon			
Redfish Lake Cr	09 Apr-31 May	2,083	0.260 (0.025)	0.255 (0.031)	0.142 (0.029)	0.125 (0.034)

Appendix Table B8. Continued.

Trap	Release dates	Number released	Lower Granite Dam	Little Goose Dam	Lower Monumental Dam	McNary Dam
Wild Steelhead						
Asotin Creek	30 Mar-31 May	783	0.164 (0.040)	0.124 (0.052)	0.039 (0.036)	0.075 (0.042)
Elgin (Grande Ronde)	03 Mar-31 May	890	0.056 (0.024)	0.168 (0.037)	0.070 (0.028)	0.058 (0.023)
Grande Ronde	03 Apr-29 May	93	0.127 (0.113)	0.154 (0.100)	NA	NA
Imnaha	26 Feb-31 May	5,931	0.105 (0.010)	0.115 (0.012)	0.043 (0.008)	0.127 (0.014)
Minam River	28 Feb-30 May	596	0.077 (0.026)	0.086 (0.038)	0.031 (0.021)	0.099 (0.035)
Salmon	20 Mar-22 May	279	0.048 (0.031)	0.150 (0.062)	0.032 (0.030)	NA
Snake	16 Mar-19 May	995	0.112 (0.021)	0.153 (0.028)	0.021 (0.014)	0.098 (0.027)
Upper Grande Ronde	10 Mar-29 May	971	0.101 (0.033)	0.130 (0.045)	0.035 (0.032)	0.035 (0.024)
Hatchery Chinook Salmon						
Grande Ronde	24 Mar-28 May	1,064	0.146 (0.020)	0.103 (0.021)	0.028 (0.012)	0.139 (0.033)
Salmon	16 Mar-05 May	4,000	0.102 (0.009)	0.086 (0.009)	0.031 (0.006)	0.124 (0.014)
Snake	17 Mar-18 May	769	0.153 (0.024)	0.112 (0.024)	0.048 (0.018)	0.192 (0.046)
Hatchery Steelhead						
Grande Ronde	30 Mar-29 May	551	0.158 (0.025)	0.178 (0.033)	0.032 (0.016)	0.076 (0.027)
Salmon	06 Apr-22 May	1,937	0.104 (0.012)	0.123 (0.015)	0.043 (0.010)	0.088 (0.015)
Snake	26 Mar-19 May	3,546	0.130 (0.009)	0.131 (0.011)	0.037 (0.006)	0.092 (0.011)

Appendix Table B9. Estimated survival probabilities for PIT-tagged yearling Chinook, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2015. 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	9,922	0.541 (0.073)	0.513 (0.096)	1.665 (0.515)	0.854 (0.266)	0.462 (0.130)
Cle Elum						
Clark Flat Pond	15,995	0.284 (0.021)	0.911 (0.154)	0.639 (0.209)	0.582 (0.173)	0.165 (0.048)
Easton Pond	11,996	0.263 (0.018)	0.769 (0.121)	0.598 (0.159)	0.460 (0.108)	0.121 (0.027)
Jack Creek Pond	11,992	0.262 (0.021)	0.964 (0.190)	0.476 (0.149)	0.459 (0.122)	0.120 (0.031)
Eastbank						
Carlton Pond	9,825	0.577 (0.108)	1.147 (0.445)	0.790 (0.517)	0.906 (0.533)	0.523 (0.292)
Chewuch Pond	15,077	0.466 (0.033)	0.776 (0.096)	1.317 (0.302)	1.022 (0.221)	0.477 (0.098)
Chiwawa Pond	10,021	0.443 (0.042)	1.159 (0.225)	0.620 (0.160)	0.718 (0.155)	0.318 (0.062)
Dryden Pond	20,486	0.760 (0.052)	1.017 (0.114)	0.935 (0.148)	0.951 (0.139)	0.723 (0.094)
Nason Creek	20,139	0.346 (0.030)	0.751 (0.110)	1.269 (0.383)	0.953 (0.278)	0.330 (0.092)
Entiat						
Entiat Hatchery	9,963	0.483 (0.052)	0.717 (0.114)	1.511 (0.400)	1.084 (0.282)	0.523 (0.124)
Leavenworth						
Leavenworth NFH	14,993	0.497 (0.034)	0.945 (0.148)	0.827 (0.191)	0.781 (0.152)	0.388 (0.071)
Methow						
Methow Hatchery	4,988	0.496 (0.093)	0.558 (0.186)	1.034 (0.449)	0.578 (0.222)	0.287 (0.096)
Twisp Pond	4,990	0.476 (0.085)	0.766 (0.267)	0.781 (0.330)	0.598 (0.207)	0.284 (0.084)
Winthrop						
Riverside Pond	4,902	0.540 (0.072)	1.983 (0.978)	0.264 (0.134)	0.525 (0.113)	0.283 (0.048)
Winthrop NFH	9,977	0.540 (0.054)	1.056 (0.218)	0.912 (0.239)	0.963 (0.206)	0.520 (0.099)

Appendix Table B9. Continued.

Hatchery/ Release site	Number released	Release to McNary Dam	McNary to John Day Dam	John Day to Bonneville Dam	McNary to Bonneville Dam	Release to Bonneville Dam
			Steelhead			
Wells						
Methow River	4,188	0.476 (0.059)	0.834 (0.189)	0.754 (0.197)	0.628 (0.136)	0.299 (0.054)
Okanogan River	5,009	0.350 (0.043)	1.183 (0.338)	0.521 (0.154)	0.616 (0.115)	0.216 (0.031)
Omak Acclimation Pond	9,984	0.299 (0.033)	0.657 (0.130)	1.580 (0.403)	1.037 (0.233)	0.310 (0.061)
Twisp Acclimation Pond	4,918	0.248 (0.081)	0.498 (0.305)	0.557 (0.372)	0.277 (0.147)	0.069 (0.029)
Wells Hatchery	3,245	0.547 (0.065)	0.718 (0.152)	1.217 (0.364)	0.874 (0.236)	0.478 (0.116)
Winthrop						
Winthrop NFH	29,891	0.375 (0.033)	0.816 (0.141)	0.625 (0.101)	0.510 (0.055)	0.191 (0.012)
			Coho Salmon			
Cascade						
Beaver Pond	5,981	0.502 (0.052)	0.657 (0.112)	1.301 (0.360)	0.854 (0.225)	0.429 (0.104)
Butcher Pond	5,982	0.222 (0.046)	0.618 (0.211)	0.773 (0.359)	0.477 (0.206)	0.106 (0.040)
Leavenworth NFH	4,492	0.347 (0.041)	0.826 (0.169)	1.309 (0.425)	1.081 (0.325)	0.375 (0.104)
Eagle						
Natches River	2,498	0.147 (0.026)	0.862 (0.300)	1.115 (0.515)	0.961 (0.375)	0.142 (0.050)
Yakima R (rkm 256)	2,501	0.134 (0.046)	NA	NA	NA	NA
Yakima R (rkm 325)	3,751	0.031 (0.008)	NA	NA	NA	NA
Prosser						
Natches River	7,521	0.073 (0.012)	0.831 (0.238)	NA	NA	NA
Willard						
Gold Creek	5,980	0.499 (0.178)	0.676 (0.400)	0.595 (0.421)	0.403 (0.257)	0.201 (0.106)
Leavenworth NFH	4,492	0.241 (0.043)	0.638 (0.234)	0.745 (0.332)	0.476 (0.170)	0.115 (0.036)
Rolfing Pond	5,976	0.366 (0.081)	0.640 (0.246)	0.806 (0.387)	0.516 (0.218)	0.189 (0.068)
Twisp Acclimation Pond	5,981	0.397 (0.105)	0.592 (0.254)	0.765 (0.361)	0.452 (0.192)	0.180 (0.060)
Winthrop NFH	5,967	0.533 (0.166)	1.081 (0.685)	0.522 (0.400)	0.564 (0.348)	0.300 (0.160)
Winthrop						
Winthrop NFH	6,630	0.249 (0.033)	0.921 (0.258)	0.936 (0.366)	0.862 (0.285)	0.215 (0.065)

Appendix Table B10. Estimated detection probabilities for PIT-tagged yearling Chinook salmon, steelhead, and coho salmon from upper-Columbia River hatcheries released in 2015. 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	9,922	0.060 (0.009)	0.076 (0.011)	0.108 (0.031)
Cle Elum				
Clark Flat Pond	15,995	0.182 (0.014)	0.082 (0.013)	0.146 (0.042)
Easton Pond	11,996	0.238 (0.018)	0.110 (0.017)	0.212 (0.049)
Jack Creek Pond	11,992	0.206 (0.018)	0.082 (0.016)	0.183 (0.048)
Eastbank				
Carlton Pond	9,825	0.052 (0.010)	0.025 (0.009)	0.053 (0.030)
Chewuch Pond	15,077	0.104 (0.008)	0.061 (0.007)	0.145 (0.030)
Chiwawa Pond	10,021	0.095 (0.010)	0.044 (0.008)	0.177 (0.035)
Dryden Pond	20,486	0.054 (0.004)	0.041 (0.004)	0.154 (0.020)
Nason Creek	20,139	0.081 (0.008)	0.057 (0.007)	0.138 (0.039)
Entiat				
Entiat Hatchery	9,963	0.067 (0.008)	0.068 (0.009)	0.134 (0.032)
Leavenworth				
Leavenworth NFH	14,993	0.128 (0.010)	0.044 (0.007)	0.142 (0.026)
Methow				
Methow Hatchery	4,988	0.068 (0.014)	0.035 (0.011)	0.189 (0.064)
Twisp Accl. Pond	4,990	0.073 (0.014)	0.031 (0.010)	0.181 (0.054)
Winthrop				
Riverside Pond	4,902	0.083 (0.012)	0.009 (0.004)	0.296 (0.052)
Winthrop NFH	9,977	0.073 (0.008)	0.028 (0.006)	0.148 (0.028)
		Steelhead		
Wells				
Methow River	4,188	0.088 (0.013)	0.043 (0.010)	0.333 (0.061)
Okanogan River	5,009	0.080 (0.012)	0.023 (0.007)	0.436 (0.063)
Omak Accl. Pond	9,984	0.076 (0.010)	0.033 (0.007)	0.206 (0.041)
Twisp Accl. Pond	4,918	0.069 (0.024)	0.030 (0.017)	0.267 (0.114)
Wells Hatchery	3,245	0.095 (0.013)	0.047 (0.010)	0.273 (0.067)
Winthrop				
Winthrop NFH	29,891	0.036 (0.004)	0.013 (0.002)	0.414 (0.027)

Appendix Table B10. Continued

Hatchery/ Release site	Number released	McNary Dam	John Day Dam	Bonneville Dam
		Coho Salmon		
Cascade				
Beaver Pond	5,981	0.094 (0.011)	0.061 (0.010)	0.218 (0.054)
Butcher Pond	5,982	0.084 (0.019)	0.055 (0.017)	0.266 (0.102)
Leavenworth NFH	4,492	0.109 (0.015)	0.061 (0.012)	0.205 (0.058)
Eagle				
Natches River	2,498	0.125 (0.028)	0.044 (0.018)	0.359 (0.128)
Yakima R (rkm 256)	2,501	0.071 (0.028)	0.013 (0.013)	0.113 (0.106)
Yakima R (rkm 325)	3,751	0.095 (0.037)	0.017 (0.017)	NA
Prosser				
Natches River	7,521	0.131 (0.026)	0.077 (0.022)	0.054 (0.052)
Willard				
Gold Creek	5,980	0.030 (0.011)	0.022 (0.011)	0.145 (0.077)
Leavenworth NFH	4,492	0.118 (0.023)	0.045 (0.016)	0.304 (0.096)
Rolfing Pond	5,976	0.060 (0.014)	0.035 (0.012)	0.194 (0.071)
Twisp Acclimation Pond	5,981	0.042 (0.012)	0.028 (0.011)	0.210 (0.070)
Winthrop NFH	5,967	0.030 (0.010)	0.012 (0.007)	0.137 (0.073)
Winthrop				
Winthrop NFH	6,630	0.095 (0.014)	0.033 (0.009)	0.244 (0.075)

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 2015 from the Columbia River DART website[1] on 26 August, 2015. We created plots to compare daily measures of flow, temperature, and spill at Little Goose Dam from 2015 to those from 2008-2014. We calculated long-term daily averages for flow, temperature, and spill as the mean daily value for 1993-2015. We created plots and calculated passage proportions to compare daily estimates of proportion of smolts passing Lower Granite Dam in 2015 to those of 2012-2014.

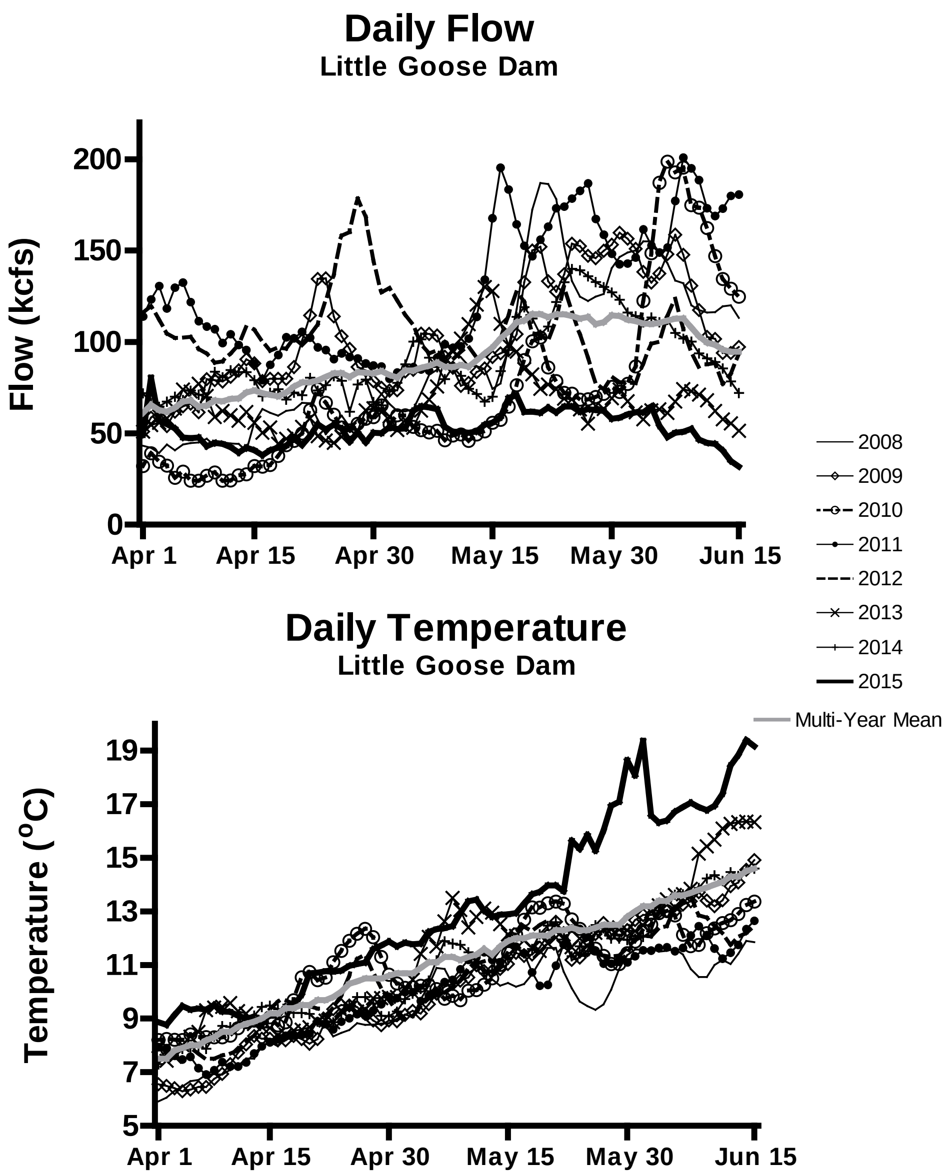
In addition, for each daily group of PIT-tagged yearling Chinook salmon and steelhead from Lower Granite Dam we calculated an index of Snake River flow exposure. For each daily group, the index was equal to the average daily flow at Lower Monumental Dam during the period between the 25th and 75th percentiles 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, the combination of conditions in the Snake River during the 2015 spring migration was unlike any year in our time series. Water temperatures and spill percentages reached record highs while flow was near record low. In terms of flow, 2015 was most like 1994, 2001, and 2007. In terms of spill percentages, 2015 was most like 2008 and 2010. In terms of water temperature, 2015 was unique. Some years in our time series have been as warm in April, but the spike in temperature in the second half of May 2015 is unprecedented.

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

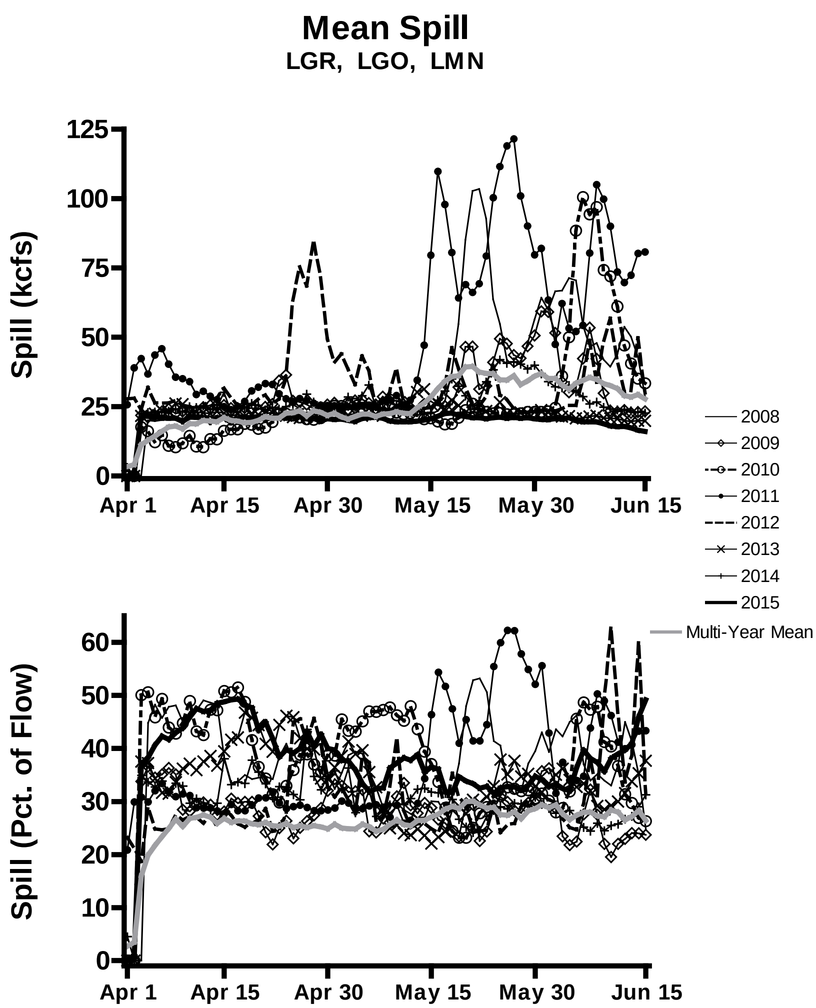
Mean flow at Little Goose Dam in 2015 during the main migration period (1 April – 15 June) was 53.0 kcfs, which was well below the long-term (1993-2015) mean of 90.2 kcfs. The only year with lower mean flow in our time series was 2001 with a mean of 48.9 kcfs, although mean flow was lower on some days in 2010. Daily flow values were below long-term daily means for every day in the main migration period (Appendix Figure C1).



Appendix Figure C1. Daily Snake River flow (kcfs) and temperature (°C) measured at Little Goose Dam from April through mid-June, 2008-2015, including daily long-term means (1993-2015).

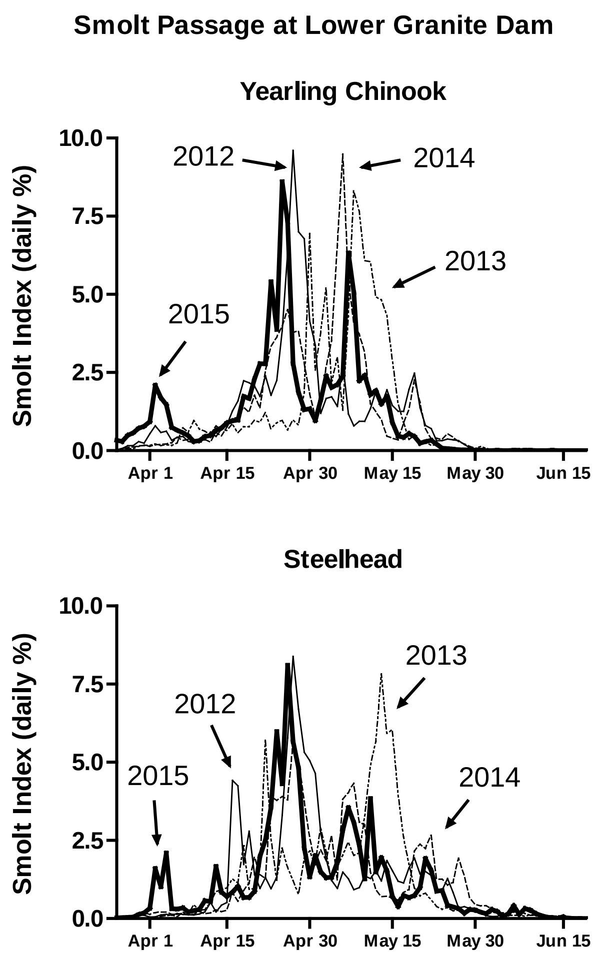
Mean water temperature at Little Goose Dam in 2015 during the migration period was 13.1 °C, which was above the long-term mean of 11.1 °C, and was the warmest year in our time series. Daily water temperatures were above the long-term daily means (1993-2015) on most days, with differences becoming greatest in late May and early June (Appendix Figure C1).

Mean spill discharge at the Snake River dams during the 2015 migration was 19.9 kcfs, which was below the long-term mean of 25.7 kcfs. Daily spill discharges were



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, 2008-2015, including daily long-term means (1993-2015).

close to long-term daily means earlier in the season, but despite being relatively constant, the daily spill values fell below the daily means starting in the middle of May and stayed low for the remainder of the migration period (Appendix Figure C2). This is because flow typically increases later in the season and forces higher spill discharge, but 2015 was an exception, with relatively constant and low flow throughout the season. Spill as a percentage of flow at Snake River dams averaged 37.7% in 2015, which was above the long-term mean of 25.9% and was actually the highest annual mean spill percentage in our time series. Daily mean spill percentages in 2015 were above the long-term daily means for almost the entire migration period (Appendix Figure C2).



Appendix Figure C3. Daily smolt passage index of yearling Chinook salmon and steelhead passing Lower Granite Dam, 2012-2015.

Flow was relatively constant throughout the migration period, with gradual increases from mid-April through mid-May (Appendix Figure C1). These gradual pulses in flow are somewhat coincident with spikes in smolt passage both yearling Chinook salmon and steelhead at Lower Granite Dam in 2015 (Appendix Figure C3), although the relationship is not clear.