UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Fisheries Science Center
Fish Ecology Division
2725 Montlake Boulevard East
Seattle, WA 98112-2097
(206) 860-3270

September 26, 2016

MEMORANDUM FOR: F/NWR5 – Ritchie Graves

FROM: F/NWC3 - Richard W. Zabel

SUBJECT: Preliminary survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2016

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 2016 spring outmigration. We also provide preliminary estimates of the proportion of Snake River smolts that were transported from Snake River dams in 2016. Our complete detailed analyses and report for the spring migration will be available by the end of the year. 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 2016, NOAA Fisheries PIT tagged 17,972 river-run hatchery steelhead, 14,774 wild steelhead, and 22,145 wild yearling Chinook salmon for release into the tailrace of Lower Granite Dam.

Survival estimates provided in this memorandum are derived from PIT-tag 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 2016 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 the seven Snake River Basin hatcheries Dworshak, Kooskia, Lookingglass/Imnaha Weir, Rapid River, McCall/Knox Bridge, Pahsimeroi, and Sawtooth every year from 1993 through 2016 (except Pahsimeroi in 1996). Across these "index" hatcheries, the annual mean estimated survival from release to Lower Granite Dam has been relatively stable since 1998 (Figure 1, Table 1). In 2016, the mean was 71.7%, which is the highest estimate in the 24 years of the study (though not statistically significantly higher than most other years). The minimum observed mean was 49.4%, in 1997 (Figure 1).

Downstream of Lower Granite Dam, mean estimated survival for Snake River yearling Chinook salmon (hatchery and wild combined) in 2016 was above average in all individual project reaches except for the Little Goose to Lower Monumental reach and the McNary to John Day reach (Table 2, Figures 2 and 3). This resulted in above average survival from Lower Granite to McNary, but below average survival in the remaining combined reaches of interest (Table 3). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to McNary Dam tailrace in 2016 was 75.2% (95% CI: 73.0, 77.4%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 67.2% (95% CI: 55.4, 79.0%). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to Bonneville Dam tailrace was 50.5% (95% CI: 41.6, 59.5%). Estimated survival for the Lower Granite project (head of reservoir to tailrace) was 93.6%, based on fish PIT tagged at and released from the Snake River trap. The combined yearling Chinook salmon survival estimate from the trap to Bonneville Dam tailrace was 47.3% (95% CI: 38.8, 55.8%), which is a little below the long-term average of 49.3%.

For wild Snake River yearling Chinook, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 70.3% (95% CI: 66.7, 73.6%), and from McNary Dam tailrace to Bonneville Dam tailrace was 49.0% (95% CI: 30.4, 67.6%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 95.7%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 33.0% (95% CI: 20.3, 45.7%).

For Snake River steelhead (hatchery and wild combined), mean estimated survival in 2016 was above average in all of the individual reaches except for John Day to Bonneville (Table 4, Figures 2 and 3). This resulted in above average survival from Lower Granite to McNary, but below average survival in the remaining combined reaches of interest (Table 5). Mean estimated survival for steelhead from Lower Granite Dam tailrace to McNary Dam tailrace was 73.0% (95% CI: 69.1, 76.9%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 60.8% (95% CI: 53.0, 68.6%). Mean estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 44.4% (95% CI: 38.2, 50.6%). Estimated survival for the Lower Granite project (head of reservoir to tailrace) was 99.8%, based on fish PIT tagged at and released from the Snake River trap. The combined steelhead survival estimate from the trap to Bonneville Dam tailrace was 44.4% (95% CI: 38.0, 50.6%).

For wild Snake River steelhead, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 64.4% (95% CI: 54.0, 74.8%), and from McNary Dam tailrace to Bonneville Dam tailrace was 43.6% (95% CI: 35.2, 52.0%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 95.8%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 27.0% (95% CI: 19.8, 34.0%).

For PIT-tagged hatchery yearling Chinook salmon originating from the upper Columbia River in 2016, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 80.7% (95% CI: 70.6, 92.2%; Table 6), which is almost exactly equal to the long-term average.

For PIT-tagged hatchery steelhead originating from the upper Columbia River in 2016, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 48.7% (95% CI: 42.8, 55.4%; Table 6). 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 2016 of Snake River sockeye salmon (hatchery and wild combined) from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 11.9% (95% CI: 7.3, 19.4%; Table 7). Estimated survival in 2016 of Columbia River sockeye salmon (hatchery and wild combined) from the tailrace of Rock Island Dam to the tailrace of Bonneville Dam was 44.8% (95% CI: 24.2%, 82.8%; Table 7). These estimates are below average for sockeye salmon from both drainages.

Our preliminary estimates of the percentage transported of non-tagged wild and hatchery spring-summer Chinook salmon smolts in 2016 are 19.3% and 21.0%, respectively. For steelhead, the estimates are 24.4% and 22.9% 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 from one of the downstream collector dams.

Discussion

For Snake River yearling Chinook salmon in 2016, estimated survival from the Snake River Trap to Bonneville Dam tailrace was 47.3%, which was a little below the long-term (1999-2016) average of 49.3%. The 2016 estimate was higher than the 2015 estimate of 38.9%, but the difference was not significantly different (P = 0.23; Table 3) due to the level of uncertainty in both estimates. Yearling Chinook survival through the hydropower system has remained relatively stable since 1999, with the exception of lower estimates in 2001, 2004, and 2015, which were all low-flow years.

For steelhead in 2016, estimated survival through the hydropower system was 44.3%, which was a little below the long-term mean of 45.1% (Table 5). The 2016 estimate was higher than the 2015 estimate of 36.4%, the difference being moderately significant (P = 0.094; Table 5). This is the second consecutive year with below average estimated survival for Snake River steelhead after seven consecutive years of survival estimates of 47.8% and higher. Note that estimated survival between McNary and Bonneville was

relatively low for both Snake River steelhead (60.8%) and Upper Columbia River steelhead (48.7%).

Estimated survival of Snake River sockeye between Lower Granite Dam and Bonneville Dam tailrace was 11.9%, which is the second lowest estimate we have in our time series (1998-2016). The component survival estimates for the Lower Granite Dam to McNary Dam reach and the McNary Dam to Bonneville Dam reach were both low. High rates of fungal infection were reported among juvenile sockeye entering the bypass systems at Lower Granite and Little Goose Dams (Fish Passage Advisory Committee notes, 26 May 2016). These fungal infections likely contributed to the high mortality rates experienced by Snake River sockeye in 2016. Survival of juvenile Upper Columbia River sockeye in the McNary to Bonneville Dam reach was also below average, but the reason for low survival among these fish is not known at this time.

Environmental conditions were close to average in 2016, with the exception of water temperature later in the season. Mean flow at Little Goose Dam in 2016 during the main migration period (1 April – 15 June) was 82.4 kcfs, which was a little below the long-term (1993-2016) mean of 89.9 kcfs. Daily flow values were above long-term daily means for the first part of the migration period, and then fell below the means in the second week of May and stayed below for the remainder of the migration period (Figure 4). Mean water temperature at Little Goose Dam in 2016 during the migration period was 12.3 °C, which was above the long-term mean of 11.2 °C, and was the third warmest year in our time series. Daily water temperatures were above the long-term daily means on most days, with differences becoming greatest in late May and early June (Figure 4).

Mean spill discharge at the Snake River dams during the 2016 migration was 24.9 kcfs, which was below the long-term (1993-2016) mean of 25.7 kcfs. Daily spill discharges were above the long-term daily means earlier in the season, but daily spill values fell below the daily means starting in the second week of May and stayed below for the remainder of the migration period (Figure 5). Spill as a percentage of flow at Snake River dams averaged 30.6% in 2016, which was above the long-term (1993-2016) mean of 26.1%, but was among the lower average spill percentages since 2007. Daily mean spill percentages in 2016 were above the long-term daily means for almost the entire migration period (Figure 5).

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2016 were the second lowest recorded in our time series of estimates (1993-2016; Figure 7). This is mostly due to the arrival timing of both species in relation to start dates of transportation, since collection probabilities at the collector dams were not unusually low during transportation operations. In 2016, collection for transportation began on 2 May at Lower Granite, Little Goose, and Lower Monumental Dams. We estimate that 76% of the annual total passage of wild yearling Chinook and 72% of hatchery yearling Chinook occurred at Lower Granite Dam before transportation began. After 2 May, 73% of wild yearling Chinook and 62% of hatchery Chinook were transported (the difference between rear-types is due to a difference in the probability of entering the collection system). Available steelhead data is not as differentiated between hatchery and wild fish (smolt sampling reports do not distinguish), so we are unable to estimate hatchery/wild differences with as much precision. We estimate that, on average, 58% of steelhead passed Lower Granite Dam before collection for transportation began, and that 51% of steelhead passing after 2 May were transported. During the period in which transportation occurred, 53% of steelhead that passed Lower Granite Dam were eventually collected and transported.

Median estimated travel times for both species between Lower Granite Dam and Bonneville Dam in April were shorter in 2016 than any other year in our time series (1998-2016; Figure 8). This coincided with relatively high flows in April. Median travel times were closer to the long-term average in May and June as flows fell below average. Since the institution of court-ordered spill in 2006, and the 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 less apparent for Chinook (Figure 8). Differences in travel times for low-flow years versus other years are not so well pronounced for either species (Figure 8). 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.

cc: F/NWC3 – Faulkner
F/NWC3 – Marsh
F/NWC3 – Smith
F/NWC3 - Widener
F/NWC3 - Zabel

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), 2014 through 2016.

	2014		2015		2016[a]	
Hatchery	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	0.816 (0.009)	0.685 (0.017)	0.768 (0.018)	0.609 (0.020)	0.714 (0.007)	0.538 (0.014)
Kooskia	0.595 (0.011)	0.406 (0.020)	0.532 (0.027)	0.397 (0.046)	0.684 (0.012)	0.499 (0.029)
Lookingglass (Catherine Cr.)	0.264 (0.005)	0.210 (0.012)	0.266 (0.016)	0.239 (0.020)	0.371 (0.005)	0.300 (0.016)
Lookingglass (Grande Ronde)	0.447 (0.048)	0.677 (0.346)	0.346 (0.050)	0.230 (0.044)	0.429 (0.016)	0.326 (0.044)
Lookingglass (Imnaha River)	0.673 (0.009)	0.545 (0.024)	0.655 (0.035)	0.457 (0.031)	0.704 (0.007)	0.526 (0.022)
Lookingglass (Lostine River)	0.662 (0.018)	0.532 (0.054)	0.556 (0.078)	0.429 (0.106)	0.586 (0.017)	0.419 (0.039)
McCall (Johnson Cr.)	0.495 (0.035)	0.374 (0.064)	0.413 (0.089)	0.185 (0.038)	---	---
McCall (Knox Bridge)	0.714 (0.008)	0.579 (0.015)	0.729 (0.030)	0.546 (0.019)	0.654 (0.006)	0.514 (0.014)
Pahsimeroi	0.794 (0.008)	0.702 (0.021)	0.771 (0.036)	0.547 (0.034)	0.772 (0.008)	0.512 (0.026)
Rapid River	0.757 (0.008)	0.641 (0.020)	0.811 (0.024)	0.712 (0.022)	0.815 (0.005)	0.632 (0.015)
Sawtooth	0.646 (0.008)	0.607 (0.033)	0.696 (0.036)	0.513 (0.027)	0.676 (0.006)	0.474 (0.015)
Entiat	---	0.362 (0.012)	---	0.483 (0.052)	---	0.631 (0.024)
Winthrop	---	0.708 (0.338)	---	0.540 (0.054)	---	0.577 (0.022)
Leavenworth	---	0.410 (0.093)	---	0.497 (0.034)	---	0.501 (0.016)

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), 1995–2016. 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.

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	0.925 (0.009)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)	NA	NA
1999	0.940 (0.009)	0.949 (0.002)	0.925 (0.004)	0.904 (0.007)	0.951	0.853 (0.027)	0.814 (0.065)	0.902
2000	0.929 (0.014)	0.938 (0.006)	0.887 (0.009)	0.928 (0.016)	0.963	0.898 (0.054)	0.684 (0.128)	0.827
2001	0.954 (0.015)	0.945 (0.004)	0.830 (0.006)	0.708 (0.007)	0.841	0.758 (0.024)	0.645 (0.034)	0.803
2002	0.953 (0.022)	0.949 (0.006)	0.980 (0.008)	0.837 (0.013)	0.915	0.907 (0.014)	0.840 (0.079)	0.917
2003	0.993 (0.023)	0.946 (0.005)	0.916 (0.011)	0.904 (0.017)	0.951	0.893 (0.017)	0.818 (0.036)	0.904
2004	0.893 (0.009)	0.923 (0.004)	0.875 (0.012)	0.818 (0.018)	0.904	0.809 (0.028)	0.735 (0.092)	0.857
2005	0.919 (0.015)	0.919 (0.003)	0.886 (0.006)	0.903 (0.010)	0.950	0.772 (0.029)	1.028 (0.132)	1.014
2006	0.952 (0.011)	0.923 (0.003)	0.934 (0.004)	0.887 (0.008)	0.942	0.881 (0.020)	0.944 (0.030	0.972
2007	0.943 (0.028)	0.938 (0.006)	0.957 (0.010)	0.876 (0.012)	0.936	0.920 (0.016)	0.824 (0.043)	0.908
2008	0.992 (0.018)	0.939 (0.006)	0.950 (0.011)	0.878 (0.016)	0.937	1.073 (0.058)	0.558 (0.082)	0.750
2009	0.958 (0.010)	0.940 (0.006)	0.982 (0.009)	0.855 (0.011)	0.925	0.866 (0.042)	0.821 (0.043)	0.906
2010	0.968 (0.040)	0.962 (0.011)	0.973 (0.019)	0.851 (0.017)	0.922	0.947 (0.021)	0.780 (0.039)	0.883
2011	0.943 (0.009)	0.919 (0.007)	0.966 (0.008)	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	0.938 (0.058)	0.827 (0.043)	0.909
2014	0.905 (0.015)	0.940 (0.007)	0.919 (0.010)	0.894 (0.017)	0.946	0.912 (0.053)	0.752 (0.104)	0.867
2015	0.909 (0.103)	0.857 (0.036)	0.964 (0.057)	0.802 (0.033)	0.896	0.724 (0.069)	0.937 (0.160)	0.968
2016[a]	0.936 (0.015)	0.956 (0.006)	0.912 (0.100)	0.872 (0.013)	0.934	0.796 (0.039)	0.871 (0.047)	0.933
Mean[b]	**0.932 (0.008)**	**0.925 (0.007)**	**0.923 (0.009)**	**0.861 (0.012)**	**0.928 (0.007)**	**0.872 (0.018)**	**0.806 (0.026)**	**0.896 (0.015)**

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), 1997–2016. 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)	0.792 (0.071)	0.622 (0.052)	0.525 (0.048)
2014	0.905 (0.015)	0.768 (0.015)	0.715 (0.107)	0.549 (0.083)	0.497 (0.075)
2015	0.909 (0.103)	0.680 (0.035)	0.629 (0.043)	0.428 (0.037)	0.389 (0.055)
2016[a]	0.936 (0.015)	0.752 (0.011)	0.672 (0.060)	0.505 (0.046)	0.473 (0.043)
Mean[b]	**0.932 (0.008)**	**0.736 (0.013)**	**0.703 (0.021)**	**0.527 (0.022)**	**0.493 (0.020)**

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), 1995–2016. 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.

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)	0.848 (0.039)	0.834 (0.060)	0.939 (0.073)	0.969	0.792 (0.066)	0.842 (0.050)	0.918
2016[a]	0.998 (0.016)	0.990 (0.007)	0.918 (0.016)	0.813 (0.025)	0.902	0.927 (0.074)	0.709 (0.071)	0.842
Mean[b]	**0.957 (0.009)**	**0.921 (0.010)**	**0.906 (0.012)**	**0.770 (0.029)**	**0.873 (0.019)**	**0.827 (0.042)**	**0.805 (0.034)**	**0.894 (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 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), 1997–2016. 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)	0.484 (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)
2016[a]	0.998 (0.016)	0.730 (0.020)	0.608 (0.040)	0.444 (0.032)	0.443 (0.032)
Mean[b]	**0.953 (0.011)**	**0.648 (0.030)**	**0.678 (0.042)**	**0.463 (0.038)**	**0.451 (0.040)**

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, 1999–2016. 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[a]	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)
Mean[b]	**0.555 (0.012)**	**0.902 (0.024)**	**0.890 (0.045)**	**0.809 (0.034)**	**0.417 (0.016)**	**0.895 (0.034)**	**0.827 (0.055)**	**0.730 (0.045)**

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, 1996–2016. 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[a]	0.523 (0.047)	0.227 (0.059)	0.119 (0.030)	0.807 (0.082)	0.545 (0.126)	0.448 (0.144)
Mean[b]	**0.629 (0.037)**	**0.558 (0.074)**	**0.405 (0.055)**	**0.671 (0.033)**	**0.730 (0.082)**	**0.503 (0.059)**

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.

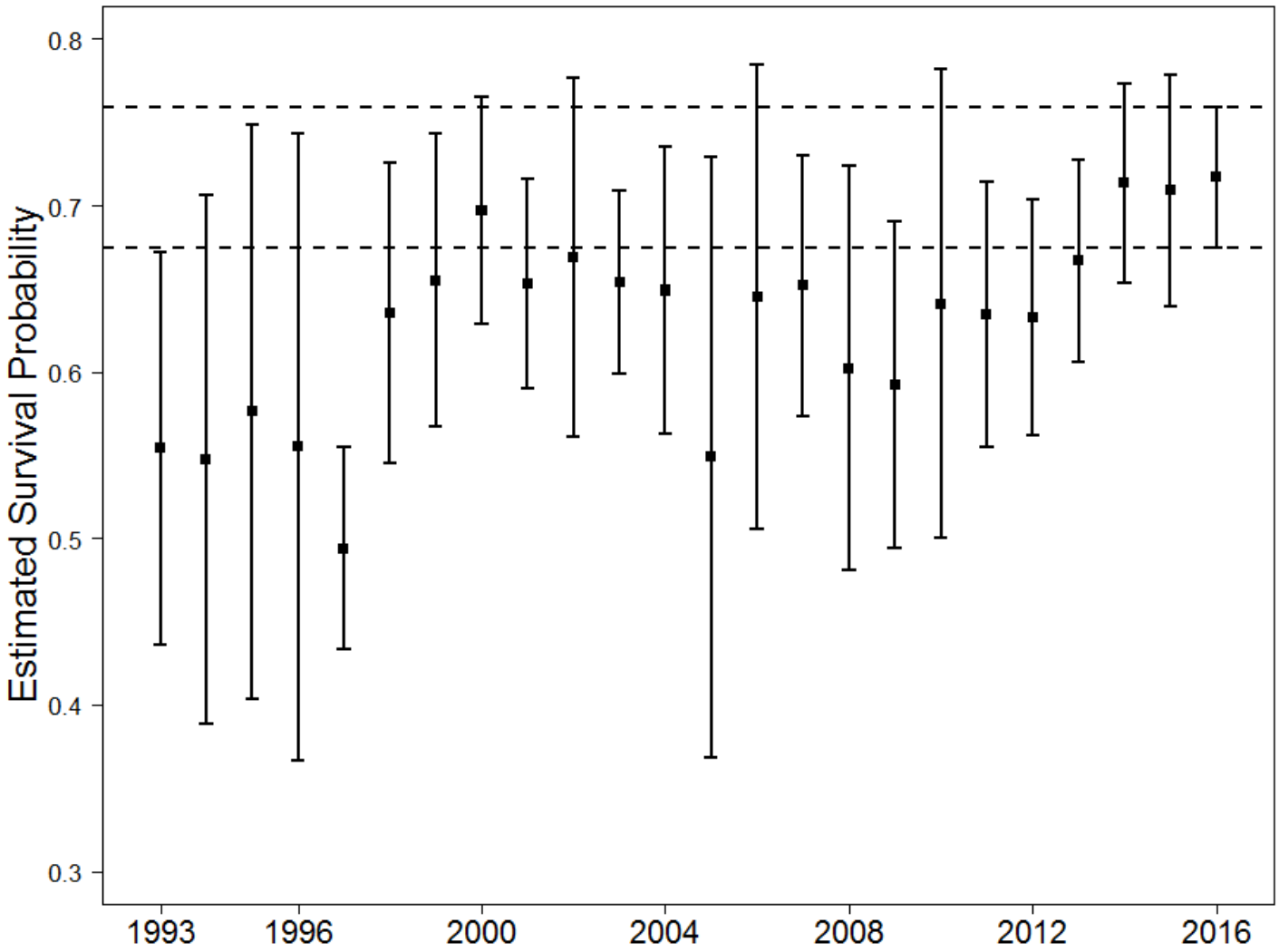

Figure 1. Annual average survival estimates from release to Lower Granite Dam for PIT-tagged yearling **Chinook** salmon released from Snake River Basin hatcheries, 1993-2016. Hatcheries used for average (index groups) are those with consistent PIT-tag releases through the series of years shown. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are the 2016 confidence interval endpoints and are shown for comparison to other years.

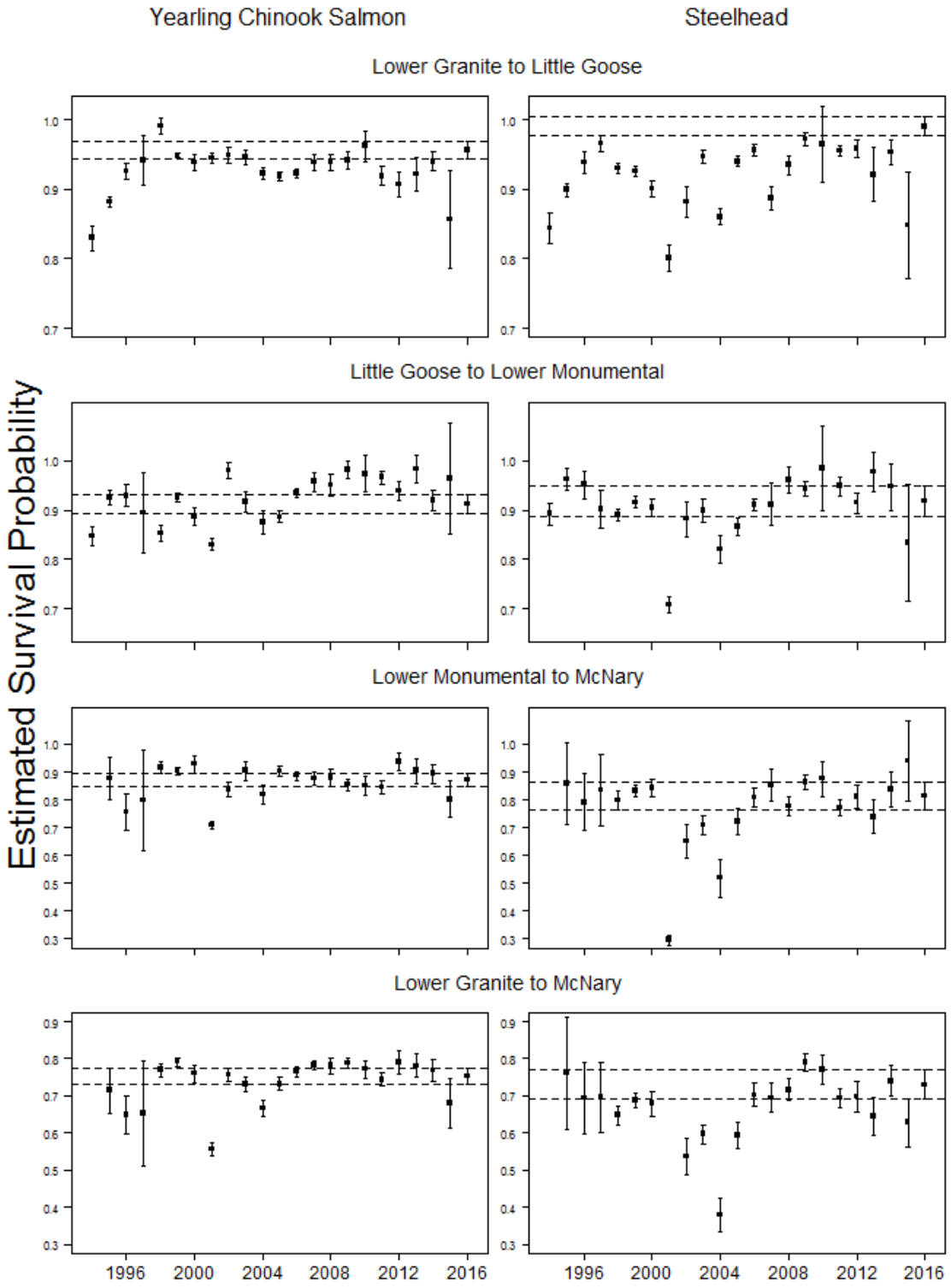

Figure 2. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2016 estimates.

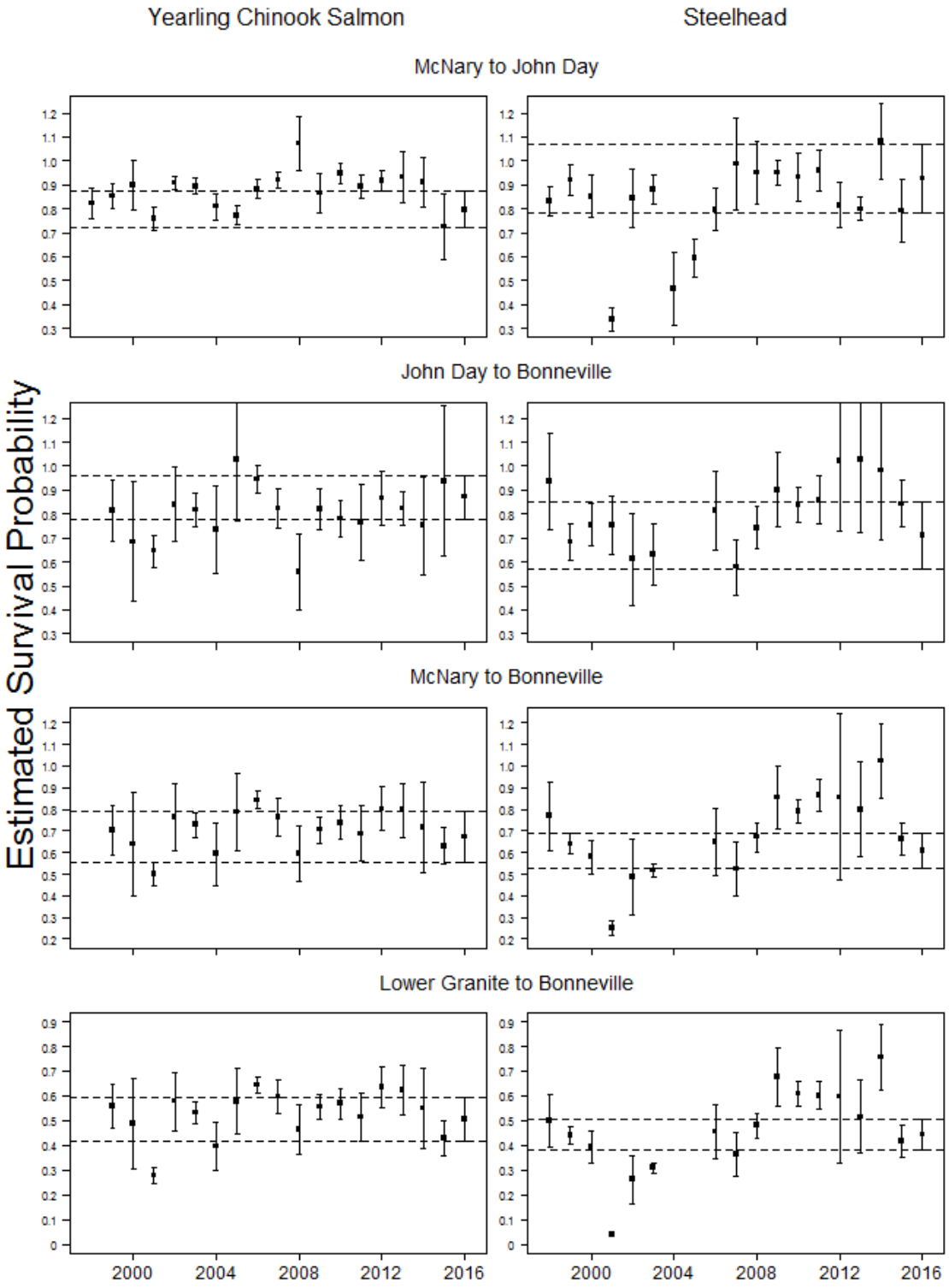

Figure 3. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2016 estimates.

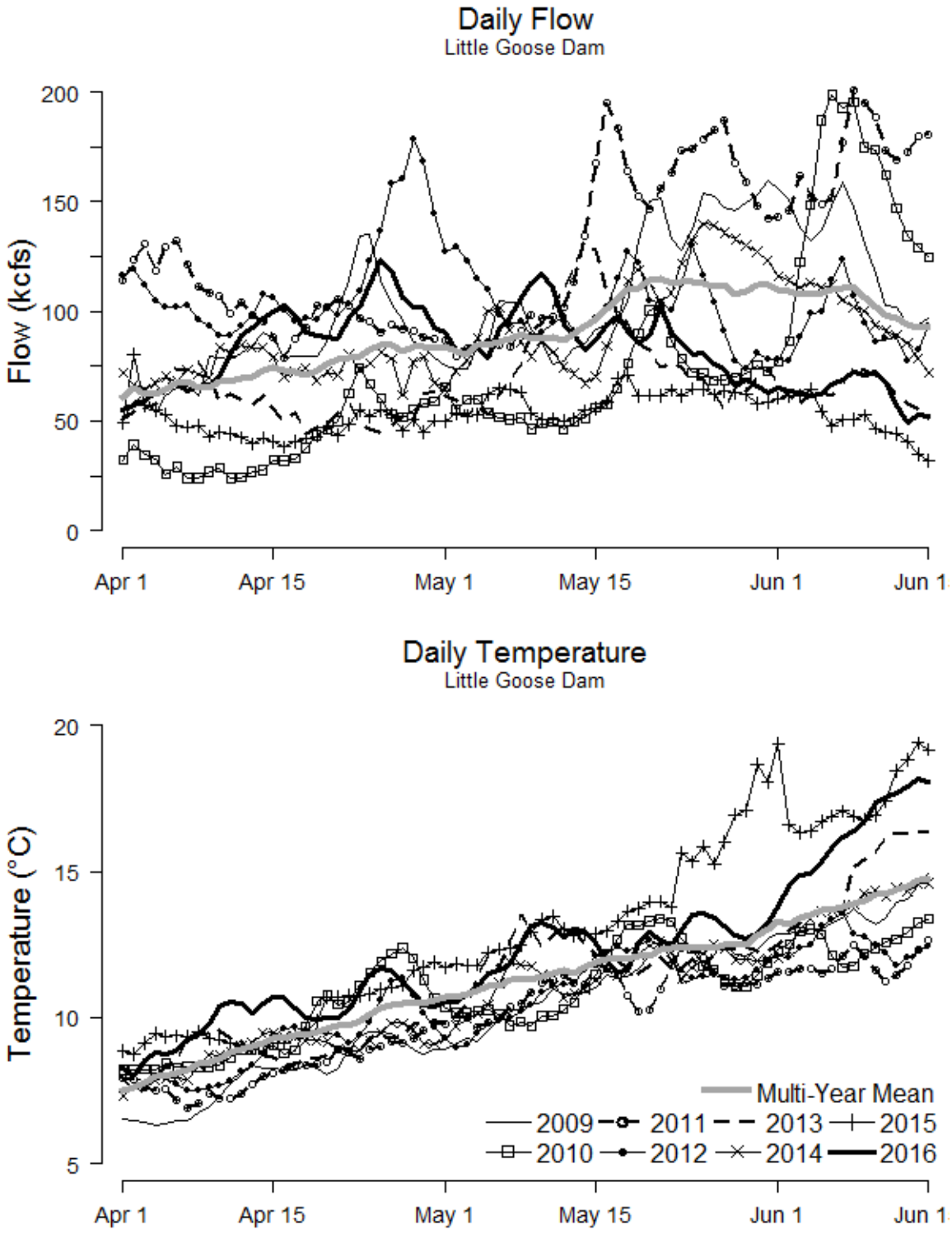

Figure 4. Snake River flow (kcfs; top panel) and water temperature (°C; bottom panel) measured at Little Goose Dam during April and May, 2009-2016, including daily long-term means (1993-2016).

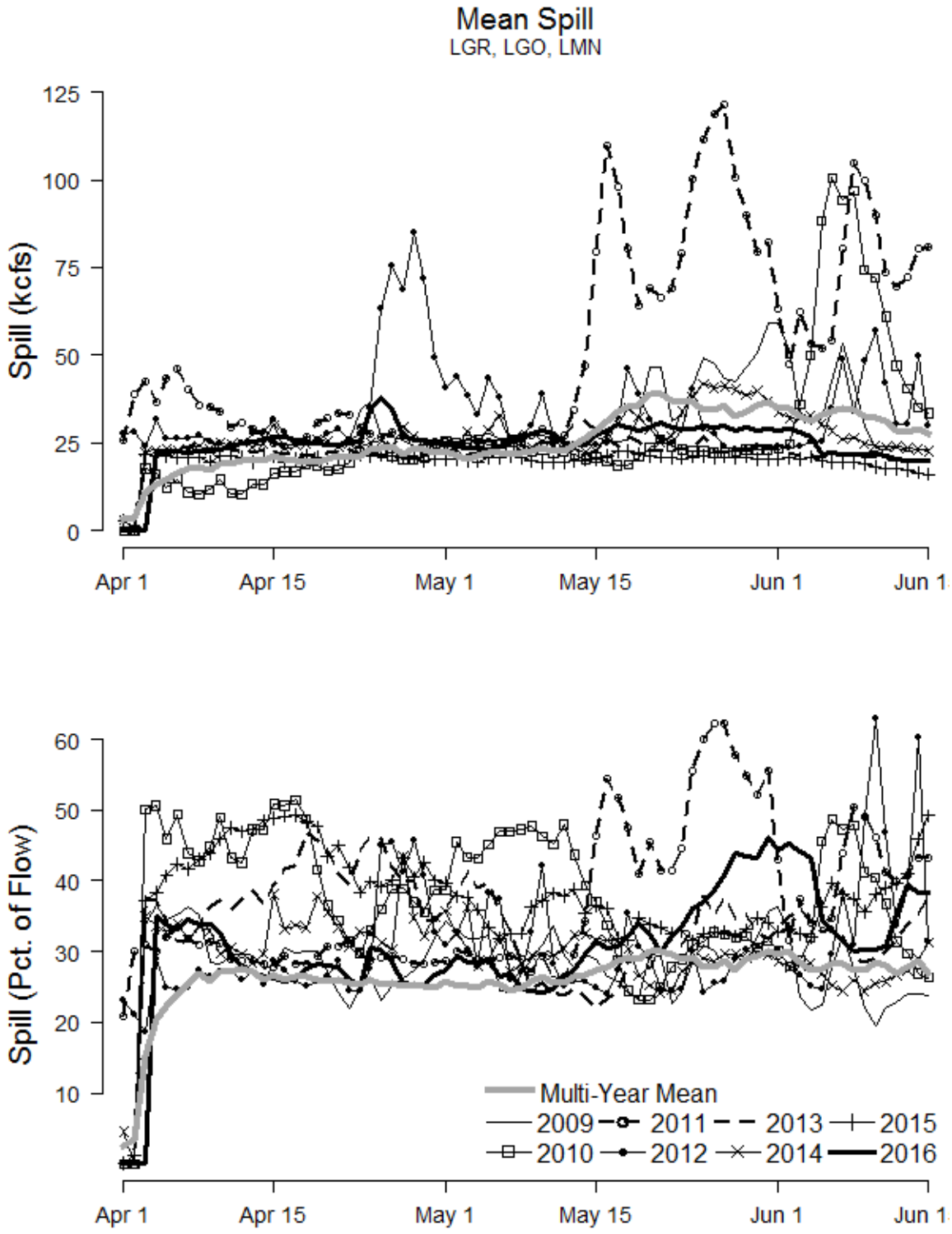

Figure 5. Mean spill (top panel shows kcfs; bottom panel shows percentage of total flow) at Snake River dams during April and May, 2009-2016, including daily long-term means (1993-2016).

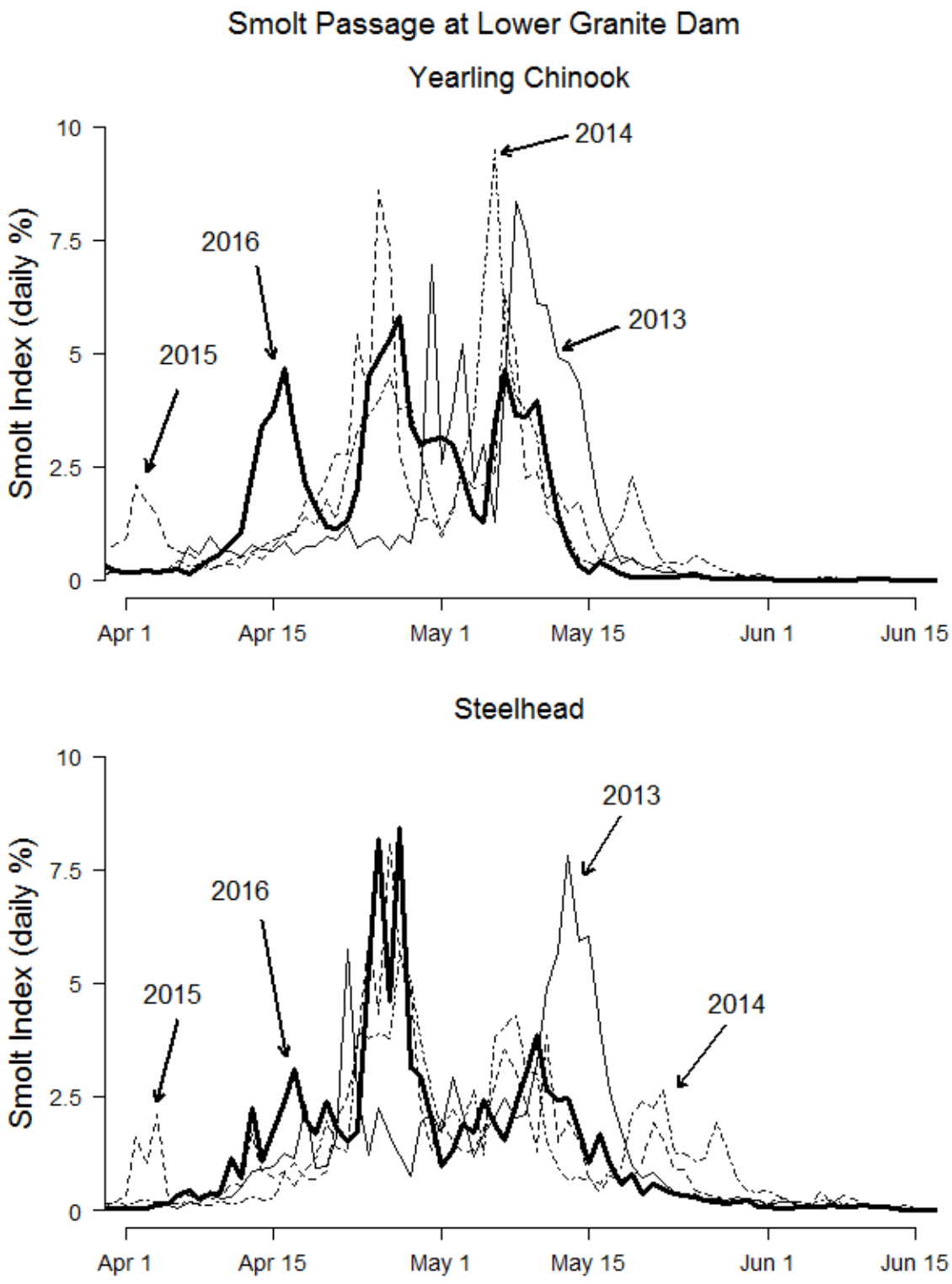

Figure 6. Smolt index as daily percentage of total passage at Lower Granite Dam 2013-2016 for hatchery and wild combined yearling Chinook and steelhead.

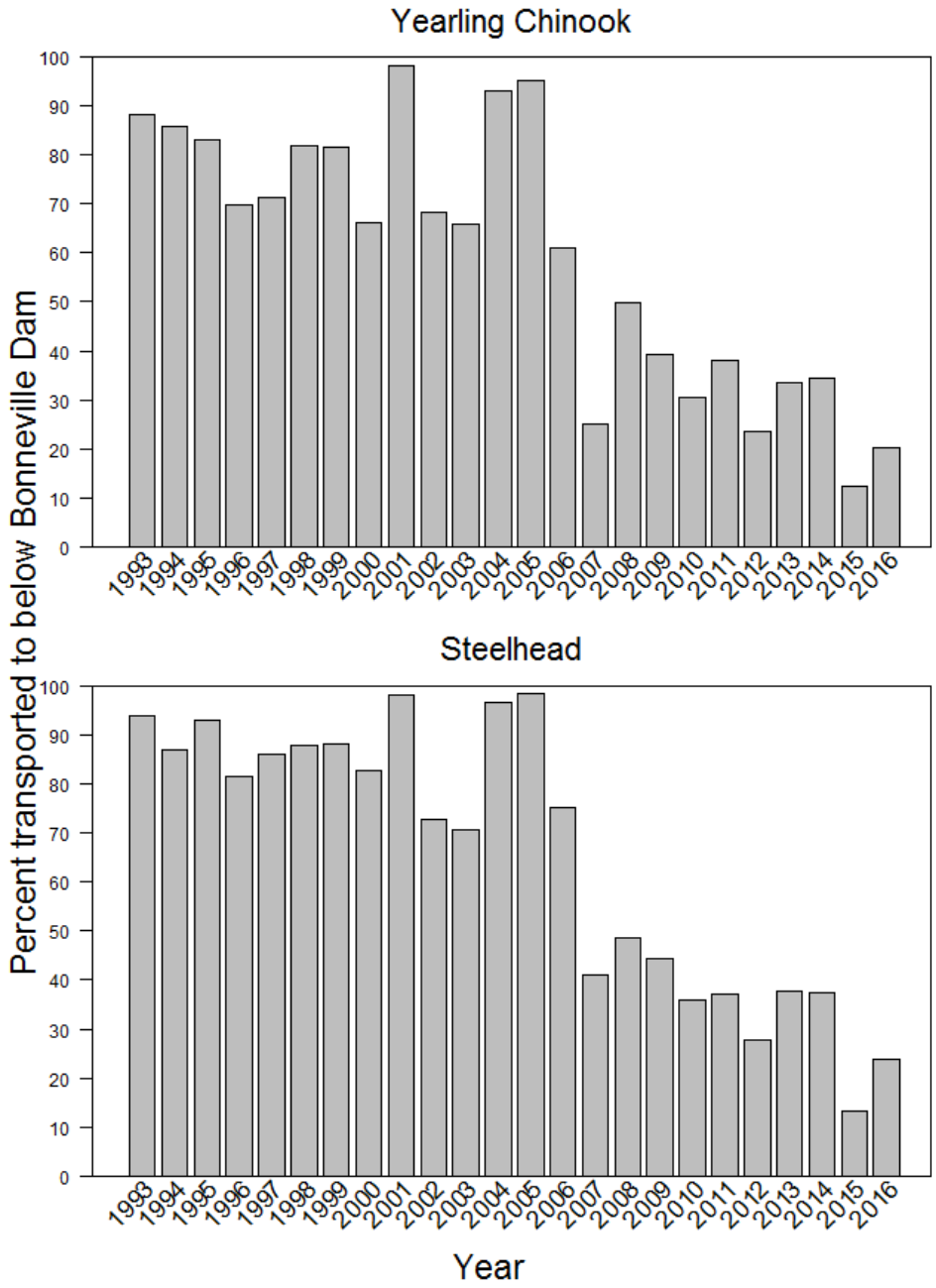

Figure 7. Estimated percent of yearling Chinook salmon and steelhead (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2016).

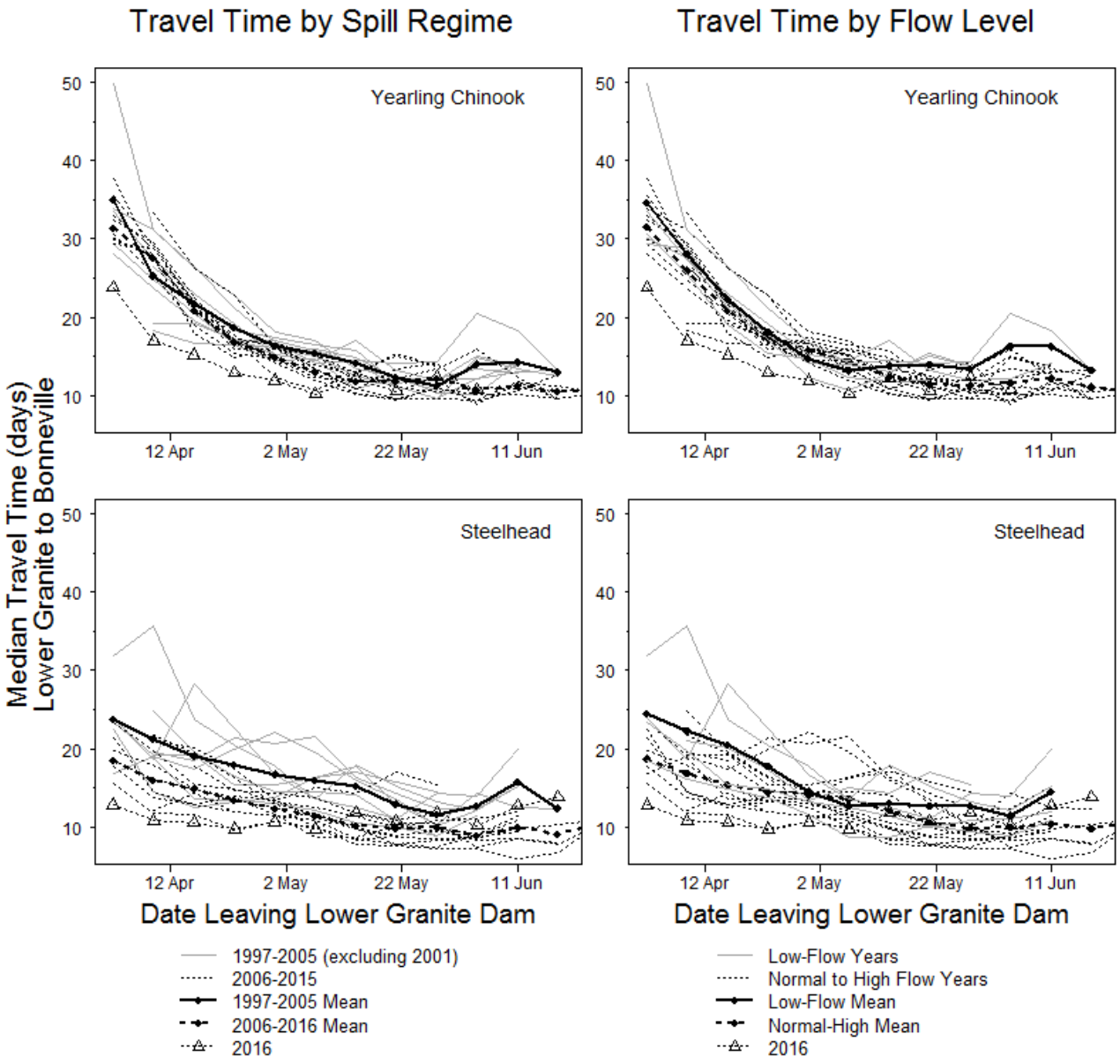

Figure 8. Median travel time from Lower Granite Dam to Bonneville Dam for yearling Chinook salmon and steelhead by spill regime (left) and mean flow category (right) in the period 1998-2016 (excluding 2001), with long-term mean for the same period. Here spill regime is defined by court-ordered spill starting in 2006 and the concurrent installation of additional surface collectors, and low-flow years are those with mean of 70 kcfs or less for the period of 1 April through 15 June. The 2001 migration year is excluded from the individual years and means due to its unusual combination of low flow and no spill and the influence that has on the group means.