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September 19, 2019

MEMORANDUM FOR: F/NWR5 – Ritchie Graves

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SUBJECT: Preliminary survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2019

This memorandum summarizes conditions in the Snake and Columbia Rivers and preliminary estimates of survival of PIT-tagged juvenile salmonids passing through reservoirs and dams during the 2019 spring outmigration. We also provide preliminary estimates of the proportion of Snake River smolts that were transported from Snake River dams in 2019. Our complete detailed analyses and report for the spring migration will follow this memo at a later date. As in past years, changes in the database between the time of our annual summer memo and the publication of our final report may result in differences of up to 3 or 4% in estimated survival values.

Summary of Research

For survival studies funded by BPA in 2019, NOAA Fisheries PIT tagged 21,332 river-run hatchery steelhead, 15,261 wild steelhead, and 6,363 wild yearling Chinook salmon for release into the tailrace of Lower Granite Dam.

Survival estimates provided in this memorandum are derived from data from fish PIT tagged by or for NOAA Fisheries, as described above, along with fish PIT tagged by others within the Columbia River Basin. Note that for technical reasons, the statistical model for survival estimation can produce estimates that exceed 100%. When this occurs, we report the actual estimate, but for practical purposes these estimates should be interpreted as representing survival probabilities which are less than or equal to 100%.

We have estimated survival probabilities for migrating PIT-tagged salmonids since 1993. In this memo, we compare 2019 estimates in various river segments to averages over periods of years. Estimates are not available for every reach in every year. Unless otherwise noted, when we refer to a long-term average for a particular river segment, the average is across all years for which estimates are available.

PIT-tagged yearling Chinook salmon have been released from each of the Snake River Basin hatcheries Dworshak, Kooskia, Lookingglass/Imnaha Weir, Rapid River, McCall/Knox Bridge, Pahsimeroi, and Sawtooth every year from 1993 through 2019 (except Pahsimeroi in 1996). Across these seven "index" hatcheries, the annual mean estimated survival from release to Lower Granite Dam has been relatively stable since 1998 (Figure 1, Table 1). However, the mean in 2019 was only 54.5%, lower than in every other year, except 1997, in the time series. The mean of the annual means from 1998 through 2018 was 63.0%, well above the mean in 2019. For individual hatcheries, 2019 estimates were lower than the 1993-2018 mean for all but McCall and Sawtooth. For each of Dworshak, Rapid River, and Pahsimeroi, 2019 estimates were the second- or third-lowest in the time series.

Downstream of Lower Granite Dam, mean estimated survival for Snake River yearling Chinook salmon (hatchery and wild combined) in 2019 was substantially below average in the Lower Granite to Little Goose and the Lower Monumental to McNary reaches, and slightly above average in the Little Goose to Lower Monumental reach (Table 2, Figure 2). Estimated survival in the McNary to John Day reach was above average; in the John Day to Bonneville reach estimated survival was nearly equal to average (Table 2, Figure 3). These estimates resulted in below average survival from Lower Granite to McNary, but average survival across the combined reach from Lower Granite to Bonneville (Table 3).

Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to McNary Dam tailrace in 2019 was 62.8% (95% CI: 57.7-67.9%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 83.8% (71.3-96.3%). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to Bonneville Dam tailrace was 52.6% (43.7-61.6%). Estimated survival for the Lower Granite project (head of reservoir to tailrace) was 78.5%, based on fish PIT tagged at and

released from the Snake River trap. The combined yearling Chinook salmon survival estimate from the Snake River trap to Bonneville Dam tailrace was 41.3% (33.8-48.9%), which was below the long-term average of 48.9%.

For wild Snake River yearling Chinook, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 66.9% (95% CI: 61.4-72.4%), and from McNary Dam tailrace to Bonneville Dam tailrace was 81.3% (59.0-103.6%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 86.8%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 47.2% (32.0-62.4%). This estimate is slightly above the long-term average of 44.9%.

For Snake River steelhead (hatchery and wild combined), mean estimated survival in 2019 was above average in every individual reach except for the John Day to Bonneville reach, where survival was below average. Survival was above average for the combined reach from Lower Granite to McNary, but below average for the reach from McNary to Bonneville and the overall reach from Lower Granite to Bonneville (Table 4, Figures 2 and 3).

Mean estimated survival for steelhead from Lower Granite Dam tailrace to McNary Dam tailrace was 71.8% (95% CI: 68.5-75.1%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 59.5% (38.1-80.7%). Estimated survival for the Lower Granite project was 96.5%, based on steelhead PIT tagged at and released from the Snake River trap. The combined Snake River steelhead survival estimate from the Snake River trap to Bonneville Dam tailrace was 41.2% (26.1-56.3%), which was below the long-term average of 45.7% (Table 5).

For wild Snake River steelhead, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 77.2% (95% CI: 68.6-85.8%), and from McNary Dam tailrace to Bonneville Dam tailrace was 64.0% (51.8-76.2%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 97.3%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 48.1% (34.5-61.7%), above the long-term average of 41.8%.

For PIT-tagged hatchery yearling Chinook salmon originating from the upper Columbia River in 2019, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 78.5% (95% CI: 68.3-90.3%; Table 6), which was near the long-term average of 81.2%.

For PIT-tagged hatchery steelhead originating from the upper Columbia River in 2019, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 60.6% (95% CI: 52.1-70.5%; Table 6). This estimate is below the long-term average of 76.4%.

For fish released from upper Columbia River hatcheries, we cannot estimate survival in reaches upstream from McNary Dam (other than the overall reach from release to McNary Dam tailrace) because of limited PIT-tag detection capabilities at Mid-Columbia River PUD dams.

Estimated survival in 2019 of Snake River sockeye salmon (hatchery and wild combined) from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 43.4% (95% CI: 37.7-49.9%; Table 7). Estimated survival in 2019 of Columbia River sockeye salmon (hatchery and wild combined) from the tailrace of Rock Island Dam to the tailrace of Bonneville Dam was 73.7% (44.7%-121.5%; Table 7). Both estimates were above their respective long-term averages of 40.7% and 50.6%.

Our preliminary estimates of the percentage transported of non-tagged wild and hatchery spring-summer Chinook salmon smolts in 2019 are 41.6% and 33.6%, respectively. For steelhead, the estimates are 36.7% and 36.4% for wild and hatchery smolts, respectively. These estimates represent the percentage of smolts that arrived at Lower Granite Dam that were subsequently transported, either from Lower Granite Dam or downstream at Little Goose or Lower Monumental Dam.

Discussion

For Snake River yearling Chinook salmon in 2019, estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 52.6%; this estimate is essentially equal to the long-term (1999-2019) average of 52.1%. Yearling Chinook survival through the hydropower system was below the mean in the previous four years 2015-2018; these low system survival estimates were driven mostly by poor survival in the McNary to Bonneville reach, while survival in Snake River reaches was generally high. These trends were reversed in 2019, with above average survival in the McNary to Bonneville reach but poor survival in several Snake River reaches.

Additionally, survival upstream of Lower Granite Dam was poor for Chinook salmon in 2019. This year's survival estimate for the Snake River Trap to Lower Granite Dam reach is the lowest on record (Table 2), and many hatchery stocks had poor survival from release to Lower Granite Dam in 2019 (Table 1).

For Snake River steelhead in 2019, estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 42.7%; below the long-term mean of 47.0% (Table 5). In contrast to Chinook in 2019, this below-average estimate is driven by poor survival in the McNary to Bonneville reach; steelhead generally had above average survival in the Snake River.

Environmental conditions and management actions in 2019 resulted in a year with overall average water temperatures (with a few spikes in temperature), high flow, and high spill for most of the migration season. Mean flow at Little Goose Dam in 2019 during the main migration period 1 April—15 June was 118.4 kcfs, which was well above the long-term (1993-2019) mean of 93.5 kcfs. Daily flow values were well above long-term daily means for nearly the entire migration period; daily flow approached the mean for a brief period in late May and after the first week of June (Figure 4). Mean water temperature at Little Goose Dam during the 2019 migration period was 11.4 °C, which was near the long-term mean of 11.2 °C. However, daily water temperatures varied substantially through the season. Water temperature fluctuated from more than a degree below the daily mean during spikes in flow in April and late May to nearly two degrees warmer than the mean during periods in early May and early June when flow was not as high (Figure 4).

Mean spill discharge at the Snake River dams during the 2019 migration was 45.5 kcfs, which was substantially above the 2006-2019 mean of 34.3 kcfs. Daily spill discharges remained above the long-term daily mean for the entire season, with peaks in early April and late April (Figure 5).

Spill as a percentage of flow at Snake River dams averaged 38.5% in 2019, which was above the long-term (2006-2019) mean of 34.6%. Daily mean spill percentages in 2019 were above the long-term daily means for the majority of the migration period (Figure 5), with well above average percent spill during early April and the first two weeks of May.

Dissolved gas was higher in 2019 than in most years in the 2006-2019 period, particularly in April (Figure 6). Dissolved gas was generally between 115% and 120%, except for spikes to above 120% in mid-April, mid-May, and early June; additionally, there was an unusually large spike in dissolved gas in early April to levels above 125%.

A significant spike in flow occurred April 9-11 in 2019 (Figure 4), associated with a decrease in water temperature (Figure 4), an increase in spill (Figure 5), and an increase in dissolved gas (Figure 6). This large freshet also promoted smolt passage; both yearling Chinook salmon and steelhead had spikes in passage at Lower Granite Dam. This was unusually early for such large passage numbers for both species (Figure 7).

In any given year the percentage of a stock that is transported is largely determined by a combination of three factors: (1) migration timing in relation to (2) the starting date of general smolt transportation, and (3) the percentage of smolts that enter the collection system during the transportation period.

In 2019, collection for transportation began on 24 April at Lower Granite, Little Goose, and Lower Monumental Dams. Similarly, in 2018 collection began on 23 April. These dates were at least 7 days earlier than the start date of May 1st, or later, typical in most recent years. As in 2018, estimated percentages transported were greater than any in 2015-2017 (Figure 8).

However, transported percentages were generally lower in 2019 than in 2018, primarily because migration timing was earlier, especially for hatchery Chinook salmon and for steelhead. We estimate that 32% of hatchery Chinook salmon, and about 47% of both hatchery and wild steelhead passed before the start of transportation. The corresponding numbers for 2018 were 24% and 37%. The trend toward earlier migration has been apparent for several years. Steelhead were particularly early in 2019: estimated dates of median passage were the earliest we've ever observed for both hatchery (24 April) and wild (28 April) steelhead, and 9 days earlier than the respective 2006-2018 mean dates.

In addition, after the start of transportation lower proportions of passing smolts were collected in 2019 than in 2018. This was a result of increased spill during the 2019 migration.

Over the last several years we have noted a trend toward shorter smolt travel times relative to levels of flow and spill. However, 2019 was an exception, especially for yearling Chinook salmon. Under the current spill regime, 2019 joined 2011, 2012, 2017, and 2018 as years we have classified as high-flow. Yearling Chinook salmon travel times in 2019 were more similar to those in 2011 and 2012 than those in 2017 and 2018. In April 2019 Chinook travel times were several days longer than in 2017 and 2018 (Figure 9). In May 2019 Chinook travel times decreased to levels similar to 2017 and 2018.

Median estimated travel time for steelhead in 2019 was also slightly longer than travel times from 2017 or 2018, but the difference was smaller than for Chinook. Steelhead travel times in 2019 were about one day longer than those from the same week in 2017 and 2018; these 2019 travel times were similar to or slightly longer than the median of high-flow years in the 2006-2019 period (Figure 9).

Since the institution of court-ordered spill in 2006, and the concurrent installation of surface collectors at four additional federal dams during that period, travel times have decreased on average between Lower Granite and Bonneville dams for steelhead, but the effect is smaller for Chinook (Figure 9). Differences in travel times for low-flow years versus other years is also more visible for Steelhead than Chinook (Figure 9). Day in season is a stronger predictor of travel time for Chinook than either flow or spill. Some of the lowest flow years were also low-spill years that occurred before the new spill regime, so the effect of average flow on travel time is difficult to separate from that of spill by simply inspecting the figures without the assistance of a statistical model. Flow and spill also vary within season, so categorizing years by seasonal averages is not optimal, but it does allow for some simple visual comparisons.

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Table 1. Estimated survival and standard error (s.e.) for yearling **Chinook** salmon released at Snake River Basin and Upper Columbia River hatcheries to Lower Granite Dam tailrace (LGR) and McNary Dam tailrace (MCN), 2017 through 2019.

Hatchery	2017		2018		2019[a]	
	Survival to LGR (s.e.)	Survival to MCN (s.e.)	Survival to LGR (s.e.)	Survival to MCN (s.e.)	Survival to LGR (s.e.)	Survival to MCN (s.e.)
Dworshak	0.693 (0.013)	0.402 (0.015)	0.744 (0.015)	0.546 (0.023)	0.688 (0.013)	0.466 (0.021)
Kooskia	0.565 (0.025)	0.351 (0.040)	0.633 (0.030)	0.438 (0.044)	0.571 (0.022)	0.352 (0.041)
Lookingglass (Catherine Cr.)	0.420 (0.014)	0.303 (0.024)	0.314 (0.008)	0.232 (0.024)	0.454 (0.018)	0.392 (0.044)
Lookingglass (Grande Ronde)	0.398 (0.032)	0.352 (0.096)	0.347 (0.013)	0.238 (0.043)	0.465 (0.038)	0.253 (0.064)
Lookingglass (Imnaha Weir)	0.585 (0.020)	0.438 (0.041)	0.651 (0.012)	0.429 (0.034)	0.627 (0.025)	0.458 (0.048)
Lookingglass (Lostine River)	0.553 (0.029)	0.409 (0.067)	0.600 (0.014)	0.418 (0.057)	0.559 (0.022)	0.414 (0.054)
McCall (Johnson Cr.)	---	---	0.487 (0.029)	0.370 (0.104)	---	---
McCall (Knox Bridge)	0.700 (0.012)	0.528 (0.021)	0.702 (0.011)	0.519 (0.026)	0.616 (0.014)	0.528 (0.029)
Pahsimeroi	0.746 (0.012)	0.560 (0.041)	0.634 (0.015)	0.342 (0.034)	0.280 (0.008)	0.161 (0.020)
Rapid River	0.652 (0.010)	0.528 (0.020)	0.651 (0.009)	0.491 (0.023)	0.491 (0.009)	0.433 (0.024)
Sawtooth	0.606 (0.010)	0.466 (0.025)	0.519 (0.013)	0.372 (0.029)	0.539 (0.021)	0.358 (0.032)
Entiat	---	0.639 (0.040)	---	0.572 (0.037)	---	0.565 (0.053)
Winthrop	---	0.578 (0.031)	---	0.587 (0.046)	---	0.490 (0.055)
Leavenworth	---	0.540 (0.022)	---	0.658 (0.038)	---	0.515 (0.035)

a. Estimates are preliminary and subject to change.

Table 2. Annual weighted means of survival probability estimates for yearling **Chinook** salmon (hatchery and wild combined), 1995–2019. Standard errors in parentheses. Reaches with asterisks comprise two dams and reservoirs (i.e., two projects); the following column gives the square root (i.e., geometric mean) of the two–project estimate to facilitate comparison with other single–project estimates. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; LGO–Little Goose Dam; LMO–Lower Monumental Dam; IHR–Ice Harbor Dam; MCN–McNary Dam; JDA–John Day Dam; TDA–The Dalles Dam; BON–Bonneville Dam. Simple arithmetic means across all available years (1993–2019) are given.

Year	Trap–LGR	LGR–LGO	LGO–LMO	LMO–MCN*	LMO–IHR IHR–MCN	MCN–JDA	JDA–BON*	JDA–TDA TDA–BON
1995	0.905 (0.010)	0.882 (0.004)	0.925 (0.008)	0.876 (0.038)	0.936	NA	NA	NA
1996	0.977 (0.025)	0.926 (0.006)	0.929 (0.011)	0.756 (0.033)	0.870	NA	NA	NA
1997	NA	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.893	NA	NA	NA
1998	0.924 (0.011)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)	NA	NA
1999	0.940 (0.009)	0.949 (0.002)	0.925 (0.004)	0.904 (0.007)	0.951	0.853 (0.027)	0.814 (0.065)	0.902
2000	0.929 (0.014)	0.938 (0.006)	0.887 (0.009)	0.928 (0.016)	0.963	0.898 (0.054)	0.684 (0.128)	0.827
2001	0.954 (0.015)	0.945 (0.004)	0.830 (0.006)	0.708 (0.007)	0.841	0.758 (0.024)	0.645 (0.034)	0.803
2002	0.953 (0.022)	0.949 (0.006)	0.980 (0.008)	0.837 (0.013)	0.915	0.907 (0.014)	0.840 (0.079)	0.917
2003	0.993 (0.023)	0.946 (0.005)	0.916 (0.011)	0.904 (0.017)	0.951	0.893 (0.017)	0.818 (0.036)	0.904
2004	0.893 (0.009)	0.923 (0.004)	0.875 (0.012)	0.818 (0.018)	0.904	0.809 (0.028)	0.735 (0.092)	0.857
2005	0.919 (0.015)	0.919 (0.003)	0.886 (0.006)	0.903 (0.010)	0.950	0.772 (0.029)	1.028 (0.132)	1.014
2006	0.952 (0.011)	0.923 (0.003)	0.934 (0.004)	0.887 (0.008)	0.942	0.881 (0.020)	0.944 (0.030	0.972
2007	0.943 (0.028)	0.938 (0.006)	0.957 (0.010)	0.876 (0.012)	0.936	0.920 (0.016)	0.824 (0.043)	0.908
2008	0.992 (0.018)	0.939 (0.006)	0.950 (0.011)	0.878 (0.016)	0.937	1.073 (0.058)	0.558 (0.082)	0.750
2009	0.958 (0.010)	0.940 (0.006)	0.982 (0.009)	0.855 (0.011)	0.925	0.866 (0.042)	0.821 (0.043)	0.906
2010	0.968 (0.040)	0.962 (0.011)	0.973 (0.019)	0.851 (0.017)	0.922	0.947 (0.021)	0.780 (0.039)	0.883
2011	0.943 (0.009)	0.919 (0.007)	0.966 (0.008)	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)	0.928 (0.031)	0.960 (0.057)	0.785 (0.032)	0.886	0.724 (0.069)	0.937 (0.160)	0.968
2016	0.936 (0.015)	0.956 (0.006)	0.912 (0.010)	0.872 (0.013)	0.934	0.796 (0.039)	0.871 (0.047)	0.933
2017	NA	0.916 (0.009)	0.908 (0.013)	0.912 (0.024)	0.956	0.720 (0.041)	0.871 (0.200)	0.933
2018	0.880 (0.022)	0.942 (0.013)	0.917 (0.019)	0.877 (0.036)	0.936	0.770 (0.074)	0.743 (0.100)	0.862
2019[a]	0.785 (0.027)	0.876 (0.015)	0.950 (0.027)	0.790 (0.032)	0.889	1.018 (0.086)	0.807 (0.109)	0.898
Mean[a]	**0.924 (0.010)**	**0.926 (0.006)**	**0.923 (0.008)**	**0.860 (0.011)**	**0.927 (0.006)**	**0.867 (0.019)**	**0.806 (0.023)**	**0.896 (0.013)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993 and 1994 are omitted from the table for space.

Table 3. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling **Chinook** salmon (hatchery and wild combined), 1997–2019. Standard errors in parentheses. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; MCN–McNary Dam; BON–Bonneville Dam.

Year	Trap–LGR	LGR-MCN	MCN-BON	LGR–BON	Trap–BON
1997	NA	0.653 (0.072)	NA	NA	NA
1998	0.924 (0.011)	0.770 (0.009)	NA	NA	NA
1999	0.940 (0.009)	0.792 (0.006)	0.704 (0.058)	0.557 (0.046)	0.524 (0.043)
2000	0.929 (0.014)	0.760 (0.012)	0.640 (0.122)	0.486 (0.093)	0.452 (0.087)
2001	0.954 (0.015)	0.556 (0.009)	0.501 (0.027)	0.279 (0.016)	0.266 (0.016)
2002	0.953 (0.022)	0.757 (0.009)	0.763 (0.079)	0.578 (0.060)	0.551 (0.059)
2003	0.993 (0.023)	0.731 (0.010)	0.728 (0.030)	0.532 (0.023)	0.528 (0.026)
2004	0.893 (0.009)	0.666 (0.011)	0.594 (0.074)	0.395 (0.050)	0.353 (0.045)
2005	0.919 (0.015)	0.732 (0.009)	0.788 (0.093)	0.577 (0.068)	0.530 (0.063)
2006	0.952 (0.011)	0.764 (0.007)	0.842 (0.021)	0.643 (0.017)	0.612 (0.018)
2007	0.943 (0.028)	0.783 (0.006)	0.763 (0.044)	0.597 (0.035)	0.563 (0.037)
2008	0.992 (0.018)	0.782 (0.011)	0.594 (0.066)	0.465 (0.052)	0.460 (0.052)
2009	0.958 (0.010)	0.787 (0.007)	0.705 (0.031)	0.555 (0.025)	0.531 (0.025)
2010	0.968 (0.040)	0.772 (0.012)	0.738 (0.039)	0.569 (0.032)	0.551 (0.038)
2011	0.943 (0.009)	0.746 (0.010)	0.687 (0.065)	0.513 (0.049)	0.483 (0.046)
2012	0.928 (0.012)	0.790 (0.016)	0.802 (0.051)	0.634 (0.042)	0.588 (0.040)
2013	0.845 (0.031)	0.781 (0.016)	0.796 (0.064)	0.622 (0.052)	0.525 (0.048)
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)	0.727 (0.033)	0.629 (0.043)	0.457 (0.038)	0.415 (0.058)
2016	0.936 (0.015)	0.752 (0.011)	0.672 (0.060)	0.505 (0.046)	0.473 (0.043)
2017	NA	0.743 (0.019)	0.643 (0.157)	0.478 (0.117)	NA
2018	0.880 (0.022)	0.733 (0.025)	0.590 (0.045)	0.432 (0.036)	0.381 (0.033)
2019[a]	0.785 (0.027)	0.628 (0.026)	0.838 (0.054)	0.526 (0.040)	0.413 (0.035)
Mean[b]	**0.924 (0.010)**	**0.733 (0.012)**	**0.702 (0.020)**	**0.521 (0.019)**	**0.485 (0.019)**

a. Estimates are preliminary and subject to change.
b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993-1996 are omitted from the table for space.

Table 4. Annual weighted means of survival probability estimates for **steelhead** (hatchery and wild combined), 1995–2019. Standard errors in parentheses. Reaches with asterisks comprise two dams and reservoirs (i.e., two projects); the following column gives the square root (i.e., geometric mean) of the two–project estimate to facilitate comparison with other single–project estimates. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; LGO–Little Goose Dam; LMO–Lower Monumental Dam; IHR–Ice Harbor Dam; MCN–McNary Dam; JDA–John Day Dam; TDA–The Dalles Dam; BON–Bonneville Dam. Simple arithmetic means across all available years (1993–2019) are given.

Year	Trap–LGR	LGR–LGO	LGO–LMO	LMO–MCN*	LMO–IHR IHR–MCN	MCN–JDA	JDA–BON*	JDA–TDA TDA–BON
1995	0.945 (0.008)	0.899 (0.005)	0.962 (0.011)	0.858 (0.076)	0.926	NA	NA	NA
1996	0.951 (0.015)	0.938 (0.008)	0.951 (0.014)	0.791 (0.052)	0.889	NA	NA	NA
1997	0.964 (0.015)	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.913	NA	NA	NA
1998	0.924 (0.009)	0.930 (0.004)	0.889 (0.006)	0.797 (0.018)	0.893	0.831 (0.031)	0.935 (0.103)	0.967
1999	0.908 (0.011)	0.926 (0.004)	0.915 (0.006)	0.833 (0.011)	0.913	0.920 (0.033)	0.682 (0.039)	0.826
2000	0.964 (0.013)	0.901 (0.006)	0.904 (0.009)	0.842 (0.016)	0.918	0.851 (0.045)	0.754 (0.045)	0.868
2001	0.911 (0.007)	0.801 (0.010)	0.709 (0.008)	0.296 (0.010)	0.544	0.337 (0.025)	0.753 (0.063)	0.868
2002	0.895 (0.015)	0.882 (0.011)	0.882 (0.018)	0.652 (0.031)	0.807	0.844 (0.063)	0.612 (0.098)	0.782
2003	0.932 (0.015)	0.947 (0.005)	0.898 (0.012)	0.708 (0.018)	0.841	0.879 (0.032)	0.630 (0.066)	0.794
2004	0.948 (0.004)	0.860 (0.006)	0.820 (0.014)	0.519 (0.035)	0.720	0.465 (0.078)	NA	NA
2005	0.967 (0.004)	0.940 (0.004)	0.867 (0.009)	0.722 (0.023)	0.850	0.595 (0.040)	NA	NA
2006	0.920 (0.013)	0.956 (0.004)	0.911 (0.006)	0.808 (0.017)	0.899	0.795 (0.045)	0.813 (0.083)	0.902
2007	1.016 (0.026)	0.887 (0.009)	0.911 (0.022)	0.852 (0.030)	0.923	0.988 (0.098)	0.579 (0.059)	0.761
2008	0.995 (0.018)	0.935 (0.007)	0.961 (0.014)	0.776 (0.017)	0.881	0.950 (0.066)	0.742 (0.045)	0.861
2009	1.002 (0.011)	0.972 (0.005)	0.942 (0.008)	0.863 (0.014)	0.929	0.951 (0.026)	0.900 (0.079)	0.949
2010	1.017 (0.030)	0.965 (0.028)	0.984 (0.044)	0.876 (0.032)	0.936	0.931 (0.051)	0.840 (0.038)	0.917
2011	0.986 (0.017)	0.955 (0.004)	0.948 (0.010)	0.772 (0.014)	0.879	0.960 (0.043)	0.858 (0.051)	0.926
2012	1.001 (0.026)	0.959 (0.006)	0.914 (0.011)	0.811 (0.022)	0.901	0.814 (0.048)	1.021 (0.148)	1.010
2013	0.973 (0.032)	0.921 (0.020)	0.977 (0.020)	0.739 (0.031)	0.860	0.799 (0.025)	1.026 (0.154)	1.013
2014	1.018 (0.028)	0.953 (0.009)	0.947 (0.024)	0.836 (0.032)	0.914	1.082 (0.080)	0.982 (0.147)	0.991
2015	0.874 (0.046)	1.017 (0.028)	0.829 (0.059)	0.923 (0.071)	0.961	0.792 (0.066)	0.842 (0.050)	0.918
2016	0.998 (0.016)	0.990 (0.007)	0.918 (0.016)	0.813 (0.025)	0.902	0.927 (0.074)	0.709 (0.071)	0.842
2017	NA	0.962 (0.008)	0.943 (0.015)	0.849 (0.022)	0.921	0.941 (0.020)	0.643 (0.040)	0.802
2018	0.983 (0.025)	0.953 (0.007)	0.950 (0.016)	0.823 (0.036)	0.907	0.851 (0.039)	0.946 (0.150)	0.974
2019[a]	0.965 (0.027)	0.968 (0.006)	0.980 (0.010)	0.776 (0.019)	0.881	1.029 (0.084)	0.734 (0.110)	0.857
Mean[b]	**0.952 (0.010)**	**0.932 (0.009)**	**0.912 (0.012)**	**0.775 (0.026)**	**0.876 (0.017)**	**0.842 (0.037)**	**0.800 (0.031)**	**0.891 (0.017)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993 and 1994 are omitted from the table for space.

Table 5. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River **steelhead** (hatchery and wild combined), 1997–2019. Standard errors in parentheses. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; MCN–McNary Dam; BON–Bonneville Dam.

Year	Trap–LGR	LGR-MCN	MCN-BON	LGR–BON	Trap–BON
1997	0.964 (0.015)	0.728 (0.053)	0.651 (0.082)	0.474 (0.069)	0.457 (0.067)
1998	0.924 (0.009)	0.649 (0.013)	0.770 (0.081)	0.500 (0.054)	0.462 (0.050)
1999	0.908 (0.011)	0.688 (0.010)	0.640 (0.024)	0.440 (0.018)	0.400 (0.017)
2000	0.964 (0.013)	0.679 (0.016)	0.580 (0.040)	0.393 (0.034)	0.379 (0.033)
2001	0.911 (0.007)	0.168 (0.006)	0.250 (0.016)	0.042 (0.003)	0.038 (0.003)
2002	0.895 (0.015)	0.536 (0.025)	0.488 (0.090)	0.262 (0.050)	0.234 (0.045)
2003	0.932 (0.015)	0.597 (0.013)	0.518 (0.015)	0.309 (0.011)	0.288 (0.012)
2004	0.948 (0.004)	0.379 (0.023)	NA	NA	NA
2005	0.967 (0.004)	0.593 (0.018)	NA	NA	NA
2006	0.920 (0.013)	0.702 (0.016)	0.648 (0.079)	0.455 (0.056)	0.418 (0.052)
2007	1.016 (0.026)	0.694 (0.020)	0.524 (0.064)	0.364 (0.045)	0.369 (0.047)
2008	0.995 (0.018)	0.716 (0.015)	0.671 (0.034)	0.480 (0.027)	0.478 (0.028)
2009	1.002 (0.011)	0.790 (0.013)	0.856 (0.074)	0.676 (0.059)	0.678 (0.060)
2010	1.017 (0.030)	0.770 (0.020)	0.789 (0.027)	0.608 (0.026)	0.618 (0.032)
2011	0.986 (0.017)	0.693 (0.013)	0.866 (0.038)	0.600 (0.029)	0.592 (0.030)
2012	1.001 (0.026)	0.698 (0.020)	0.856 (0.196)	0.597 (0.138)	0.598 (0.139)
2013	0.973 (0.032)	0.645 (0.026)	0.798 (0.112)	0.515 (0.075)	0.501 (0.075)
2014	1.018 (0.028)	0.740 (0.021)	1.023 (0.088)	0.757 (0.069)	0.771 (0.073)
2015	0.874 (0.046)	0.733 (0.027)	0.663 (0.039)	0.486 (0.034)	0.425 (0.037)
2016	0.998 (0.016)	0.730 (0.020)	0.608 (0.040)	0.444 (0.032)	0.443 (0.032)
2017	NA	0.759 (0.019)	0.605 (0.037)	0.459 (0.030)	NA
2018	0.983 (0.025)	0.733 (0.031)	0.802 (0.098)	0.588 (0.076)	0.579 (0.076)
2019[a]	0.965 (0.027)	0.718 (0.017)	0.595 (0.109)	0.427 (0.079)	0.412 (0.077)
Mean[b]	**0.952 (0.010)**	**0.663 (0.027)**	**0.676 (0.037)**	**0.470 (0.033)**	**0.457 (0.036)**

a. Estimates are preliminary and subject to change.
b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993-1996 are omitted for space.

Table 6. Estimated survival and standard error (s.e.) through reaches of the lower Columbia River hydropower system for hatchery yearling **Chinook** salmon and **steelhead** originating in the upper Columbia River, 1999–2019. Abbreviations: Rel–Release site; MCN–McNary Dam; JDA–John Day Dam; BON–Bonneville Dam.

	Yearling Chinook Salmon				Steelhead			
Year	Rel–MCN	MCN-JDA	JDA-BON	MCN–BON	Rel–MCN	MCN-JDA	JDA-BON	MCN–BON
1999	0.572 (0.014)	0.896 (0.044)	0.795 (0.129)	0.712 (0.113)	NA	NA	NA	NA
2000	0.539 (0.025)	0.781 (0.094)	NA	NA	NA	NA	NA	NA
2001	0.428 (0.009)	0.881 (0.062)	NA	NA	NA	NA	NA	NA
2002	0.555 (0.003)	0.870 (0.011)	0.940 (0.048)	0.817 (0.041)	NA	NA	NA	NA
2003	0.625 (0.003)	0.900 (0.008)	0.977 (0.035)	0.879 (0.031)	0.471 (0.004)	0.997 (0.012)	0.874 (0.036)	0.871 (0.036)
2004	0.507 (0.005)	0.812 (0.019)	0.761 (0.049)	0.618 (0.038)	0.384 (0.005)	0.794 (0.021)	1.037 (0.112)	0.823 (0.088)
2005	0.545 (0.012)	0.751 (0.042)	NA	NA	0.399 (0.004)	0.815 (0.017)	0.827 (0.071)	0.674 (0.057)
2006	0.520 (0.011)	0.954 (0.051)	0.914 (0.211)	0.871 (0.198)	0.397 (0.008)	0.797 (0.026)	0.920 (0.169)	0.733 (0.134)
2007	0.584 (0.009)	0.895 (0.028)	0.816 (0.091)	0.730 (0.080)	0.426 (0.016)	0.944 (0.064)	0.622 (0.068)	0.587 (0.059)
2008	0.582 (0.019)	1.200 (0.085)	0.522 (0.114)	0.626 (0.133)	0.438 (0.015)	NA	NA	NA
2009	0.523 (0.013)	0.847 (0.044)	1.056 (0.143)	0.895 (0.116)	0.484 (0.018)	0.809 (0.048)	0.935 (0.133)	0.756 (0.105)
2010	0.660 (0.014)	0.924 (0.040)	0.796 (0.046)	0.735 (0.037)	0.512 (0.017)	0.996 (0.054)	0.628 (0.038)	0.626 (0.033)
2011	0.534 (0.010)	1.042 (0.047)	0.612 (0.077)	0.637 (0.077)	0.435 (0.012)	1.201 (0.064)	0.542 (0.101)	0.651 (0.119)
2012	0.576 (0.012)	0.836 (0.035)	1.140 (0.142)	0.953 (0.115)	0.281 (0.011)	0.862 (0.047)	1.240 (0.186)	1.069 (0.159)
2013	0.555 (0.013)	0.965 (0.050)	1.095 (0.129)	1.056 (0.117)	0.384 (0.020)	0.957 (0.071)	0.974 (0.104)	0.932 (0.099)
2014	0.571 (0.013)	0.974 (0.047)	0.958 (0.122)	0.933 (0.114)	0.468 (0.043)	0.883 (0.124)	0.807 (0.153)	0.712 (0.130)
2015	0.512 (0.015)	0.843 (0.043)	1.032 (0.081)	0.870 (0.062)	0.351 (0.019)	0.807 (0.084)	0.707 (0.073)	0.570 (0.043)
2016	0.610 (0.009)	0.857 (0.027)	0.942 (0.068)	0.807 (0.055)	0.416 (0.011)	0.771 (0.037)	0.633 (0.046)	0.487 (0.032)
2017	0.582 (0.013)	0.853 (0.030)	1.107 (0.142)	0.944 (0.120)	0.437 (0.025)	0.880 (0.062)	1.095 (0.210)	0.964 (0.188)
2018	0.608 (0.016)	0.914 (0.044)	0.820 (0.096)	0.749 (0.084)	0.416 (0.021)	0.942 (0.062)	1.232 (0.194)	1.161 (0.186)
2019[a]	0.506 (0.018)	0.853 (0.042)	0.920 (0.066)	0.785 (0.056)	0.342 (0.016)	0.812 (0.048)	0.746 (0.054)	0.606 (0.047)
Mean[b]	**0.557 (0.011)**	**0.897 (0.021)**	**0.900 (0.039)**	**0.812 (0.029)**	**0.414 (0.014)**	**0.892 (0.028)**	**0.864 (0.054)**	**0.764 (0.048)**

a. Estimates are preliminary and subject to change.
b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment.

Table 7. Estimated survival and standard error (s.e.) 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, 1996–2019. Note that this table represents all available data on sockeye; estimates are provided regardless of the precision, which in some years was very poor. Abbreviations: LGR–Lower Granite Dam; MCN–McNary Dam; BON–Bonneville Dam; RIS–Rock Island Dam.

	Snake River Sockeye			Upper Columbia River Sockeye		
Year	LGR-MCN	MCN-BON	LGR-BON	RIS-MCN	MCN-BON	RIS-BON
1996	0.283 (0.184)	NA	NA	NA	NA	NA
1997	NA	NA	NA	0.397 (0.119)	NA	NA
1998	0.689 (0.157)	0.142 (0.099)	0.177 (0.090)	0.624 (0.058)	1.655 (1.617)	1.033 (1.003)
1999	0.655 (0.083)	0.841 (0.584)	0.548 (0.363)	0.559 (0.029)	0.683 (0.177)	0.382 (0.097)
2000	0.679 (0.110)	0.206 (0.110)	0.161 (0.080)	0.487 (0.114)	0.894 (0.867)	0.435 (0.410)
2001	0.205 (0.063)	0.105 (0.050)	0.022 (0.005)	0.657 (0.117)	NA	NA
2002	0.524 (0.062)	0.684 (0.432)	0.342 (0.212)	0.531 (0.044)	0.286 (0.110)	0.152 (0.057)
2003	0.669 (0.054)	0.551 (0.144)	0.405 (0.098)	NA	NA	NA
2004	0.741 (0.254)	NA	NA	0.648 (0.114)	1.246 (1.218)	0.808 (0.777)
2005	0.388 (0.078)	NA	NA	0.720 (0.140)	0.226 (0.209)	0.163 (0.147)
2006	0.630 (0.083)	1.113 (0.652)	0.820 (0.454)	0.793 (0.062)	0.767 (0.243)	0.608 (0.187)
2007	0.679 (0.066)	0.259 (0.084)	0.272 (0.073)	0.625 (0.046)	0.642 (0.296)	0.401 (0.183)
2008	0.763 (0.103)	0.544 (0.262)	0.404 (0.179)	0.644 (0.094)	0.679 (0.363)	0.437 (0.225)
2009	0.749 (0.032)	0.765 (0.101)	0.573 (0.073)	0.853 (0.076)	0.958 (0.405)	0.817 (0.338)
2010	0.723 (0.039)	0.752 (0.098)	0.544 (0.077)	0.778 (0.063)	0.627 (0.152)	0.488 (0.111)
2011	0.659 (0.033)	NA	NA	0.742 (0.088)	0.691 (0.676)	0.513 (0.498)
2012	0.762 (0.032)	0.619 (0.084)	0.472 (0.062)	0.945 (0.085)	0.840 (0.405)	0.794 (0.376)
2013	0.691 (0.043)	0.776 (0.106)	0.536 (0.066)	0.741 (0.068)	0.658 (0.217)	0.487 (0.155)
2014	0.873 (0.054)	0.817 (0.115)	0.713 (0.096)	0.428 (0.056)	0.565 (0.269)	0.242 (0.111)
2015	0.702 (0.054)	0.531 (0.151)	0.373 (0.037)	0.763 (0.182)	0.446 (0.200)	0.340 (0.130)
2016	0.523 (0.047)	0.227 (0.059)	0.119 (0.030)	0.807 (0.082)	0.545 (0.126)	0.448 (0.144)
2017	0.544 (0.081)	0.324 (0.107)	0.176 (0.055)	0.719 (0.113)	0.611 (0.181)	0.500 (0.332)
2018	0.684 (0.061)	0.940 (0.151)	0.643 (0.088)	0.927 (0.118)	0.560 (0.112)	0.344 (0.124)
2019[a]	0.836 (0.053)	0.520 (0.044)	0.434 (0.031)	0.941 (0.125)	0.697 (0.119)	0.737 (0.191)
Mean[b]	**0.637 (0.034)**	**0.564 (0.066)**	**0.407 (0.049)**	**0.697 (0.033)**	**0.714 (0.070)**	**0.506 (0.052)**

a. Estimates are preliminary and subject to change.
b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment.

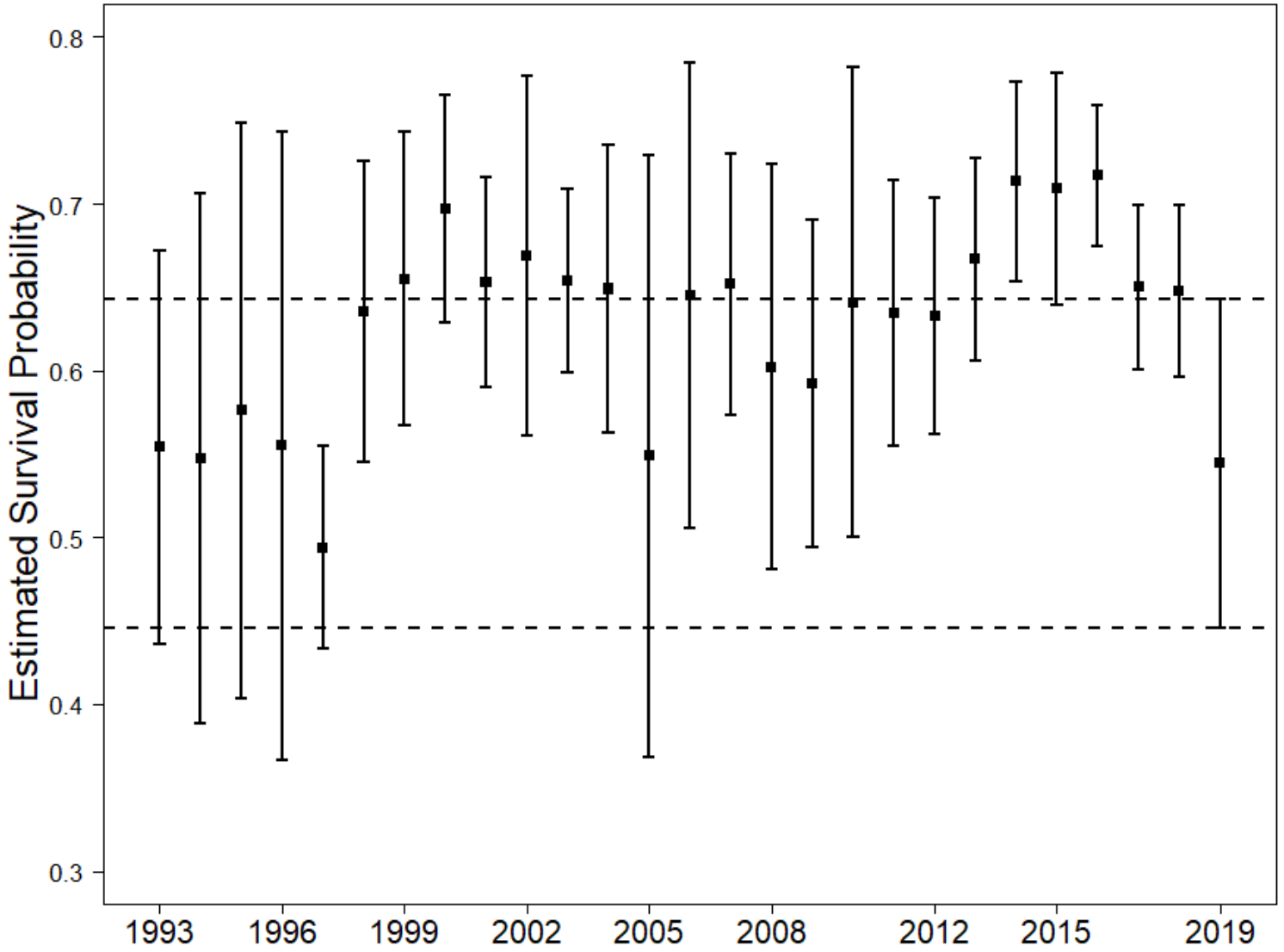

Figure 1. Annual average survival estimates from release to Lower Granite Dam for PIT-tagged yearling **Chinook** salmon released from Snake River Basin hatcheries, 1993-2019. Hatcheries used for average (index groups) are those with consistent PIT-tag releases through the series of years shown. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are the 2019 confidence interval endpoints and are shown for comparison to other years.

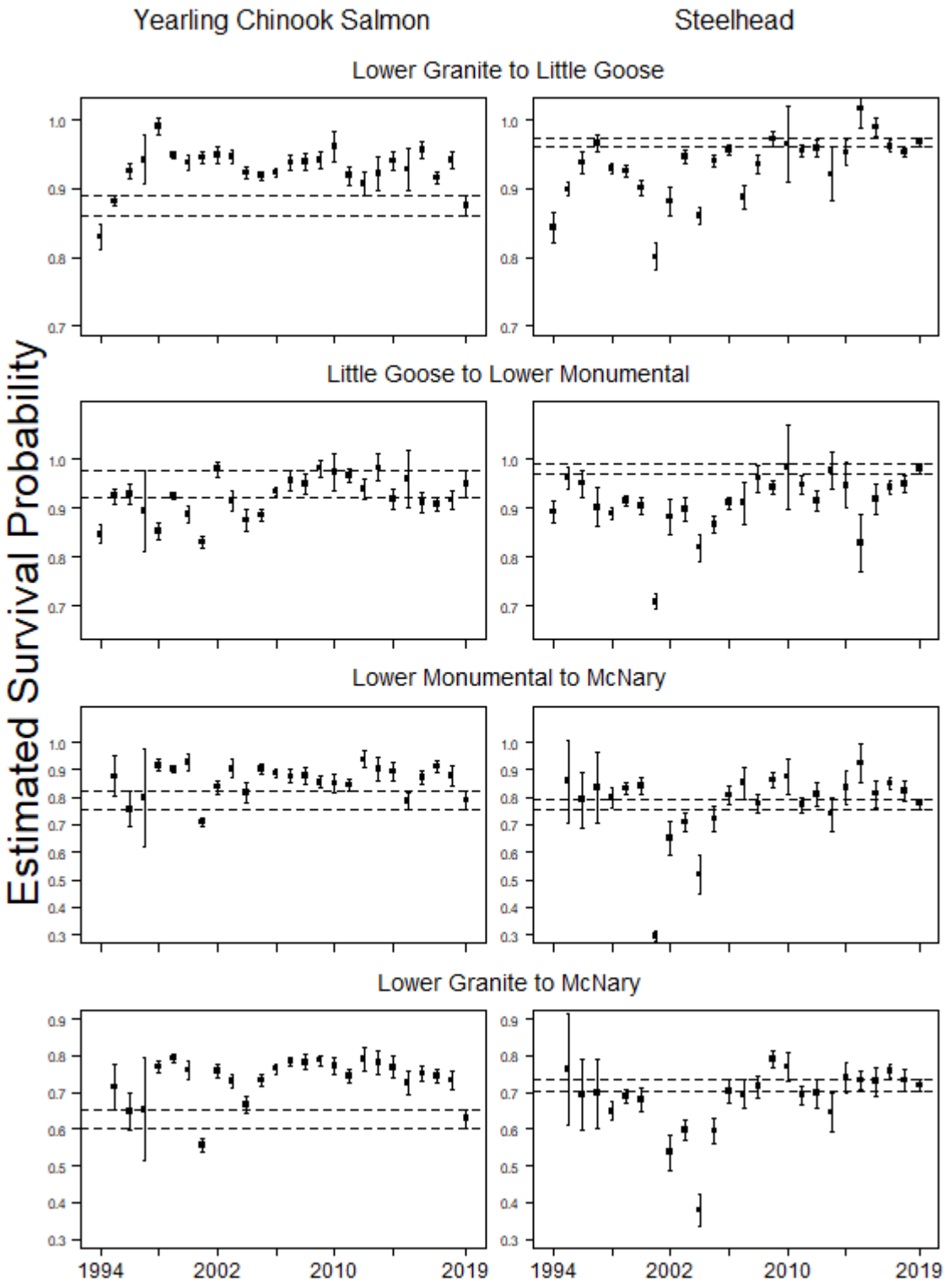

Figure 2. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2019 estimates.

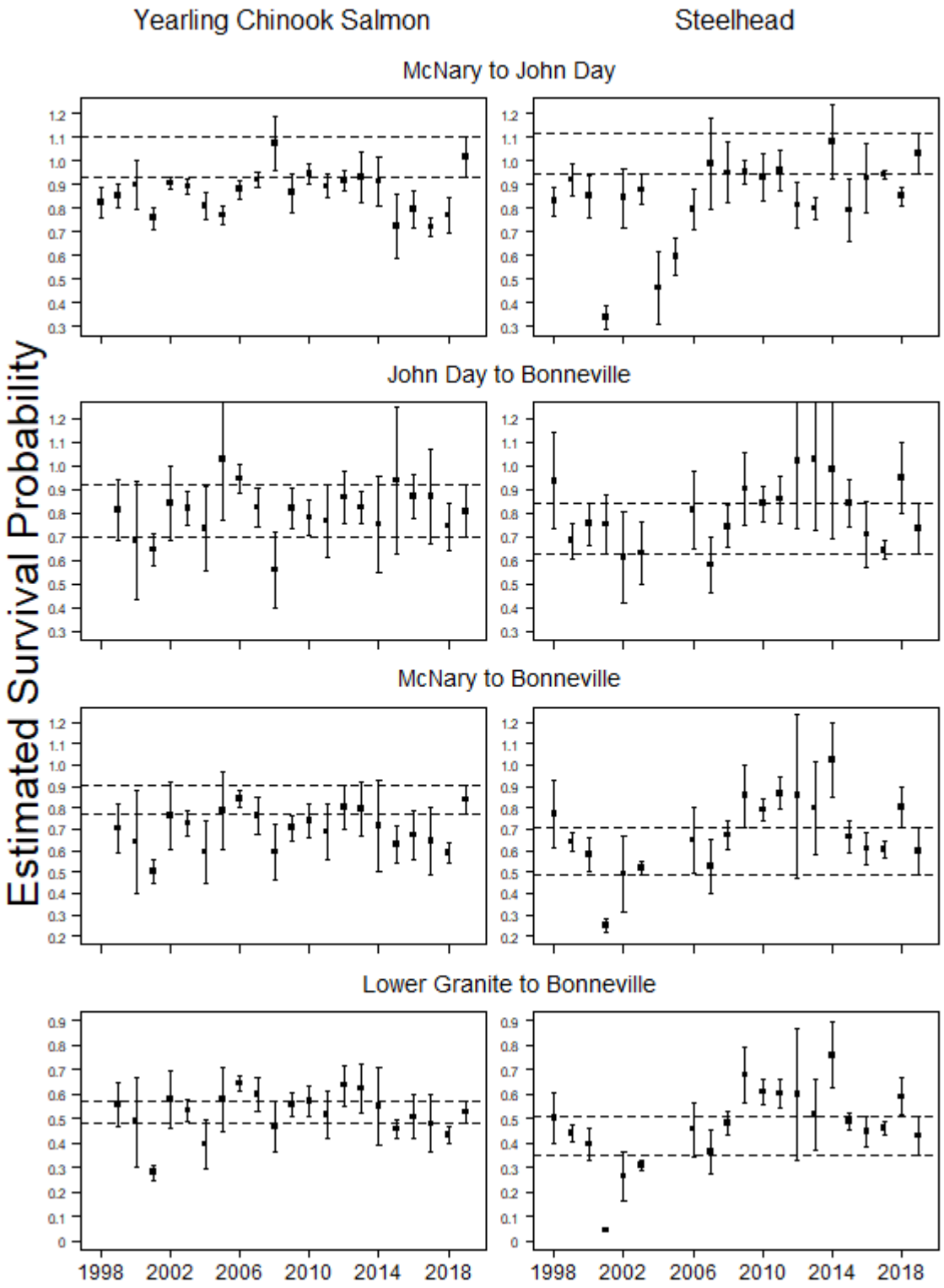

Figure 3. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2019 estimates.

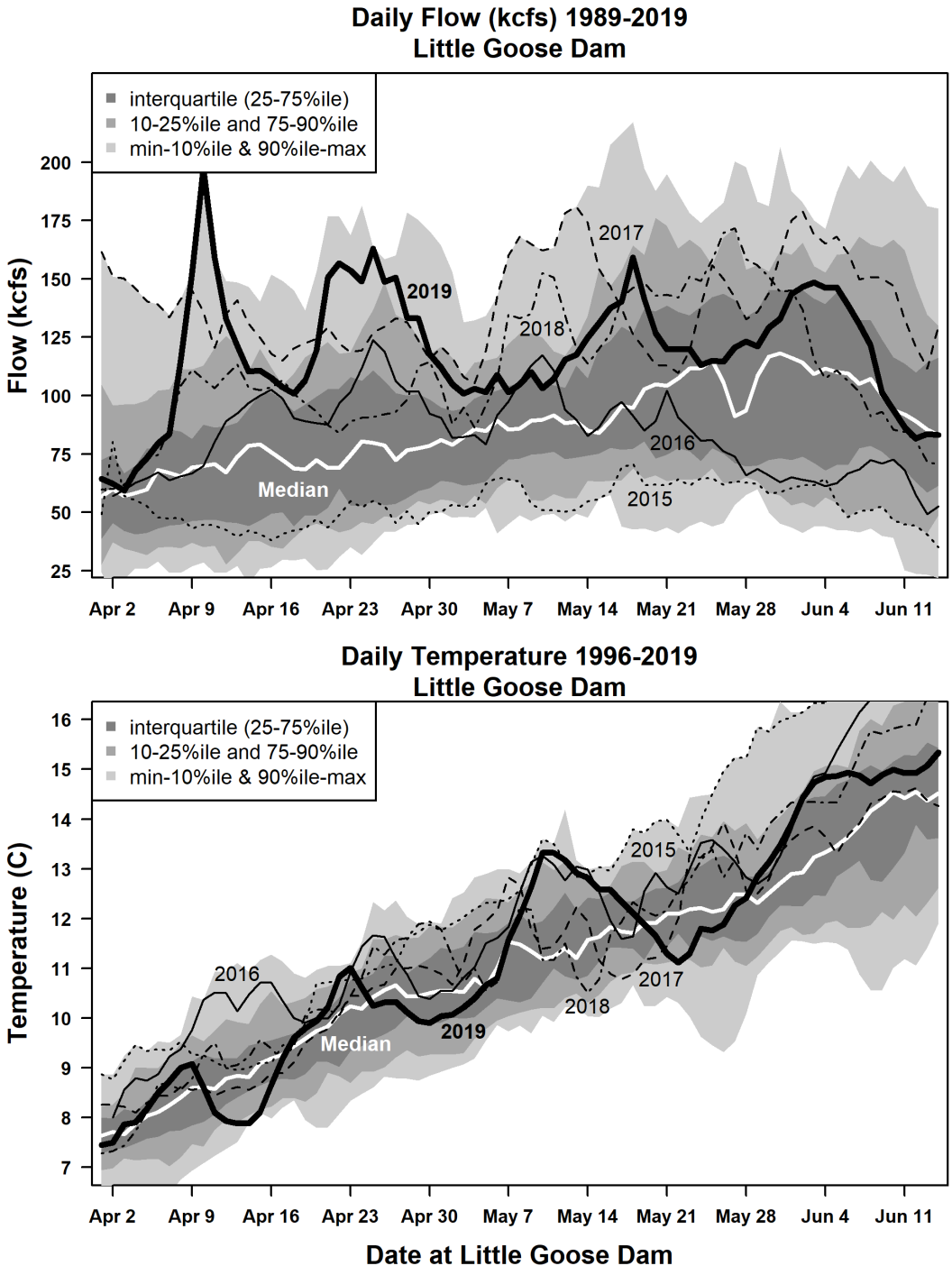

Figure 4. Upper panel shows daily mean Snake River flow from April to mid-June at Little Goose Dam. Long-term median flow and daily mean flows for 2015-2019 are plotted as lines. Shaded areas illustrate quantiles for each date in the 1989-2019 data set. Lower panel uses the same format to show daily mean temperature at Little Goose Dam. Quantiles for daily temperature are calculated from the 1996-2019 data set.

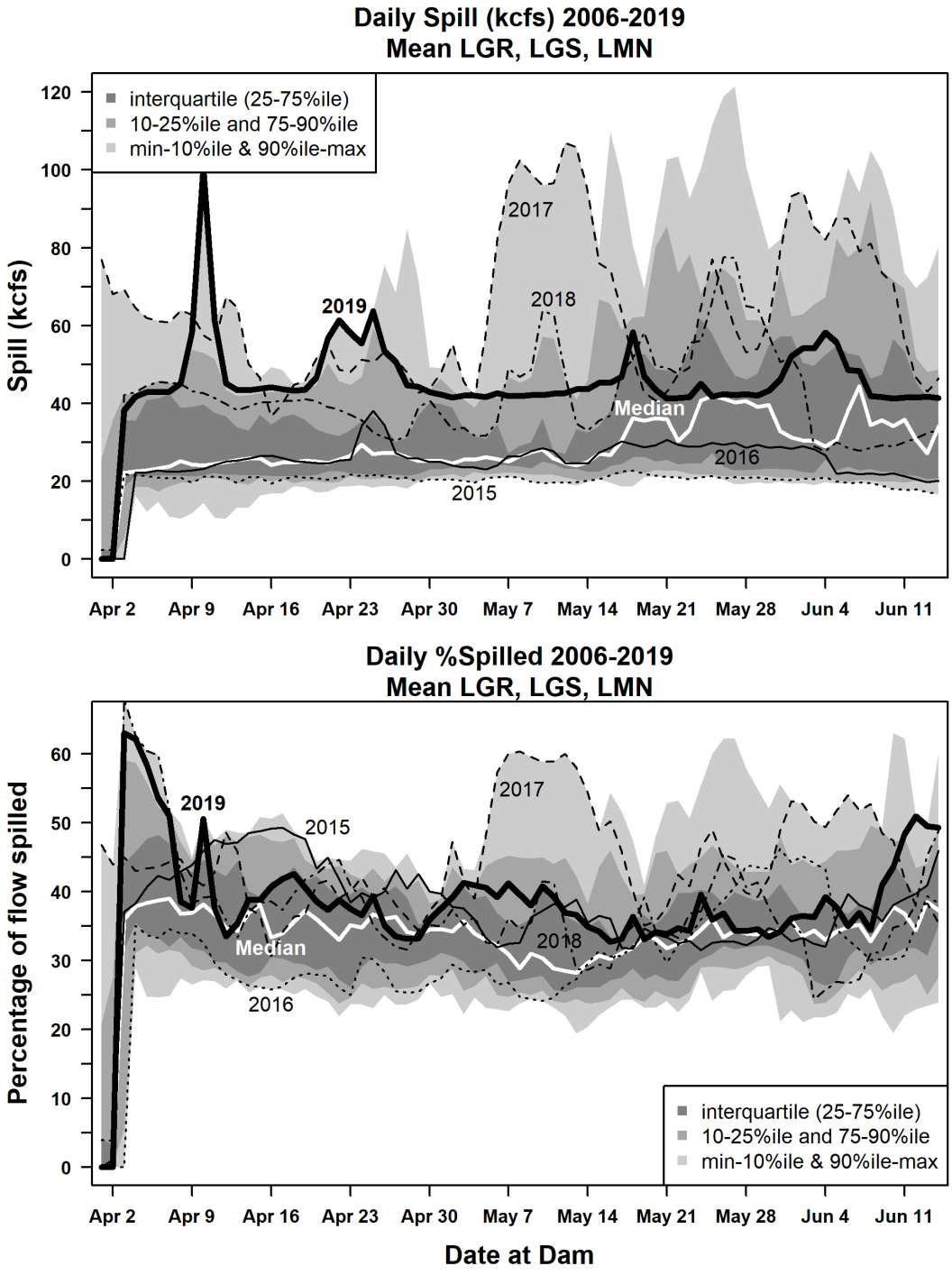

Figure 5. Upper panel shows daily mean (kcfs) Snake River spill from April to mid-June, averaged across Lower Granite, Little Goose and Lower Monumental Dams. Lower panel shows daily spill as a percentage of

total flow. Daily values for the years 2015-2019 and for long-term median are plotted as lines. Shaded areas indicate quantiles for each date from the long-term data set 2006-2019.

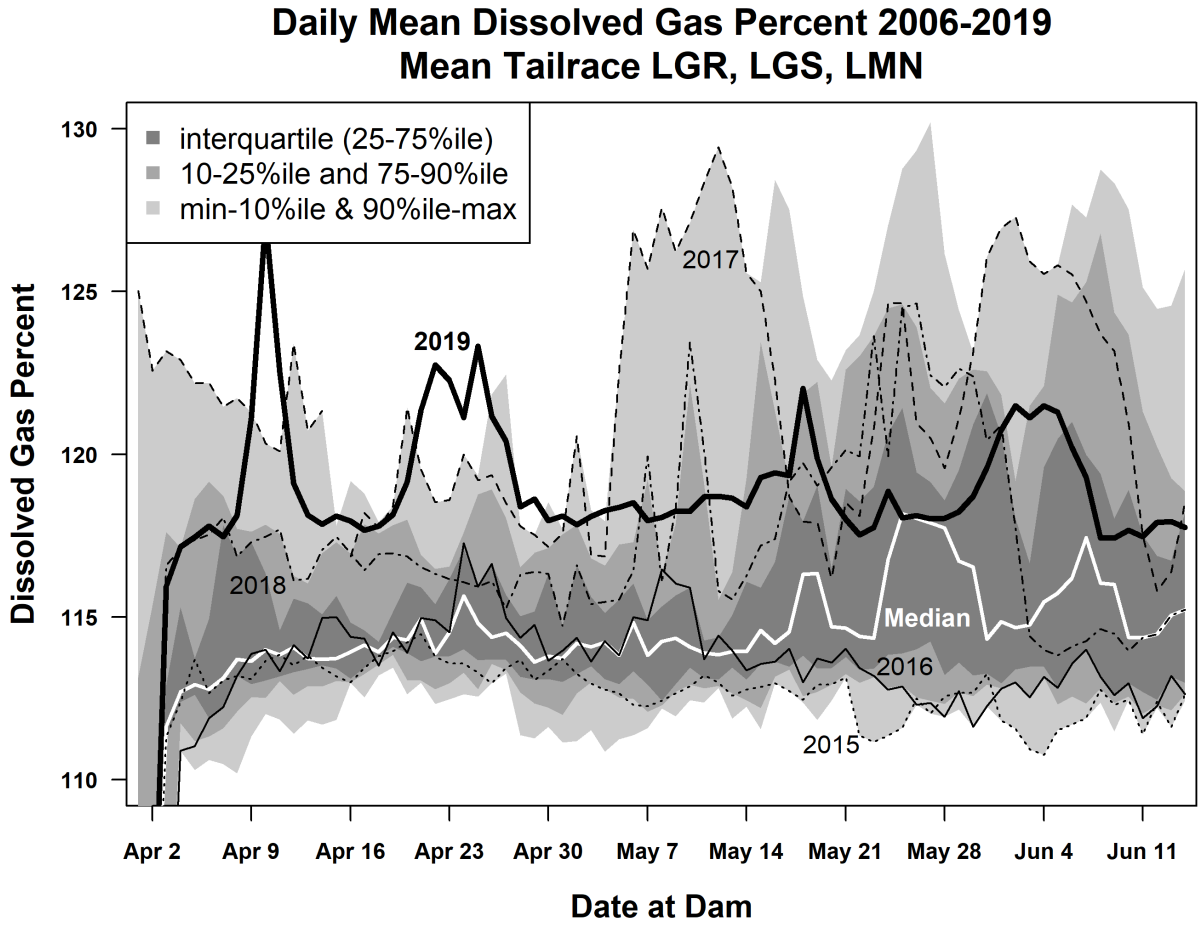

Figure 6. Daily mean percentage of dissolved gas averaged across Lower Granite, Little Goose and Lower Monumental Dam from April to mid-June. Daily percentages from individual years 2015-2019 are plotted against the long-term median from 2006 to 2019, with shaded areas indicating daily mean quantiles.

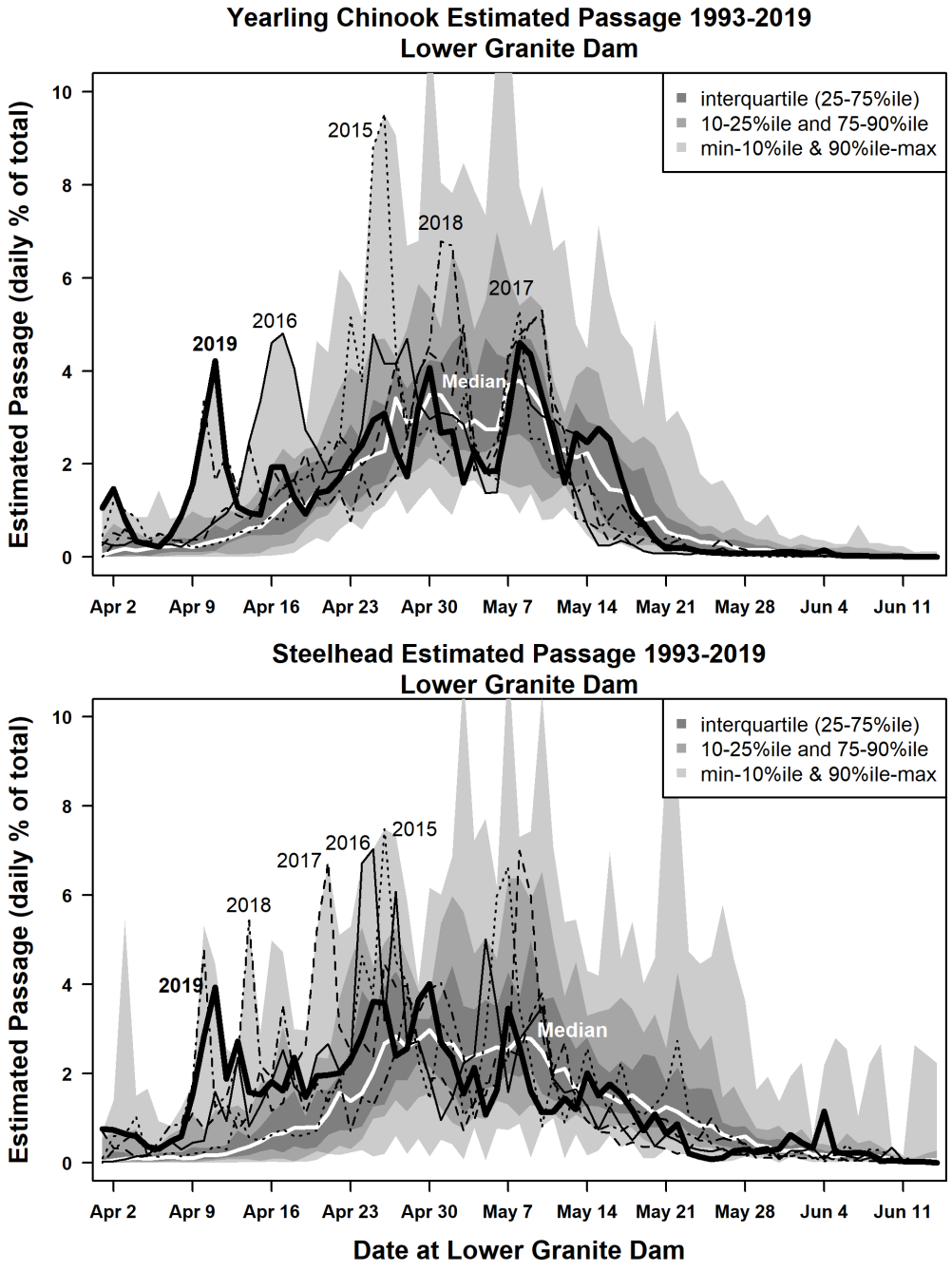

Figure 7. Estimated daily smolt passage at Lower Granite Dam for yearling Chinook salmon and steelhead. Daily passage expressed as percentage of the total for the year. Daily values for each year 2015-2019 and for long-term median are plotted as lines. Shaded areas indicate quantiles for each date from the long-term data set 1993-2019.

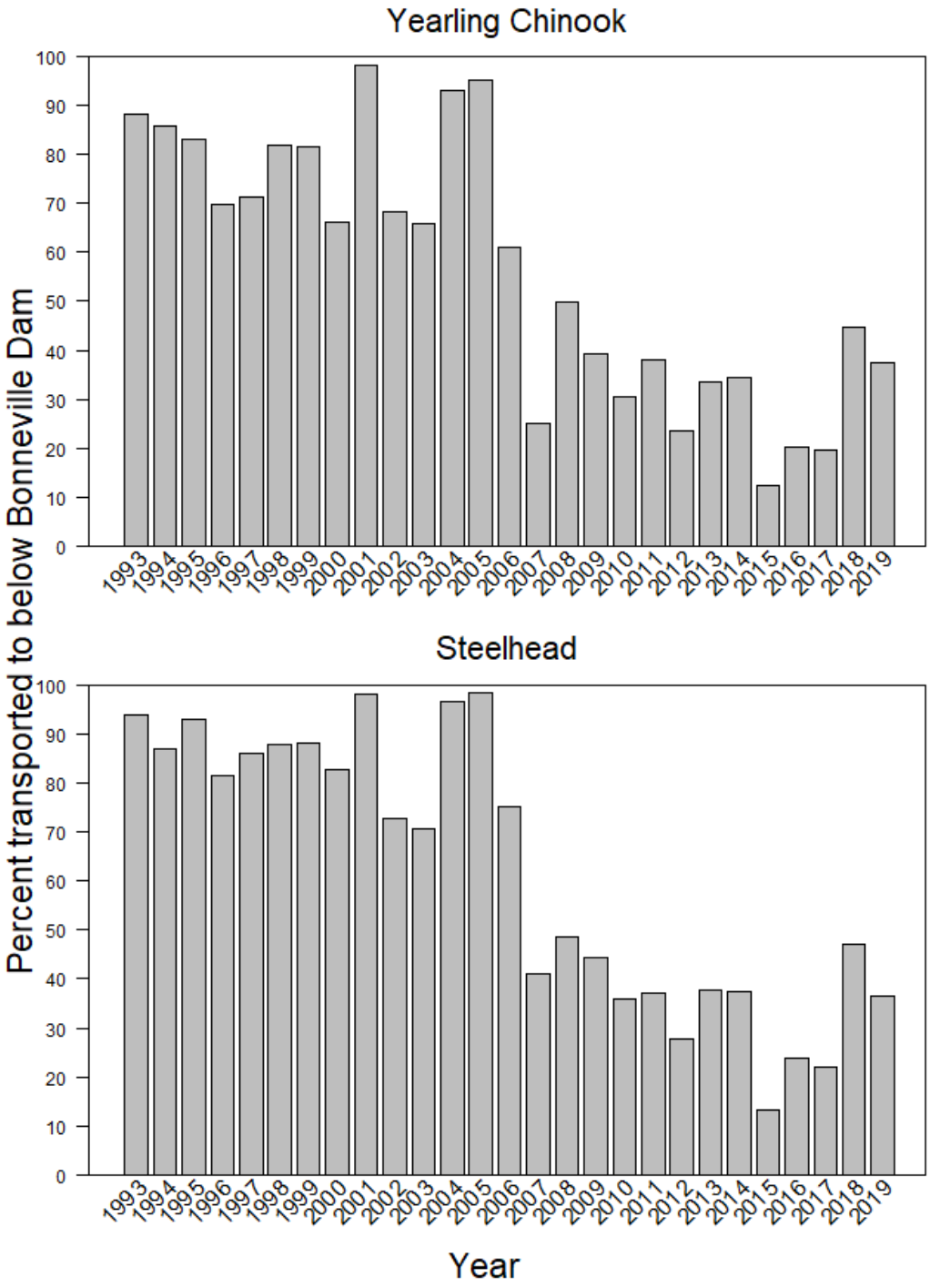

Figure 8. Annual estimates of the percentage of yearling Chinook salmon and steelhead smolts (mean of estimates for hatchery and wild smolts) that arrived at Lower Granite Dam that were subsequently transported, either from Lower Granite Dam or downstream from Little Goose or Lower Monumental Dam, to below Bonneville Dam (1993-2019).

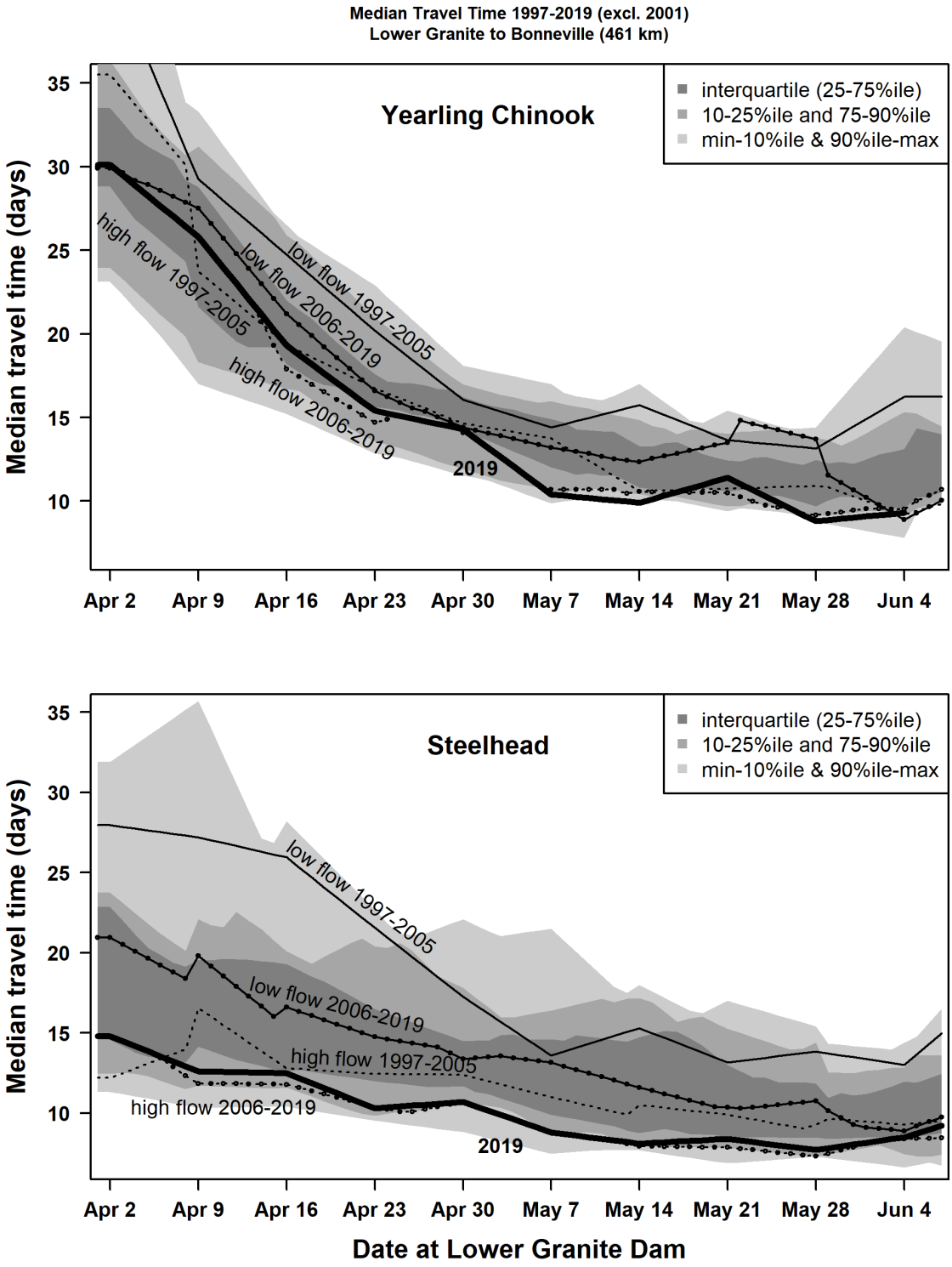

Figure 9. Median travel time (d) from Lower Granite to Bonneville Dam (461 km) for weekly groups of yearling Chinook salmon and steelhead. Shaded regions show daily quantiles during 1997-2019 (excluding 2001). Lines show daily medians from low- and high-flow years by spill regime, with low-flow years for the

former (2004-2005) and present regime (2007, 2010, 2013, and 2015) and high-flow years for the former (1997 and 2006) and present regime (2011, 2012, 2017, 2018, and 2019).