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MEMORANDUM FOR: F/NWR5 - Ritchie Graves

FROM: F/NWC3 - Richard W. Zabel *Richard W. Zabel*

SUBJECT: Preliminary survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2017

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 2017 spring outmigration. We also provide preliminary estimates of the proportion of Snake River smolts that were transported from Snake River dams in 2017. 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 2017, NOAA Fisheries PIT tagged 22,049 river-run hatchery steelhead, 18,422 wild steelhead, and 14,241 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 2017 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 2017 (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 2017, the mean was 65.0%; while lower than mean survival in the past three years, the mean hatchery survival to Lower Granite in 2017 was very close to the overall mean from 1998 through 2017 of 65.1%. The annual mean has ranged from 49.4% in 1997 to 71.7% in 2016 (Figure 1).

Downstream of Lower Granite Dam, mean estimated survival for Snake River yearling Chinook salmon (hatchery and wild combined) in 2017 was nearly average in the Lower Granite to Little Goose and Little Goose to Lower Monumental reaches, and above average in the Lower Monumental to McNary and John Day to Bonneville reaches. However, estimated survival in the McNary to John Day reach was the lowest on record (Table 2, Figures 2 and 3). These estimates 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 2017 was 74.3% (95% CI: 72.0, 76.6%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 64.3% (95% CI: 33.5, 95.1%). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to Bonneville Dam tailrace was 47.8% (95% CI: 24.9, 70.7%).



In almost all past years of our study, we have estimated survival from the Snake River trap to Lower Granite Dam, and combined that reach with those from Lower Granite and Bonneville Dam to estimate survival throughout the entire hydropower system. For 2017, no estimate is possible from the Snake River trap, because unusually high flow conditions throughout the migration season prevented the operation of the trap.

For wild Snake River yearling Chinook, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 70.9% (95% CI: 67.0, 74.8%), and from McNary Dam tailrace to Bonneville Dam tailrace was 43.6% (95% CI: 31.3, 55.9%). We were unable to estimate survival from the Snake River trap to Bonneville Dam because tagged fish were not released at the trap. Estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 30.9% (95% CI: 22.1, 40.0%).

For Snake River steelhead (hatchery and wild combined), mean estimated survival in 2017 was above average in all of the individual reaches except for John Day to Bonneville (Table 4, Figures 2 and 3). For combined reaches, estimated survival was above average from Lower Granite to McNary and below average from McNary to Bonneville. The resulting overall survival from Lower Granite to Bonneville was very close to the long-term average (Table 5). Mean estimated survival for steelhead from Lower Granite Dam tailrace to McNary Dam tailrace was 75.9% (95% CI: 72.2, 79.6%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 60.5% (95% CI: 53.3, 67.8%). Mean estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 45.9% (95% CI: 40.0, 51.8%). We were unable to estimate survival from the Snake River trap in 2017 because tagged fish were not released at the trap.

For wild Snake River steelhead, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 72.3% (95% CI: 64.7, 80.0%), and from McNary Dam tailrace to Bonneville Dam tailrace was 41.3% (95% CI: 30.0, 52.7%). We were unable to estimate survival from the Snake River trap to Bonneville Dam because tagged fish were not released at the trap. Estimated



survival for wild Snake River steelhead from Lower Granite Dam tailrace to Bonneville Dam tailrace was 29.9% (95% CI: 21.1, 38.7%).

For PIT-tagged hatchery yearling Chinook salmon originating from the upper Columbia River in 2017, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 94.4% (95% CI: 73.7, 120.1%; Table 6), which was above the long-term average.

For PIT-tagged hatchery steelhead originating from the upper Columbia River in 2017, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 96.4% (95% CI: 66.0, 140.8%; Table 6). As with Columbia River Chinook, this estimate is above the long-term average, but has high uncertainty.

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 2017 of Snake River sockeye salmon (hatchery and wild combined) from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 17.6% (95% CI: 9.7, 32.0%; Table 7). Estimated survival in 2017 of Columbia River sockeye salmon (hatchery and wild combined) from the tailrace of Rock Island Dam to the tailrace of Bonneville Dam was 50.0% (95% CI: 15.3%, 163.5%; Table 7). The estimate for Snake River sockeye was well below average, while estimated survival for Columbia River sockeye was very near the long-term average, but highly uncertain.

Our preliminary estimates of the percentage transported of non-tagged wild and hatchery spring-summer Chinook salmon smolts in 2017 are 17.8% and 21.6%, respectively. For steelhead, the estimates are 23.3% and 20.9% 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

Because the Snake River Trap was not operated in 2017 due to high flows, comparisons to previous years we make here will instead use the Lower Granite Dam to Bonneville Dam reach. For Snake River yearling Chinook salmon in 2017, estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 47.8%; below the long-term (1999-2017) average of 52.4%. The 2017 estimate was slightly lower than the 2016 estimate of 50.5%, but the estimates were not significantly different ($P = 0.83$; Table 3). 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 2017, estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 45.9%; slightly below the long-term mean of 46.3% (Table 5). The 2017 estimate was slightly higher than the 2016 estimate of 44.4%, but the difference is not significant ($P = 0.73$; Table 5). This is the third consecutive year with below average estimated survival for Snake River steelhead after seven consecutive years of survival estimates above the mean.

Estimated survival of Snake River sockeye between Lower Granite Dam and Bonneville Dam tailrace was 17.6%, which is the fourth lowest estimate we have in our time series (1998-2017). The component survival estimates for the Lower Granite Dam to McNary Dam reach and the McNary Dam to Bonneville Dam reach were both low. This is the third consecutive year with below average survival for Snake River sockeye. Survival of juvenile Upper Columbia River sockeye in the McNary to Bonneville Dam reach was also below average, but mortality was not nearly as high as that for Snake River sockeye.

Environmental conditions in 2017 resulted in a year with average water temperatures, but very high flow and spill throughout the migration season. Mean flow at Little Goose Dam in 2017 during the main migration period (1 April - 15 June) was 138.7 kcfs, which was much above the long-term (1993-2017) mean of 91.8 kcfs; only 1997 had higher mean flow. Daily flow values were



well above long-term daily means for almost the entire migration period; daily flow only approached the mean for a brief period in late May (Figure 4). Mean water temperature at Little Goose Dam in 2017 during the migration period was 11.3 °C, which was very near the long-term mean of 11.2 °C. Daily water temperatures generally tracked the long-term daily mean, oscillating between slightly above and slightly below the mean through May and June (Figure 4).

Mean spill discharge at the Snake River dams during the 2017 migration was 63.7 kcfs, which was far above the long-term (1993-2017) mean of 27.2 kcfs, and was the year with the most spill discharge on average in our time series. Daily spill discharges remained above the long-term daily mean throughout the season, with especially high spill discharge in early May and early June (Figure 5).

Spill as a percentage of flow at Snake River dams averaged 44.5% in 2017, which was above the long-term (1993-2017) mean of 26.8%, and was the highest mean spill percentage in our time series. Daily mean spill percentages in 2017 were above the long-term daily means for the entire migration period (Figure 5).

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2017 were low, relative to the rest of our time series of estimates (1993-2017; Figure 7). This continued the recent trend, as estimates for 2015 through 2017 are now the three lowest in the series.

The 2017 migration year saw the continuation of another trend from recent years: smolts arrived earlier in the season than was typical in earlier years. In 2017, collection of transportation began on 2 May at Lower Granite, Little Goose, and Lower Monumental Dams. We estimate that 70% of the annual total passage of wild yearling Chinook and 53% of hatchery yearling Chinook occurred at Lower Granite Dam before transportation began. The average percentages that arrived before the beginning of transportation in 2006-2014 were 42% for wild and 31% for hatchery yearling Chinook. Similarly, we estimate that 60% of wild steelhead arrived before transportation began in 2017,



versus the 2006-2014 average of 29%, and 63% of hatchery steelhead versus the average of 33%.

In addition, lower-than-average proportions of smolts were collected for transportation after transportation began in 2017, presumably because higher spill percentages meant a lower proportion of smolts entering collection systems. The combination of early migration timing and of relatively low collection proportions late in the season resulted in the low percentages of smolts transported in 2017.

Median estimated travel times for both species between Lower Granite Dam and Bonneville Dam in April were shorter in 2017 than any other year in our time series, even outdoing the short travel times seen in 2016 (1998-2017; Figure 8). These short travel times coincided with high flows in 2017; and as flows remained high for the entire migration period, travel time remained shorter than the long-term mean through June.

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
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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), 2015 through 2017.

Hatchery	2015		2016		2017 ^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	0.768 (0.018)	0.609 (0.020)	0.714 (0.007)	0.538 (0.014)	0.693 (0.013)	0.402 (0.015)
Kooskia	0.532 (0.027)	0.397 (0.046)	0.684 (0.012)	0.499 (0.029)	0.565 (0.025)	0.351 (0.040)
Lookingglass (Catherine Cr.)	0.266 (0.016)	0.239 (0.020)	0.371 (0.005)	0.300 (0.016)	0.420 (0.014)	0.303 (0.024)
Lookingglass (Grande Ronde)	0.346 (0.050)	0.230 (0.044)	0.429 (0.016)	0.326 (0.044)	0.398 (0.032)	0.352 (0.096)
Lookingglass (Imnaha River)	0.655 (0.035)	0.457 (0.031)	0.704 (0.007)	0.526 (0.022)	0.585 (0.020)	0.438 (0.041)
Lookingglass (Lostine River)	0.556 (0.078)	0.429 (0.106)	0.586 (0.017)	0.419 (0.039)	0.553 (0.029)	0.409 (0.067)
McCall (Johnson Cr.)	0.413 (0.089)	0.185 (0.038)	---	---	---	---
McCall (Knox Bridge)	0.729 (0.030)	0.546 (0.019)	0.654 (0.006)	0.514 (0.014)	0.700 (0.012)	0.528 (0.021)
Pahsimeroi	0.771 (0.036)	0.547 (0.034)	0.772 (0.008)	0.512 (0.026)	0.746 (0.012)	0.560 (0.041)
Rapid River	0.811 (0.024)	0.712 (0.022)	0.815 (0.005)	0.632 (0.015)	0.652 (0.010)	0.528 (0.020)
Sawtooth	0.696 (0.036)	0.513 (0.027)	0.676 (0.006)	0.474 (0.015)	0.606 (0.010)	0.466 (0.025)
Entiat	---	0.483 (0.052)	---	0.631 (0.024)	---	0.639 (0.040)
Winthrop	---	0.540 (0.054)	---	0.577 (0.022)	---	0.578 (0.031)
Leavenworth	---	0.497 (0.034)	---	0.501 (0.016)	---	0.540 (0.022)

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), 1995–2017. 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 (1993–2017) are given.

Year	Trap–LGR	LGR–LGO	LGO–LMO	LMO–MCN*	LMO–IHR		JDA–TDA	
					IHR–MCN	MCN–JDA	JDA–BON*	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	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
2017 ^a	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
Mean^b	0.932 (0.008)	0.925 (0.007)	0.922 (0.009)	0.863 (0.012)	0.929 (0.006)	0.865 (0.019)	0.809 (0.025)	0.898 (0.014)

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), 1997–2017. 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	0.936 (0.015)	0.752 (0.011)	0.672 (0.060)	0.505 (0.046)	0.473 (0.043)
2017 ^a	NA	0.743 (0.019)	0.643 (0.157)	0.478 (0.117)	NA
Mean^b	0.932 (0.008)	0.736 (0.012)	0.700 (0.020)	0.524 (0.021)	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), 1995–2017. 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 (1993–2017) are given.

Year	Trap–LGR	LGR–LGO	LGO–LMO	LMO–MCN*	LMO–IHR		JDA–TDA	
					IHR–MCN	MCN–JDA	JDA–BON*	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	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 ^a	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
Mean^b	0.950 (0.011)	0.922 (0.010)	0.908 (0.012)	0.773 (0.028)	0.875 (0.018)	0.833 (0.040)	0.796 (0.033)	0.889 (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), 1997–2017. 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	0.998 (0.016)	0.730 (0.020)	0.608 (0.040)	0.444 (0.032)	0.443 (0.032)
2017 ^a	NA	0.759 (0.019)	0.605 (0.037)	0.459 (0.030)	NA
Mean^b	0.950 (0.011)	0.653 (0.029)	0.674 (0.040)	0.463 (0.036)	0.449 (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, 1999–2017. Abbreviations: Rel–Release site; MCN–McNary Dam; JDA–John Day Dam; BON–Bonneville Dam.

Year	Yearling Chinook Salmon				Steelhead			
	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 ^a	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)
Mean^b	0.557 (0.012)	0.899 (0.023)	0.904 (0.044)	0.818 (0.033)	0.419 (0.015)	0.894 (0.031)	0.846 (0.055)	0.747 (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, 1996–2017. 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.

Year	Snake River Sockeye			Upper Columbia River Sockeye		
	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 ^a	0.544 (0.081)	0.324 (0.107)	0.176 (0.055)	0.719 (0.113)	0.611 (0.181)	0.500 (0.332)
Mean^b	0.625 (0.036)	0.544 (0.071)	0.392 (0.053)	0.673 (0.032)	0.723 (0.078)	0.503 (0.055)

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.

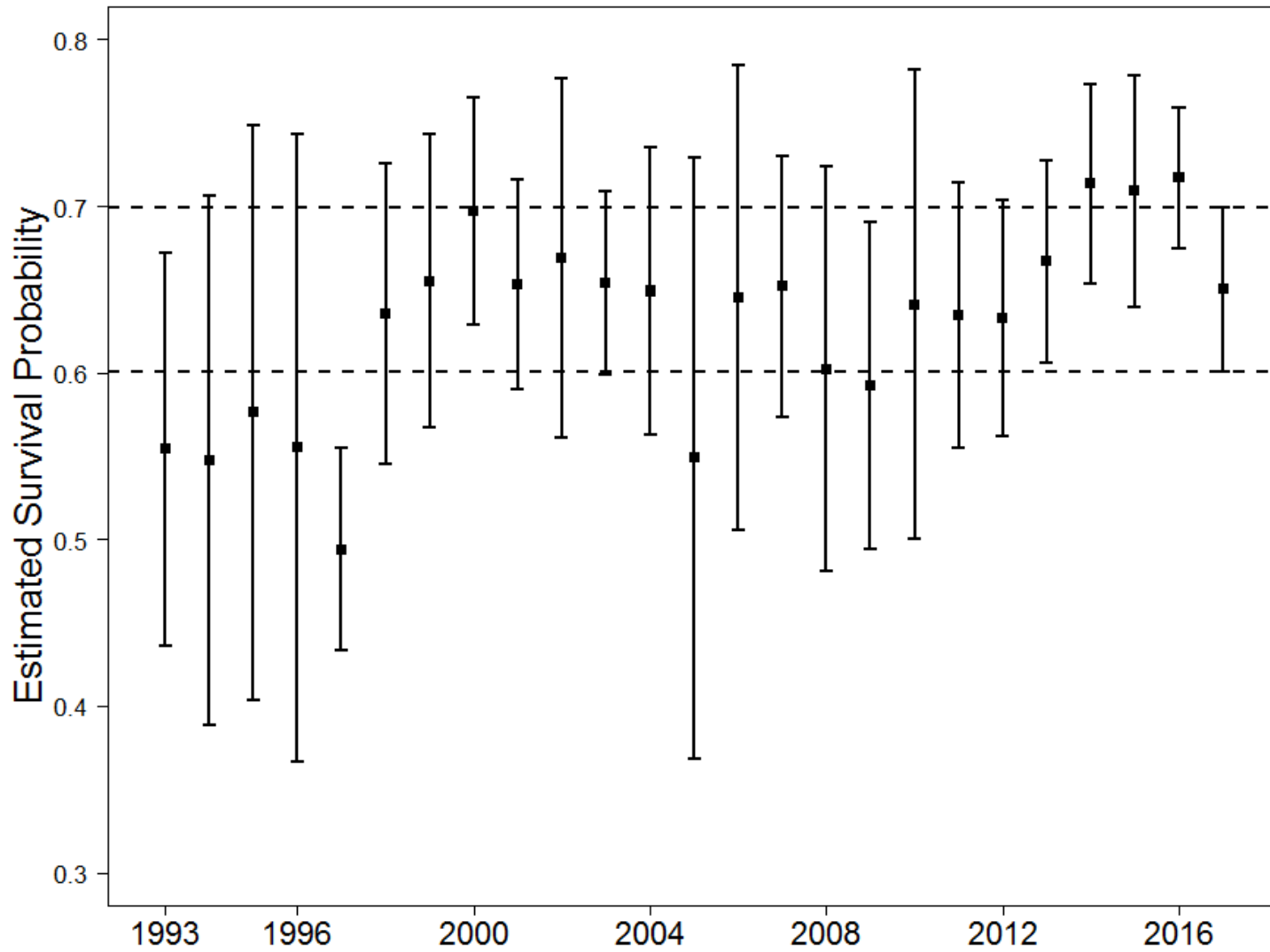


Figure 1. Annual average survival estimates from release to Lower Granite Dam for PIT-tagged yearling **Chinook** salmon released from Snake River Basin hatcheries, 1993-2017. Hatcheries used for average (index groups) are those with consistent PIT-tag releases through the series of years shown. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are the 2017 confidence interval endpoints and are shown for comparison to other years.

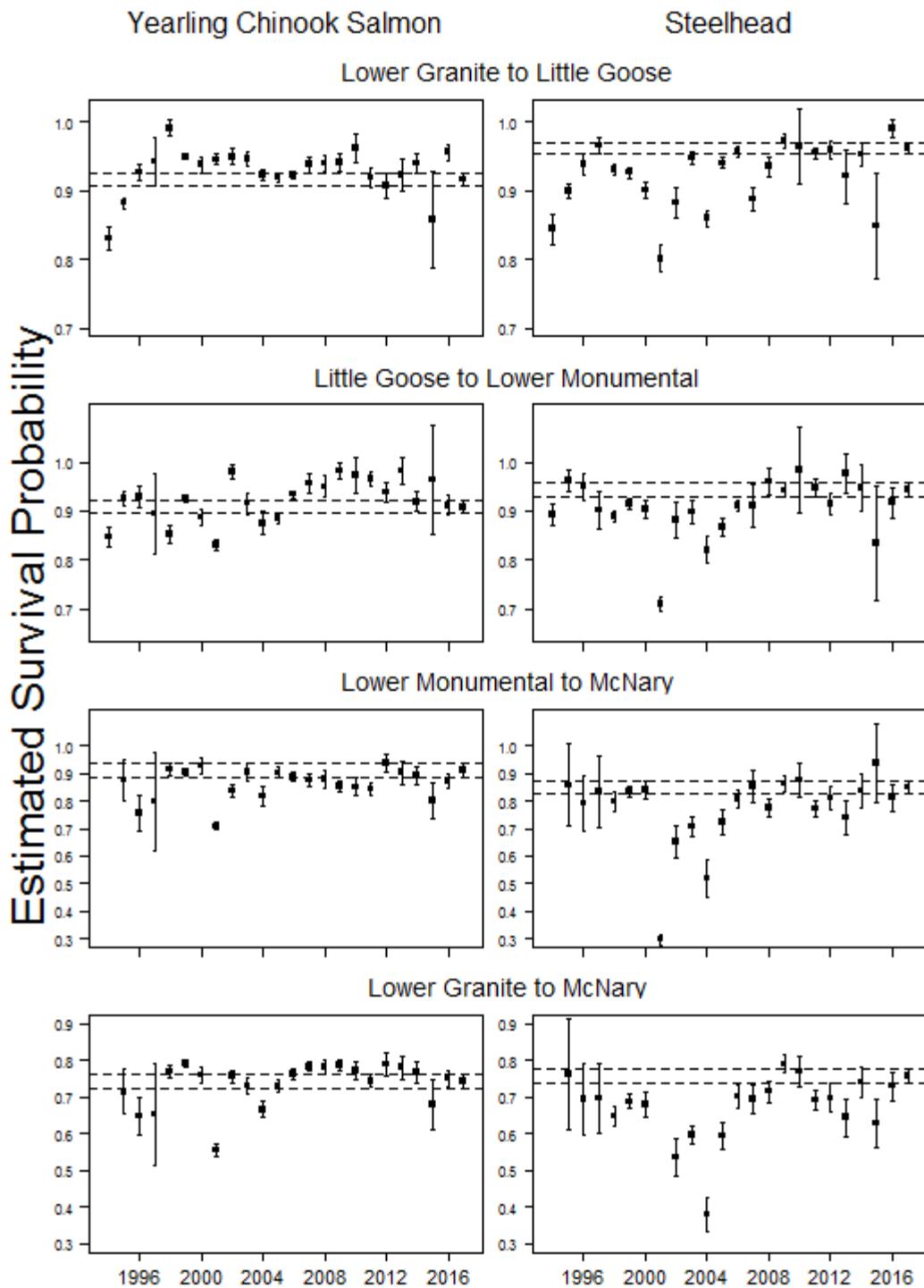


Figure 2. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2017 estimates.

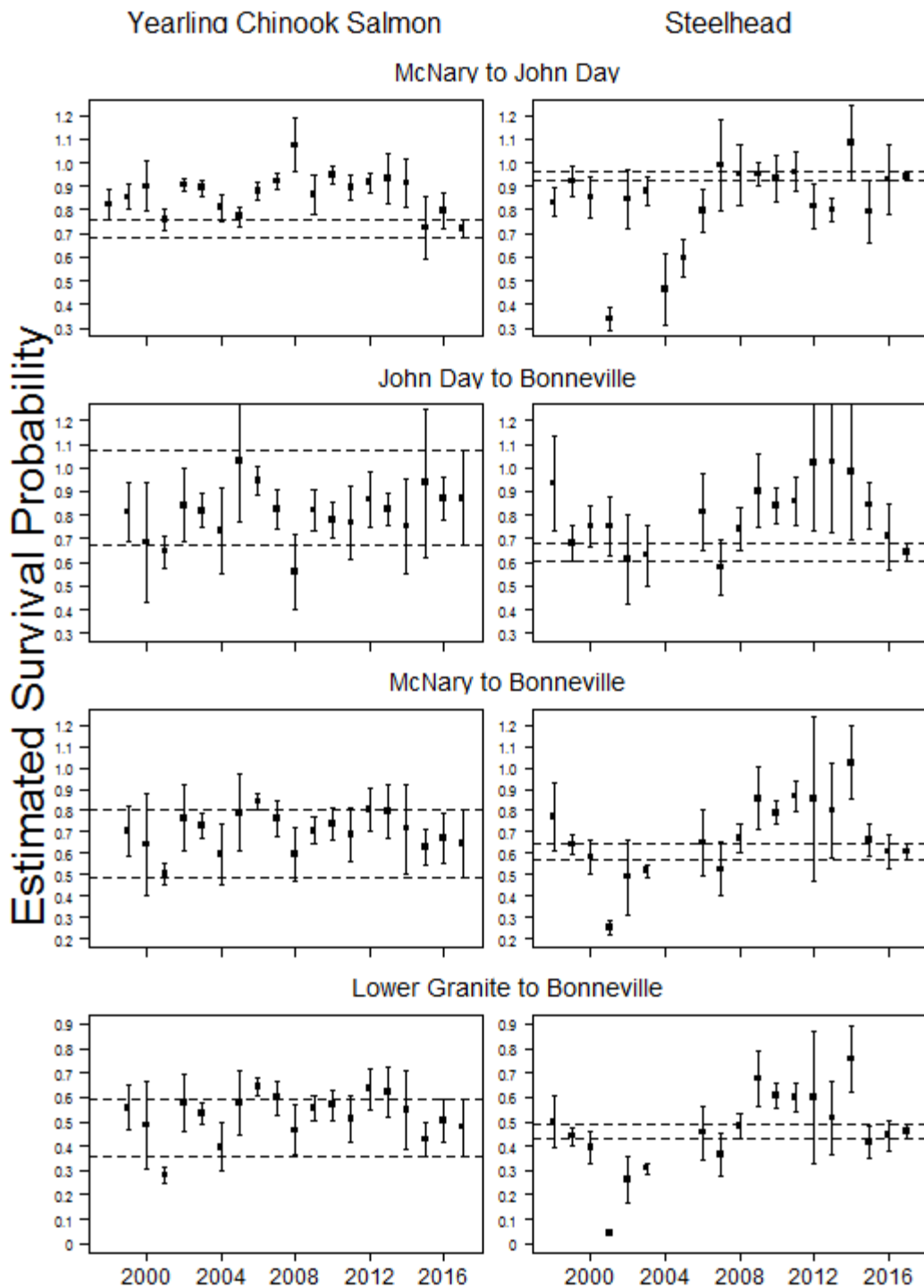


Figure 3. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2017 estimates.

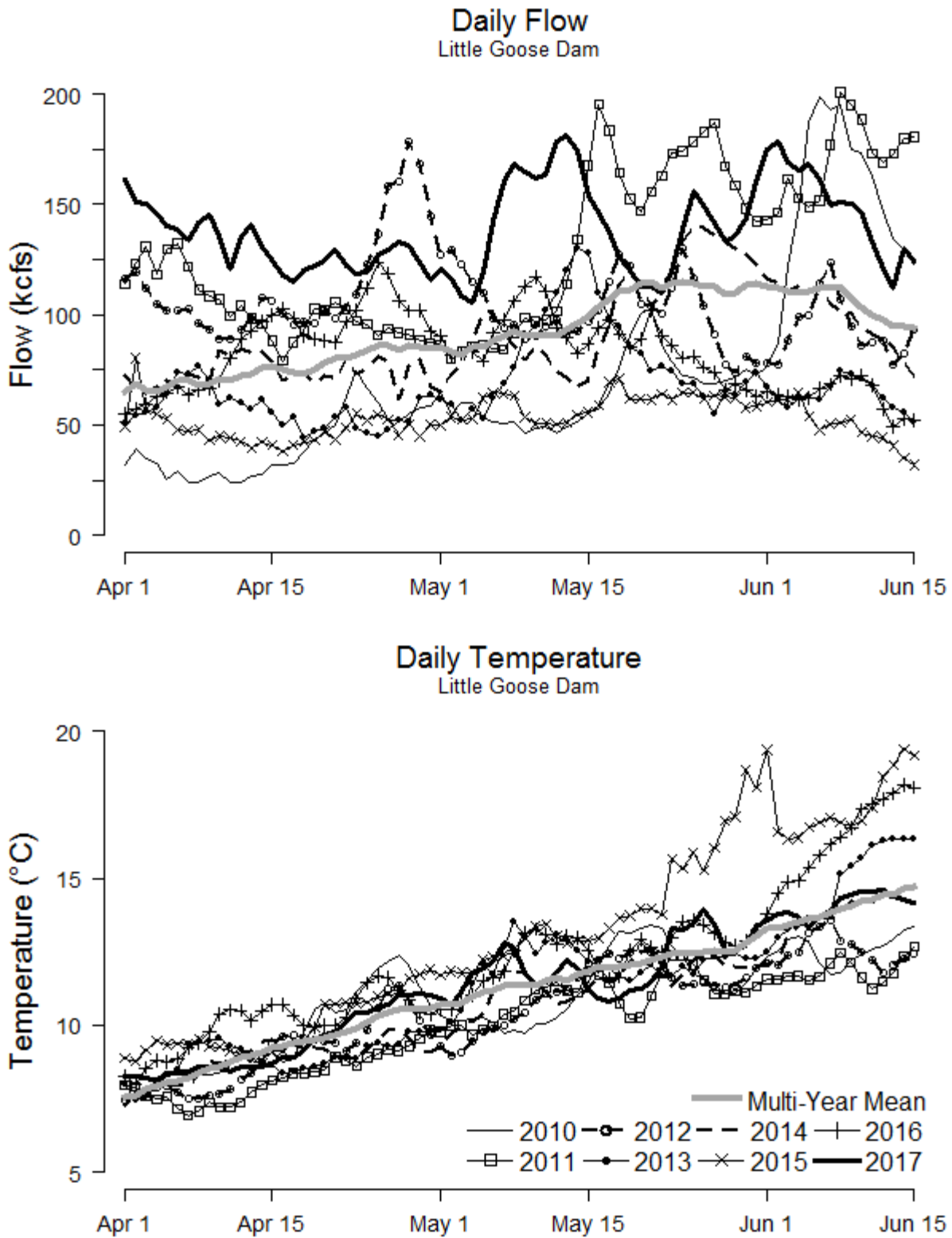


Figure 4. Snake River flow (kcfs; top panel) and water temperature (°C; bottom panel) measured at Little Goose Dam during April and May, 2010-2017, including daily long-term means (1993-2017).

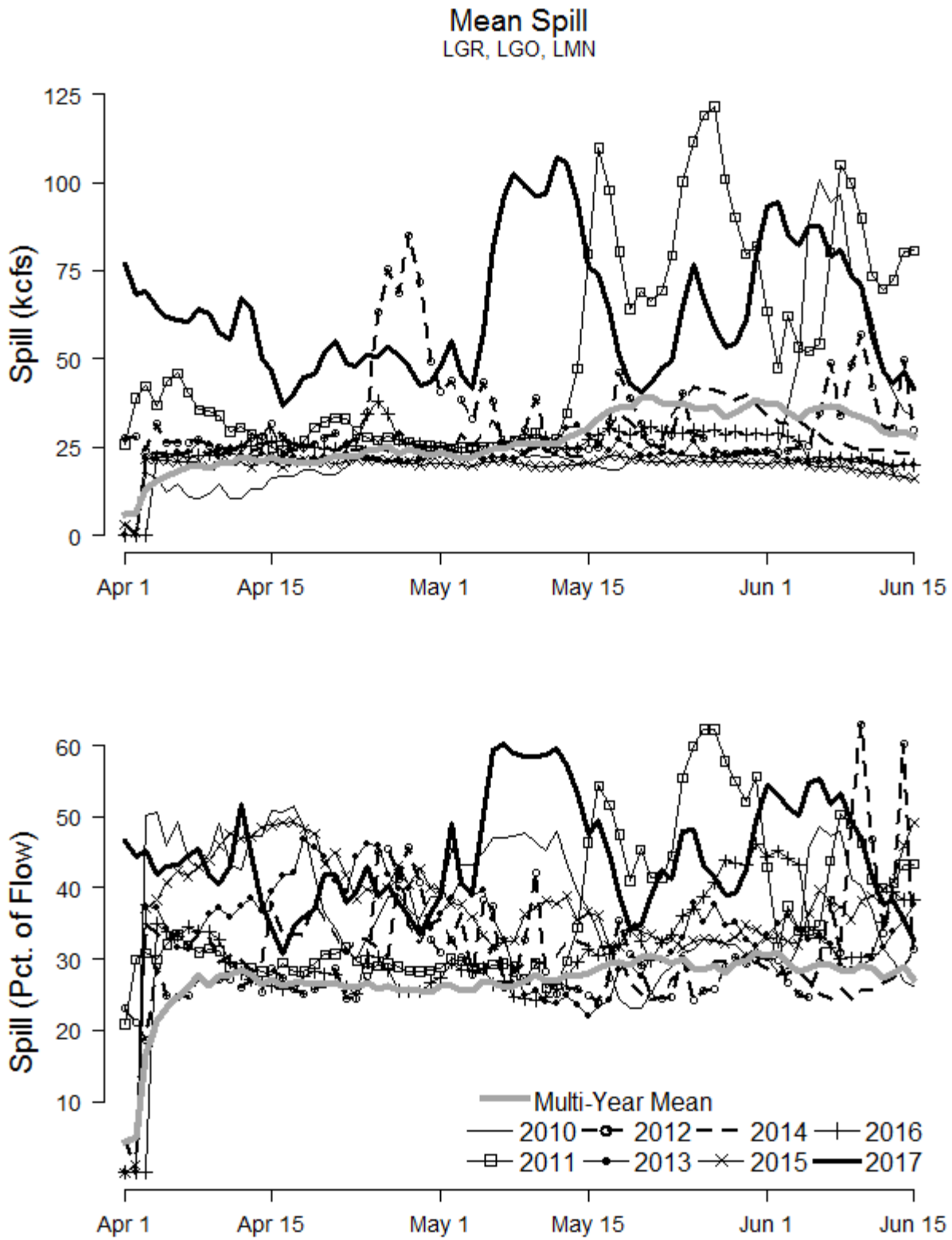


Figure 5. Mean spill (top panel shows kcfs; bottom panel shows percentage of total flow) at Snake River dams during April and May, 2010-2017, including daily long-term means (1993-2017).

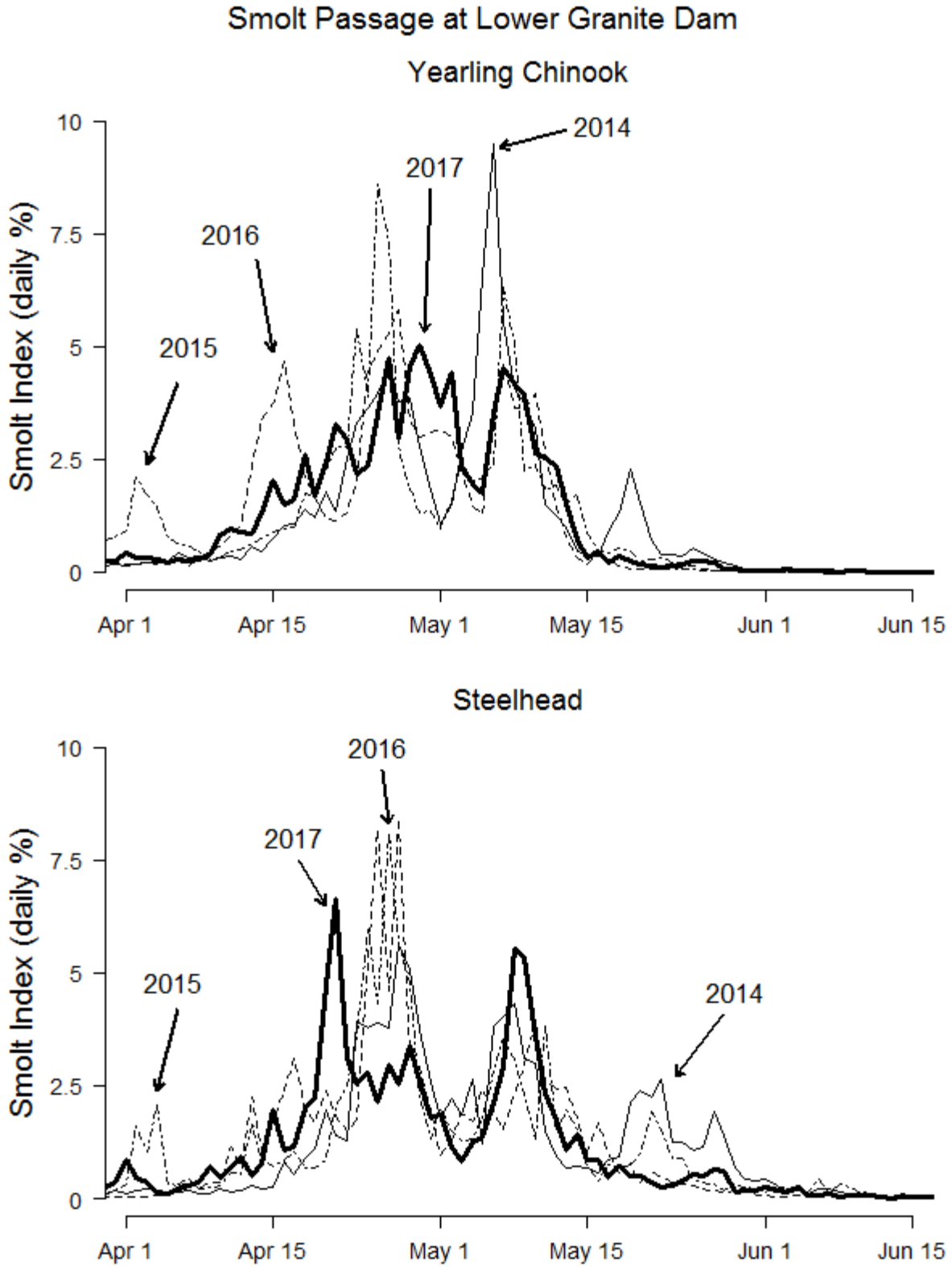


Figure 6. Smolt index as daily percentage of total passage at Lower Granite Dam 2014-2017 for hatchery and wild combined yearling Chinook and steelhead.

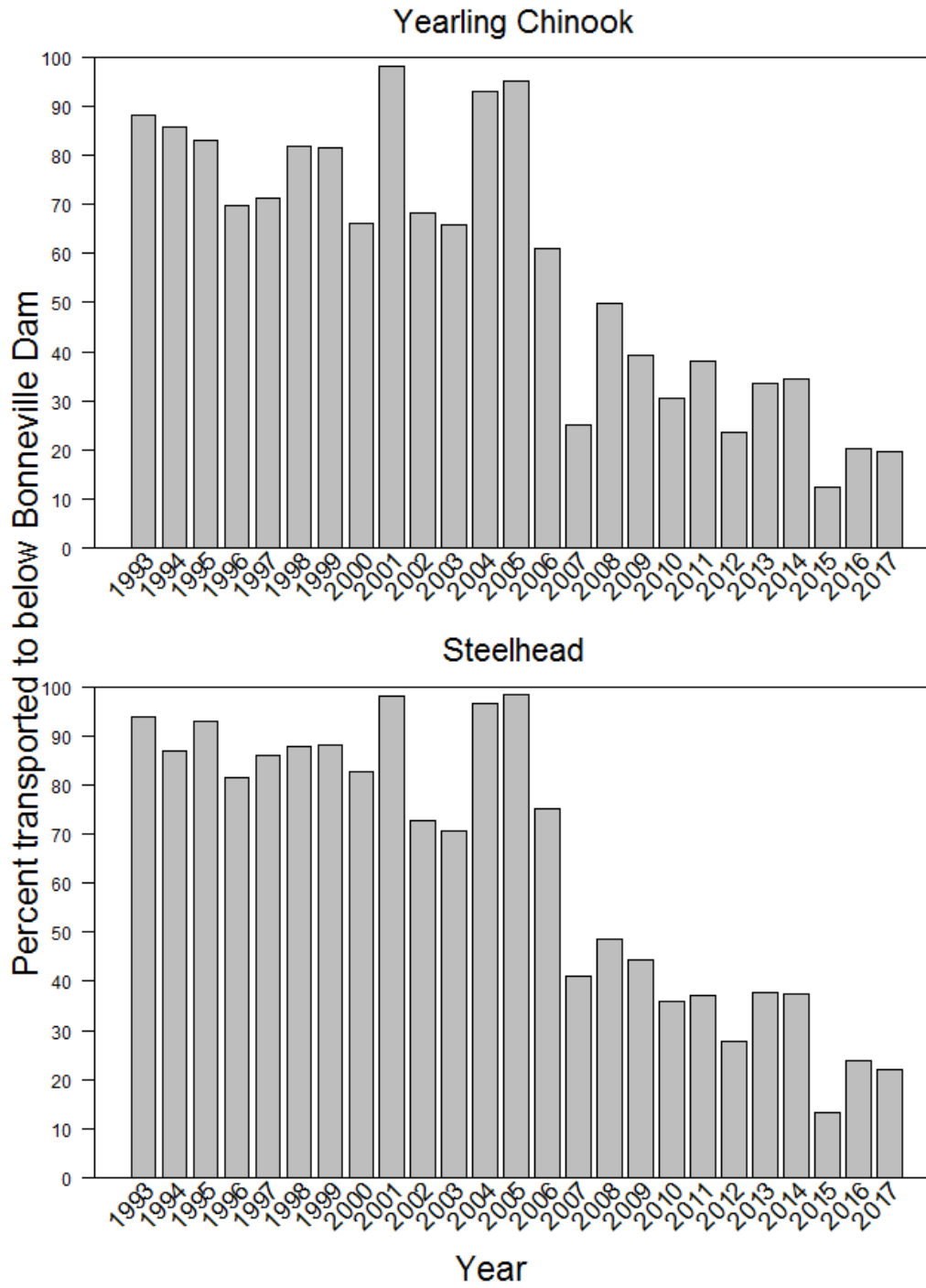


Figure 7. Estimated percent of yearling Chinook salmon and steelhead (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2017).

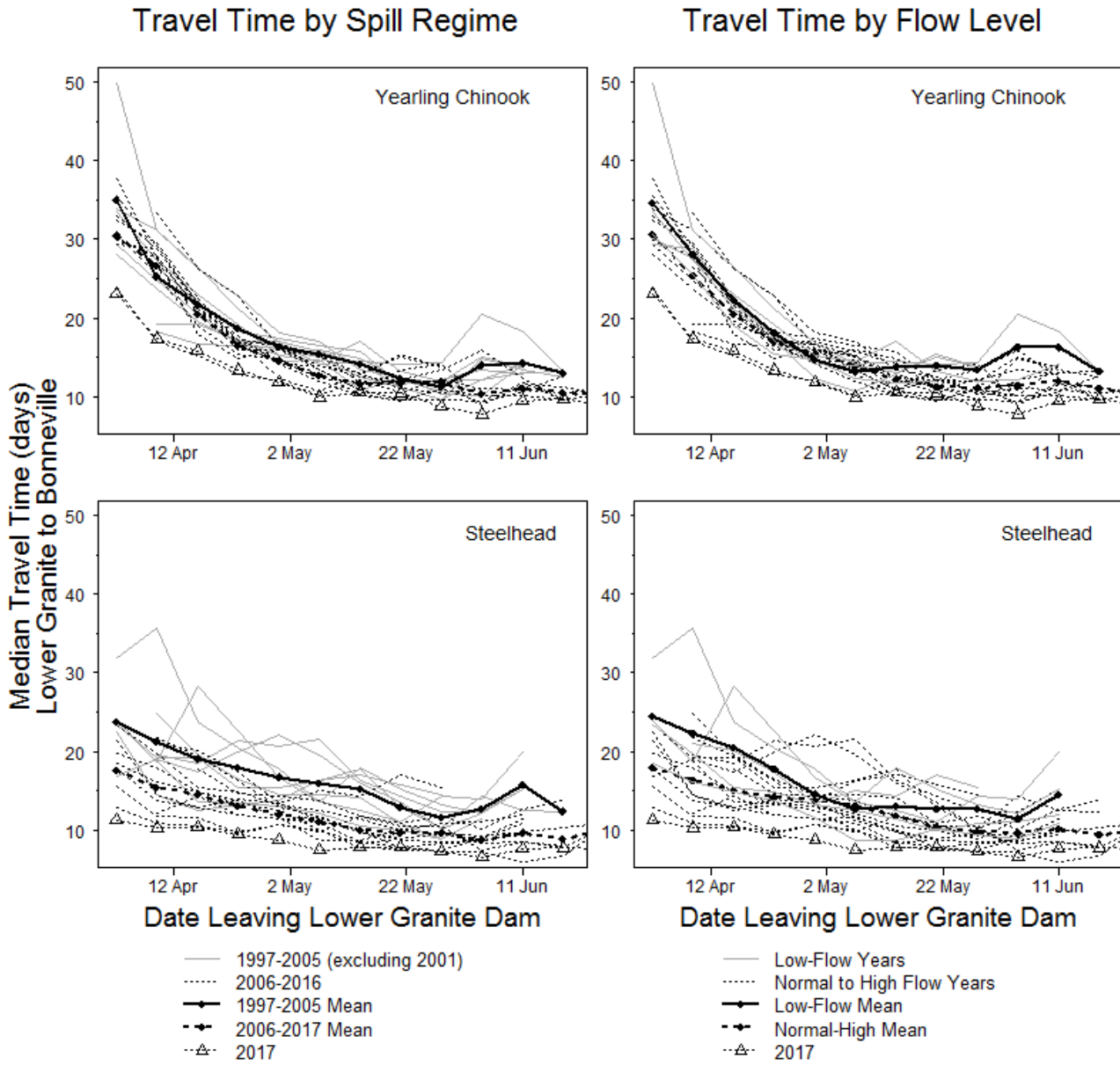


Figure 8. Median travel time from Lower Granite Dam to Bonneville Dam for yearling Chinook salmon and steelhead by spill regime (left) and mean flow category (right) in the period 1998-2017 (excluding 2001), with long-term mean for the same period. Here spill regime is defined by court-ordered spill 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.