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MEMORANDUM FOR: F/WCR3 - 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, 2015

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 2015 spring outmigration. We also provide preliminary estimates of the proportion of Snake River smolts that were transported from Snake River dams in 2015. 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 2015, NOAA Fisheries PIT tagged 19,088 river-run hatchery steelhead, 10,752 wild steelhead, and 5,379 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 2015 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 2015 (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 2015, the mean was 70.9%, which is second only to 2014 (71.1%) in the 22 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 2015 was below average in all individual project reaches except for the John Day to Bonneville reach (Table 2, Figures 2 and 3), which resulted in below average survival for the combined reaches of interest (Table 4). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to McNary Dam tailrace in 2015 was 69.4% (95% CI: 61.4, 77.4%). Mean estimated survival in from McNary Dam tailrace to Bonneville Dam tailrace was 62.9% (95% CI: 54.5, 71.3%). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to Bonneville Dam tailrace was 43.7% (95% CI: 35.9, 51.4%). Estimated survival for the Lower Granite project (head of reservoir to tailrace) was 90.9%, 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 39.7% (95% CI: 28.4, 50.9%),

which is well below the long-term average of 49.5% and is the lowest estimate for Chinook in that reach since 2004.

For wild Snake River yearling Chinook, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 52.6% (95% CI: 42.2, 63.0%), and from McNary Dam tailrace to Bonneville Dam tailrace was 84.3% (95% CI: 63.5, 105.1%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 86.7%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 38.4% (95% CI: 17.8, 59.0%).

For Snake River steelhead (hatchery and wild combined), mean estimated survival in 2015 was below average in some but not all individual project reaches (Table 3, Figures 2 and 3), but estimated survival was below average in all combined reaches of interest (Table 5). Mean estimated survival for steelhead from Lower Granite Dam tailrace to McNary Dam tailrace was 62.3% (95% CI: 56.0, 68.6%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 66.3% (95% CI: 58.7, 73.9%). Mean estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 41.3% (95% CI: 35.0, 47.6%). Estimated survival for the Lower Granite project (head of reservoir to tailrace) was 87.4%, based on fish PIT tagged at and released from the Snake River trap. The combined steelhead survival estimate from the trap to the Bonneville Dam tailrace was 36.1% (95% CI: 29.5, 42.7%).

For wild Snake River steelhead, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 57.2% (95% CI: 47.6, 66.8%), and from McNary Dam tailrace to Bonneville Dam tailrace was 60.8% (95% CI: 50.8, 70.8%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 86.7%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 30.1% (95% CI: 18.3, 42.0%).

For PIT-tagged hatchery yearling Chinook salmon originating from the upper Columbia River in 2015, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 87.0% (95% CI: 75.6, 100.0%; Table 6).

For PIT-tagged hatchery steelhead originating from the upper Columbia River in 2015, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 57.0% (95% CI: 49.2, 66.1%; 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 2015 of Snake River sockeye salmon (hatchery and wild combined) from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 37.3% (95% CI: 30.0, 44.6%; Table 7). Estimated survival in 2015 of Columbia River sockeye salmon (hatchery and wild combined) from the tailrace of Rock Island Dam to the tailrace of Bonneville Dam was 34.0% (95% CI: 8.5%, 59.5%; Table 7). These estimates are well 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 2015 are 11.4% and 13.6%, respectively. For steelhead, the estimates are 12.4% and 13.9% 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 2015, estimated survival from the Snake River Trap to Bonneville Dam tailrace was 39.7%, which was the third lowest out of 17 years with observations (1999-2015), and below the long-term average of 49.5%. The 2015 estimate was lower than the 2014 estimate of 49.7%, but the difference was not significantly different (P = 0.29; Table 4) 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 2015, estimated survival through the hydropower system was 36.1%, which was below the long-term mean of 45.1% and was the fourth lowest estimate in our time series (1997-2015; Table 5). This 2015 estimate was 41.0 percentage points lower than the estimate from 2014 of 77.1%, and significantly different ($P < 0.001$; Table 5).

The lower survival estimates in 2015 for both yearling Chinook and steelhead were associated with a set of extreme environmental conditions and unusual operational conditions compared to past years. Mean flow at Little Goose Dam in 2015 during the main migration period (1 April - 15 June) was 53.0 kcfs, which was well below the long-term (1993-2015) mean of 90.2 kcfs. The only year with lower flow in our time series was 2001 with a mean of 48.9 kcfs. Daily flow values were below long-term daily means for every day in the main migration period (Figure 4). Mean water temperature at Little Goose Dam in 2015 during the migration period was 13.1 °C, which was above the long-term mean of 11.1 °C, and was the warmest year in our time series. Daily water temperatures were above the long-term daily means 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 2015 migration was 19.9 kcfs, which was below the long-term mean of 25.7 kcfs. Daily spill discharges were close to long-term daily means earlier in the season, but despite being relatively constant, the daily spill values fell below the daily means starting in the middle of May and stayed low for the remainder of the migration period (Figure 5). This is because flow typically increases later in the season and forces higher spill discharge, but 2015 was an exception, with relatively constant and low flow throughout the season. Spill as a percentage of flow at Snake River dams averaged 37.7% in 2015, which was above the long-term mean of 25.9% and was actually the highest annual mean spill percentage in our time series. Daily mean spill percentages in 2015 were above the long-term daily means for almost the entire migration period (Figure 5).

In general, the combination of conditions in the Snake River during the 2015 spring migration was unlike any year in our time series. Water temperatures and spill percentages reached record highs while flow was near record low. In terms of flow, 2015 was most like 1994, 2001, and 2007. In terms of spill percentages, 2015 was most like 2008 and 2010. In terms of water temperature, there are no comparable years in our times series.

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2015 were by far the lowest recorded in our time series of estimates (1993-2015). This is partly due to the arrival timing of both species in relation to start dates of transportation, and partly due to very low collection probabilities at the collector dams during transportation operations. In 2015, collection for transportation began on 1 May at Lower Granite and Little Goose Dams and 2 May at Lower Monumental Dam. We estimate that 58% of the annual total passage of wild yearling Chinook and 58% of hatchery yearling Chinook passed Lower Granite Dam before transportation began. After 1 May, 25% of wild yearling Chinook and 30% 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, 48% of steelhead passed Lower Granite Dam before collection for transportation began, and that 24% of steelhead passing after 1 May were transported. In comparison to 2014, a lower proportion of both species passed before transportation began, but a far lower proportion was transported after the program began. The resulting overall percentages transported in 2015 were much lower than those in 2014.

Travel times for both species between Lower Granite Dam and Bonneville Dam were longer than some recent years (2008-2014), but still shorter than the long-term average (1998-2015) and shorter than most other low-flow years (Figure 7). The main differences between conditions in 2015 and those in earlier low-flow years such as 2001 and 2004 were that those years had

extended periods with no spill and most dams had limited surface bypass structures or none at all. Even small amounts of spill, especially surface spill, during low-flow conditions can be attractive to fish looking for passage through a dam. When spill is shut off completely, fish delay passage because the only available routes are through powerhouse intake bays which have horizontal entrance depths of 20 meters or more below the surface. This is in contrast to entrances to normal spillways which lie approximately 10 meters below the surface and spillway weirs which entrain the top 1-2 meters of surface flow. Migrating smolts are naturally surface orientated, so depth can be a behavioral barrier to passage.

Detection probabilities for PIT-tagged fish in the juvenile bypass systems were extremely low at several dams in 2015 (Figures 8 and 9). In fact, mean detection probabilities in 2015 were the lowest we have recorded for all detection sites except Bonneville Dam. Detection probabilities have been lower at most dams in general in recent years since programs were instituted in 2007 to increase spill and since the addition of surface collectors at most sites. There is evidence that surface spill is disproportionately more attractive to fish at lower flow than at higher flow levels. This results in a high proportion of fish passing through spill routes and very few fish entering juvenile bypass systems where PIT tags can be detected. Low detection probabilities result in survival estimates and travel time estimates with poor precision, but can also lead to other estimation problems such as bias, especially in the presence of certain violations of capture-recapture model assumptions. Poor precision and bias can cloud our ability to interpret the resulting estimates and can lead to potentially poor and uncertain predictions from predictive models built on such data. Any efforts that can be made to improve detection probabilities of PIT-tagged fish at hydropower dams will improve our ability to estimate and predict juvenile survival through the hydropower system.

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Table 2. Annual weighted means of survival probability estimates for yearling **Chinook** salmon (hatchery and wild combined), 1995–2015. 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[a]	0.909 (0.103)	0.835 (0.038)	0.920 (0.055)	0.860 (0.040)	0.927	0.724 (0.069)	0.937 (0.160)	0.968
Mean[b]	**0.932 (0.009)**	**0.923 (0.008)**	**0.921 (0.010)**	**0.864 (0.012)**	**0.929 (0.009)**	**0.876 (0.019)**	**0.802 (0.027)**	**0.893 (0.016)**

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), 1997–2015. 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[a]	0.909 (0.103)	0.694 (0.041)	0.629 (0.043)	0.437 (0.039)	0.397 (0.057)
Mean[b]	**0.931 (0.009)**	**0.736 (0.013)**	**0.705 (0.022)**	**0.529 (0.023)**	**0.495 (0.021)**

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), 1995–2015. 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[a]	0.874 (0.046)	0.828 (0.042)	0.833 (0.057)	0.924 (0.064)	0.961	0.792 (0.066)	0.842 (0.050)	0.918
Mean[b]	**0.948 (0.011)**	**0.917 (0.010)**	**0.905 (0.013)**	**0.767 (0.030)**	**0.871 (0.020)**	**0.821 (0.044)**	**0.811 (0.035)**	**0.897 (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 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), 1997–2015. 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[a]	0.874 (0.046)	0.623 (0.032)	0.663 (0.039)	0.413 (0.032)	0.361 (0.034)
Mean[b]	**0.948 (0.011)**	**0.644 (0.031)**	**0.682 (0.044)**	**0.464 (0.041)**	**0.451 (0.043)**

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, 1999–2015. 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[a]	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)
Mean[b]	**0.552 (0.012)**	**0.904 (0.026)**	**0.887 (0.048)**	**0.809 (0.036)**	**0.418 (0.017)**	**0.905 (0.035)**	**0.843 (0.057)**	**0.750 (0.043)**

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, 1996–2015. 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[a]	0.702 (0.054)	0.531 (0.151)	0.373 (0.037)	0.763 (0.182)	0.446 (0.200)	0.340 (0.130)
Mean[b]	**0.635 (0.039)**	**0.580 (0.075)**	**0.424 (0.055)**	**0.663 (0.034)**	**0.741 (0.087)**	**0.506 (0.062)**

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.

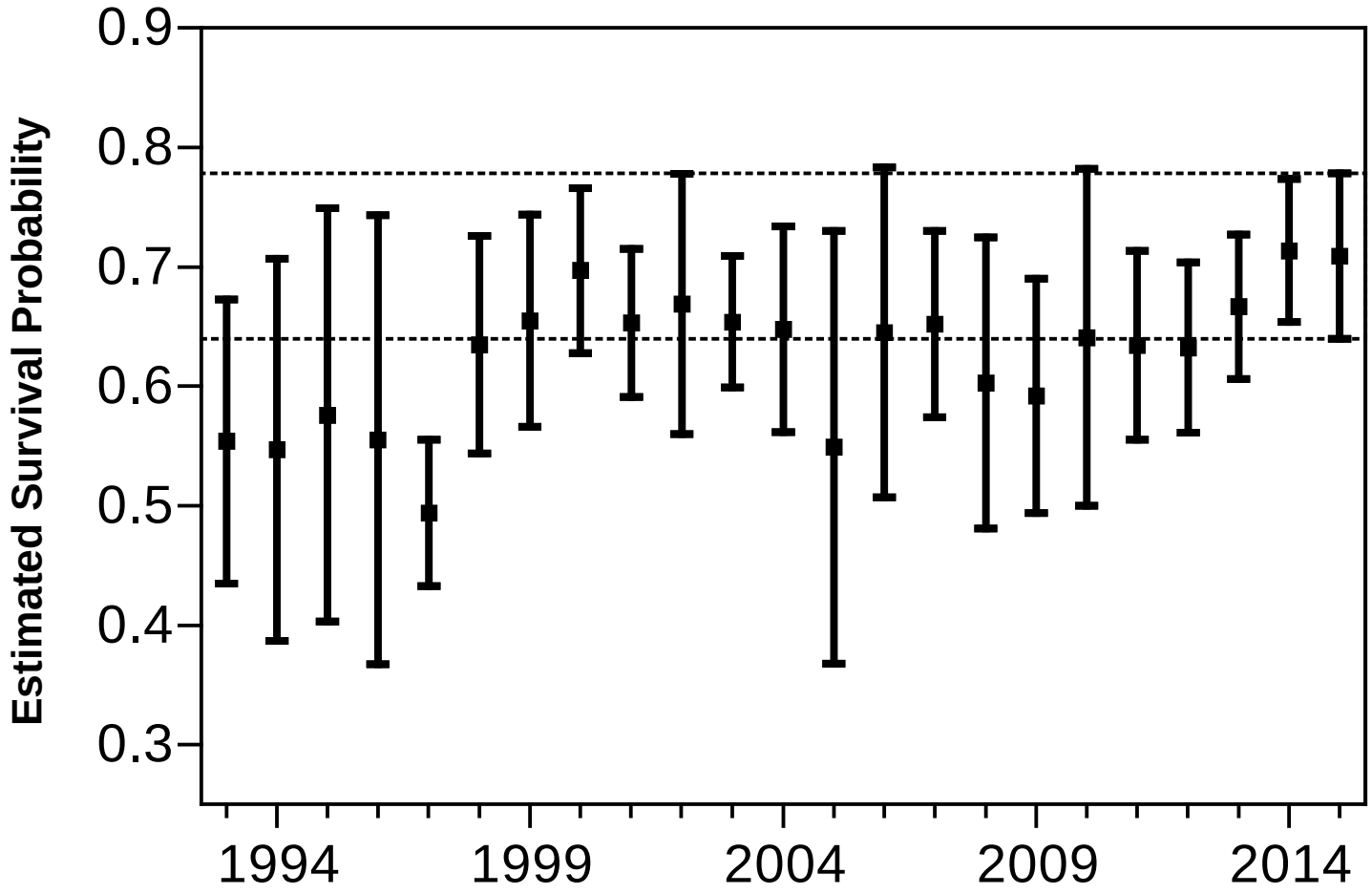

Figure 1. Annual average survival estimates from release to Lower Granite Dam for PIT-tagged yearling **Chinook** salmon released from Snake River Basin hatcheries, 1993-2015. Hatcheries used for average (index groups) are those with consistent PIT-tag releases through the series of years shown. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are the 2015 confidence interval endpoints and are shown for comparison to other years.

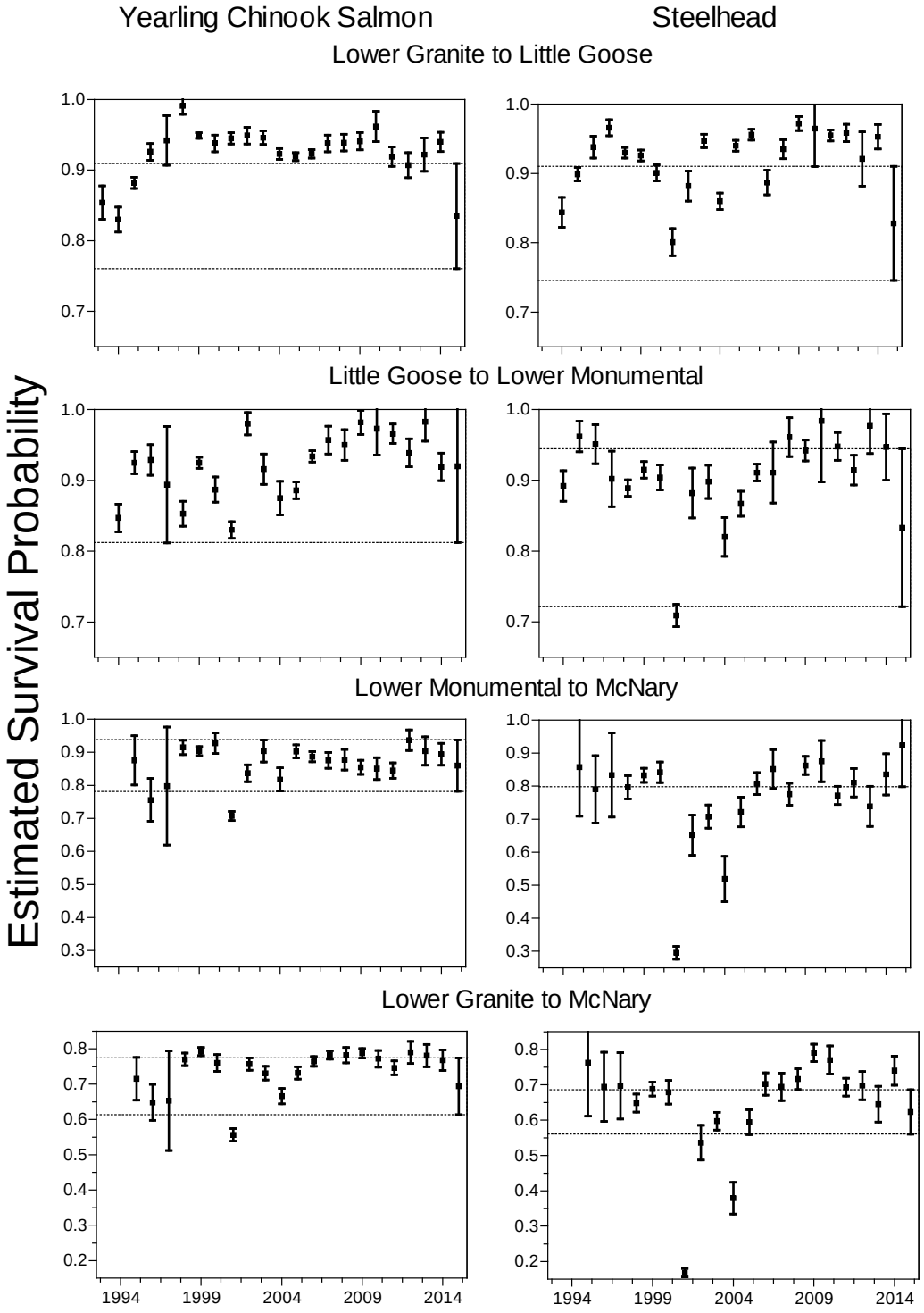

Figure 2. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2015 estimates.

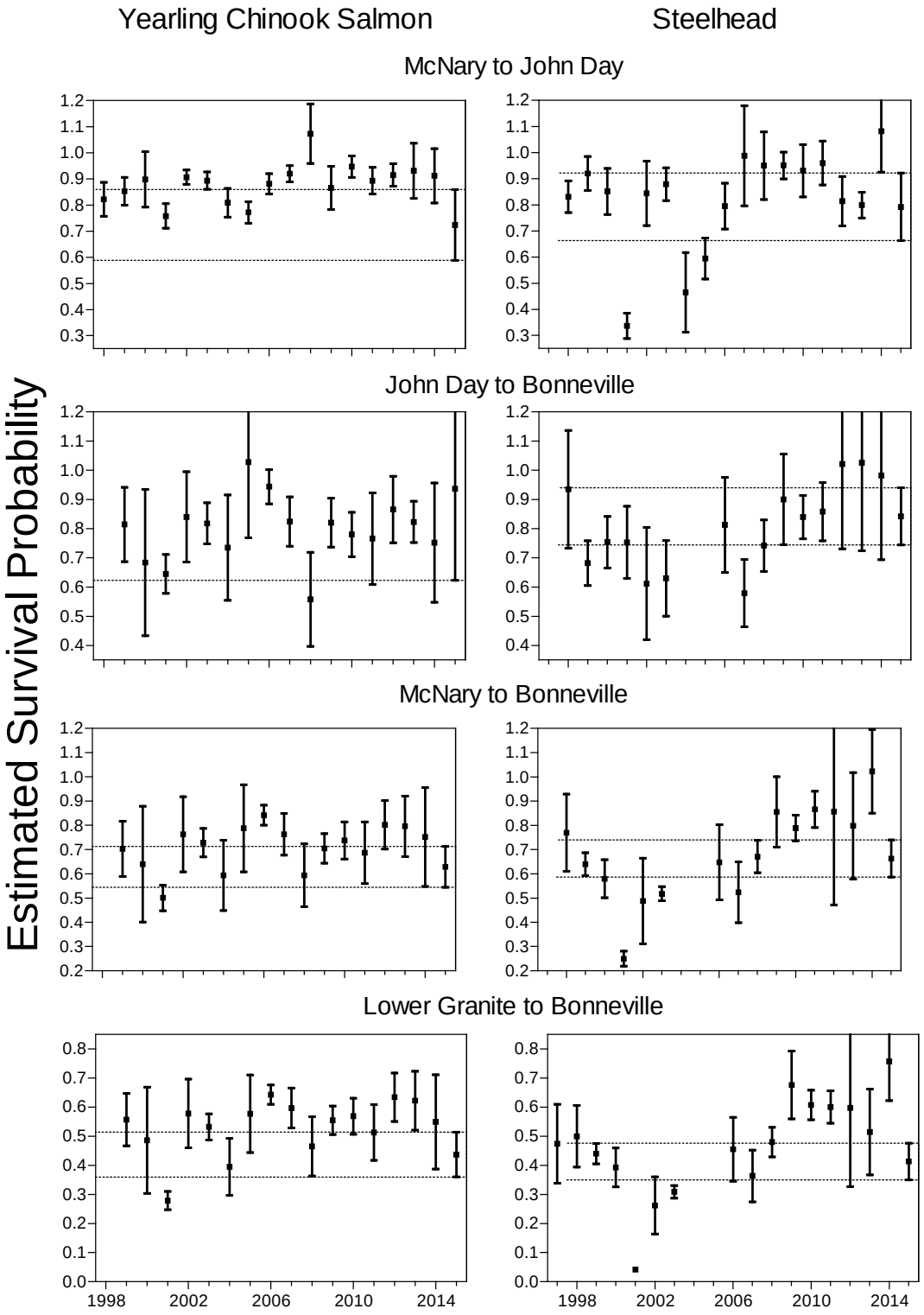

Figure 3. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2015 estimates.

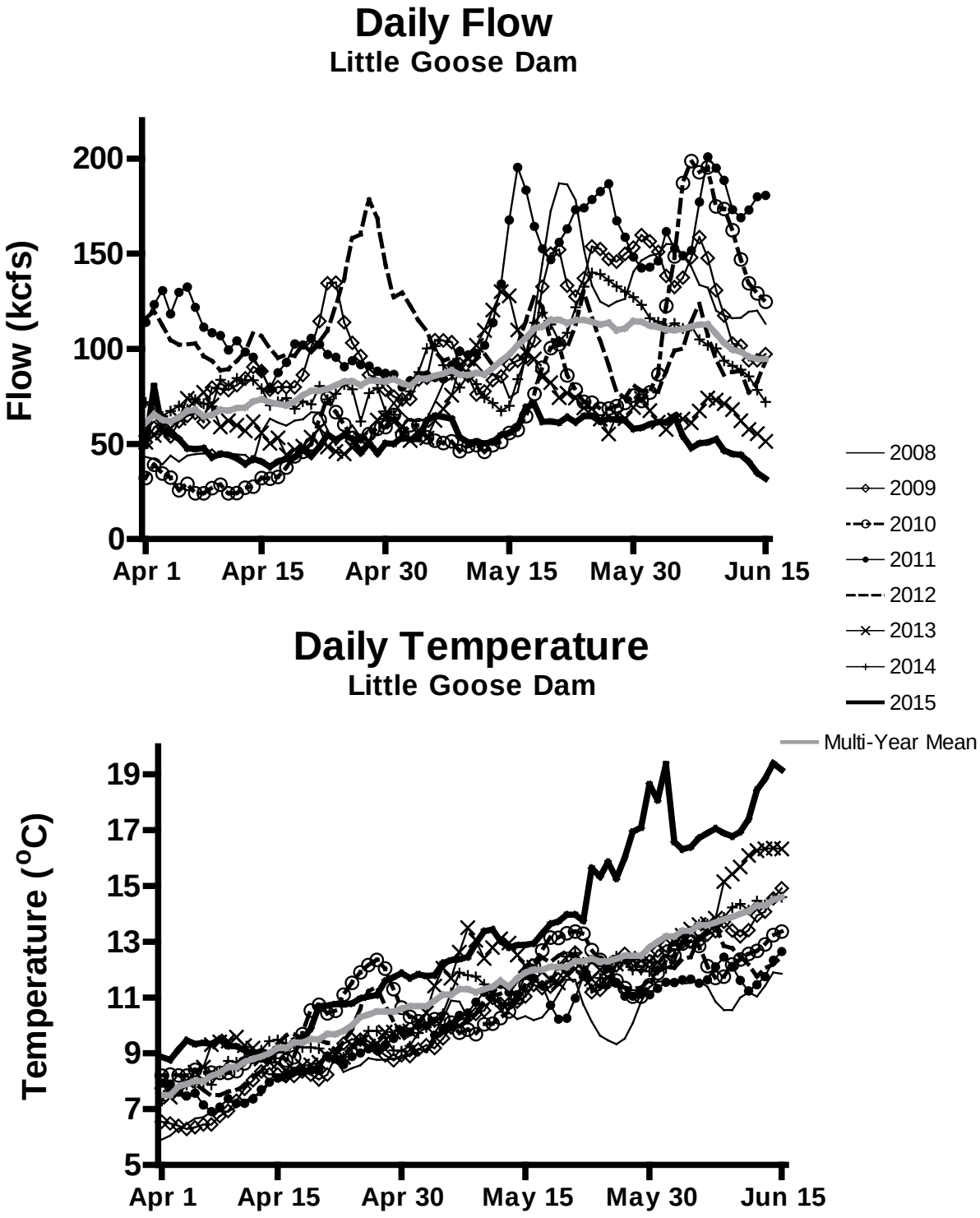

Figure 4. Snake River flow (kcfs; top panel) and water temperature (^{o}C; bottom panel) measured at Little Goose Dam during April and May, 2008-2015, including daily long-term means (1993-2015).

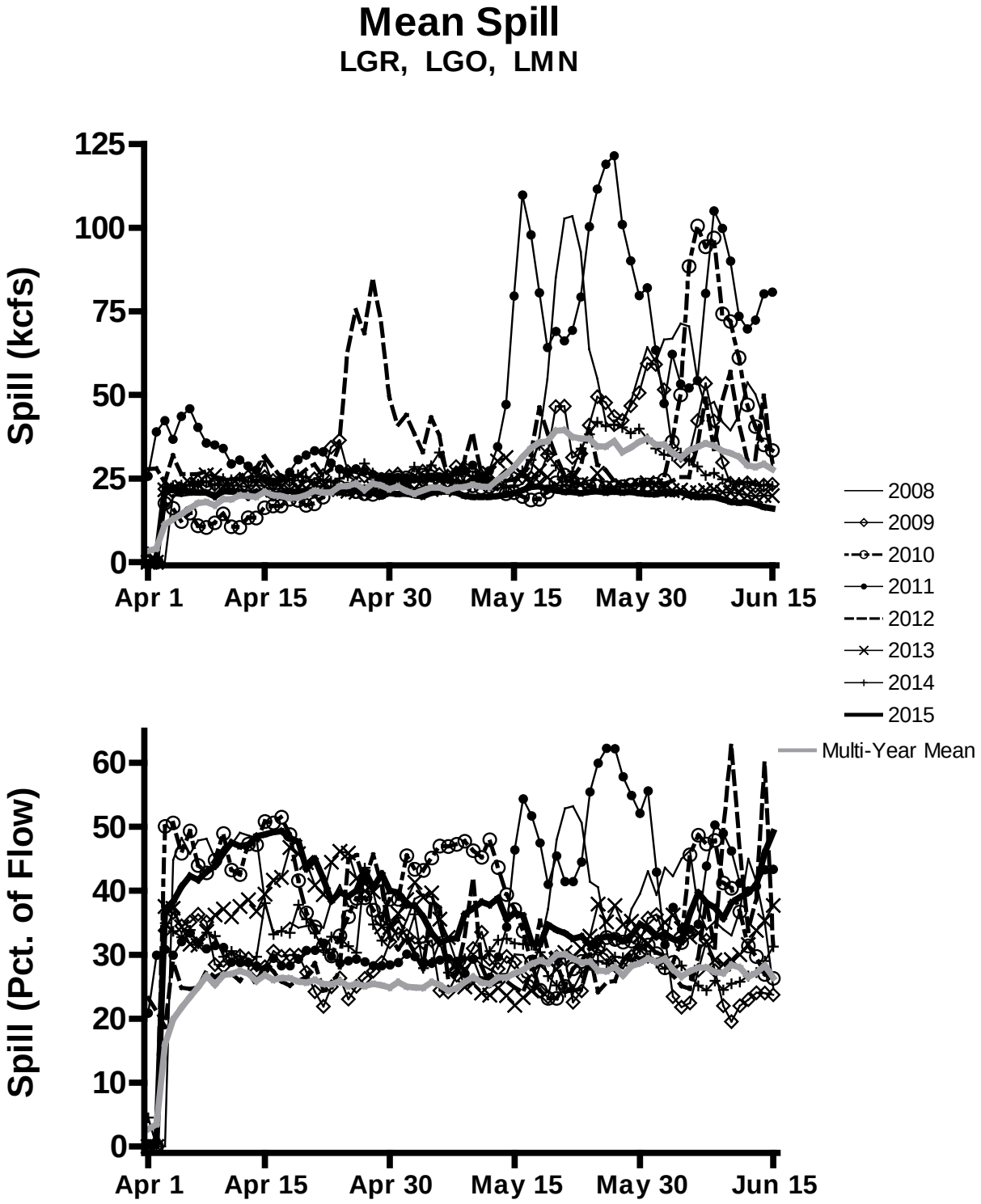

Figure 5. Mean spill (top panel shows kcfs; bottom panel shows percentage of total flow) at Snake River dams during April and May, 2008-2015, including daily long-term means (1993-2015).

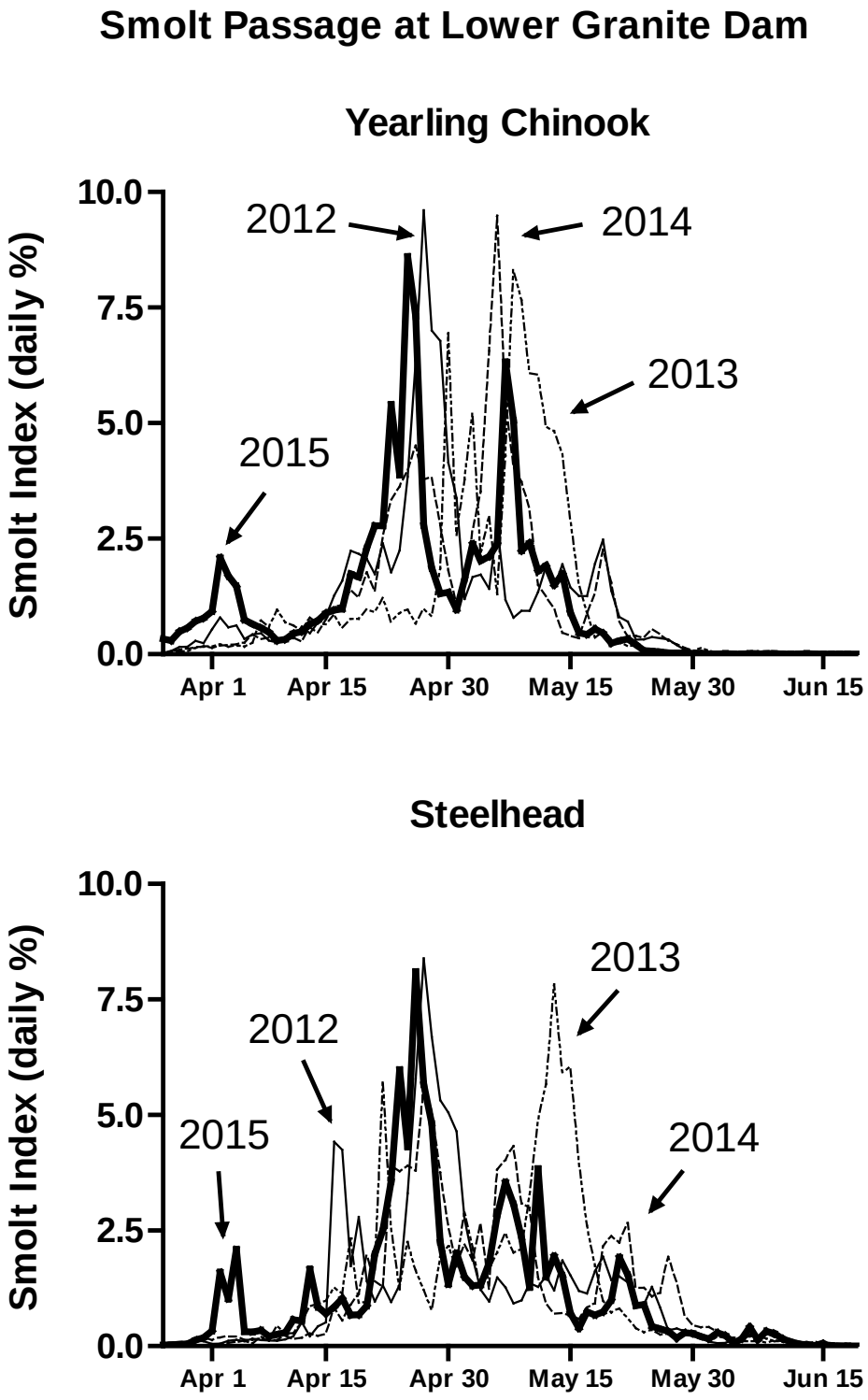

Figure 6. Smolt index as daily percentage of total passage at Lower Granite Dam 2012-2015 for hatchery and wild combined yearling Chinook and steelhead.

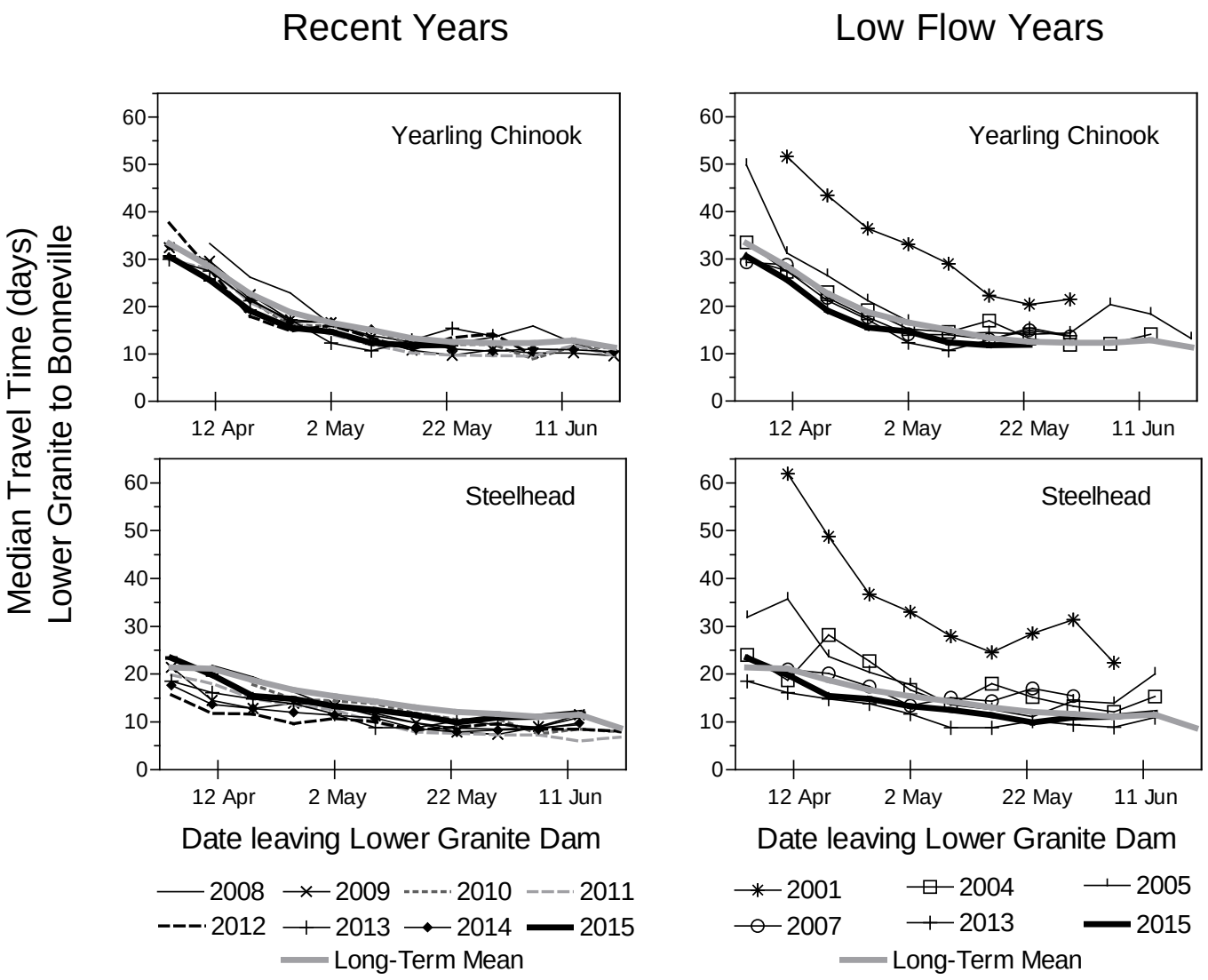

Figure 7. Median travel time from Lower Granite Dam to Bonneville Dam for yearling Chinook salmon and steelhead for the most recent eight years (left) and for the six lowest flow years (right) in the period 1998-2015, with long-term mean for the same period.

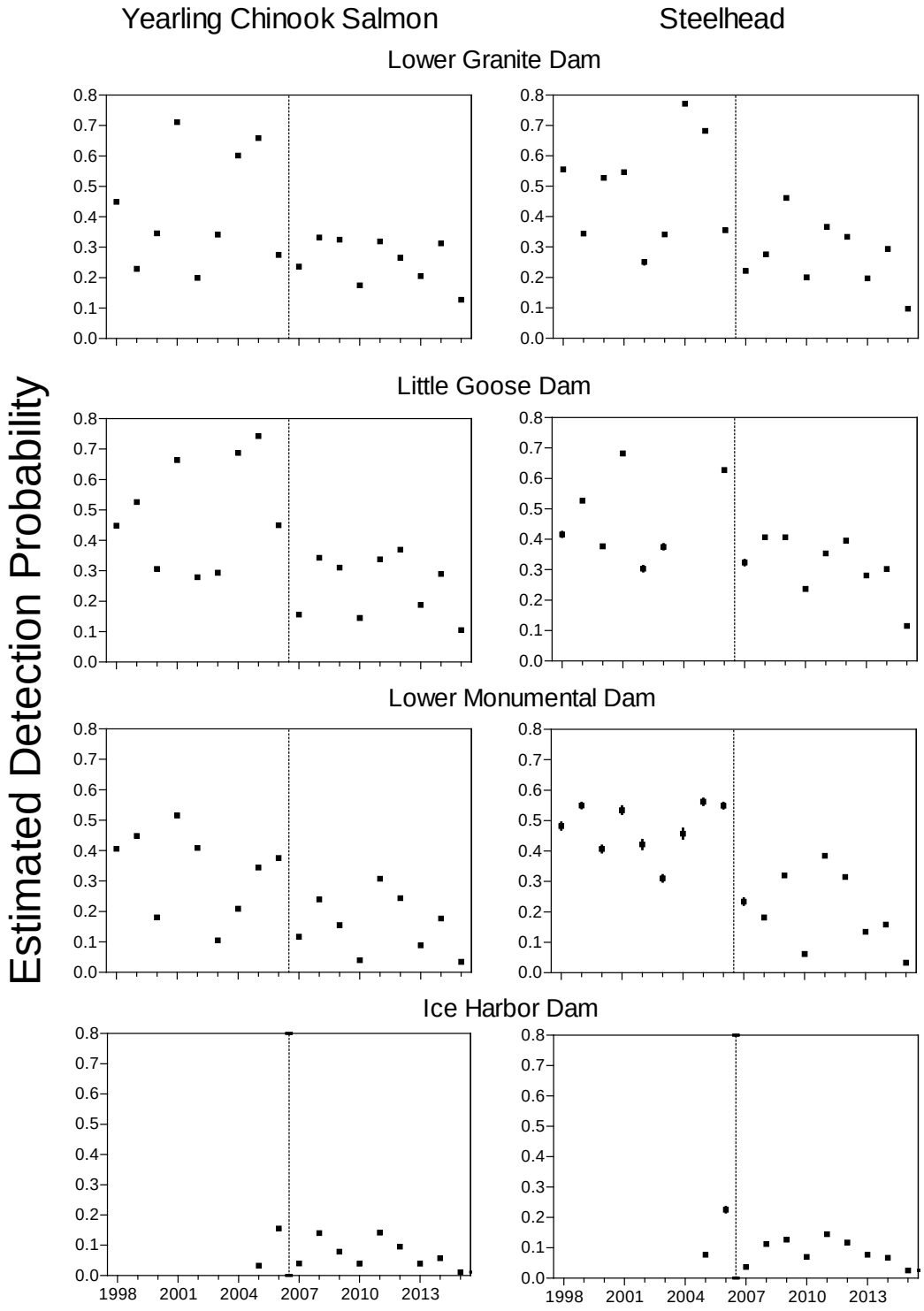

Figure 8. Annual average detection probability estimates at Snake River dams for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. The vertical dashed line represents the change in spill regime that started in the 2007 migration season.

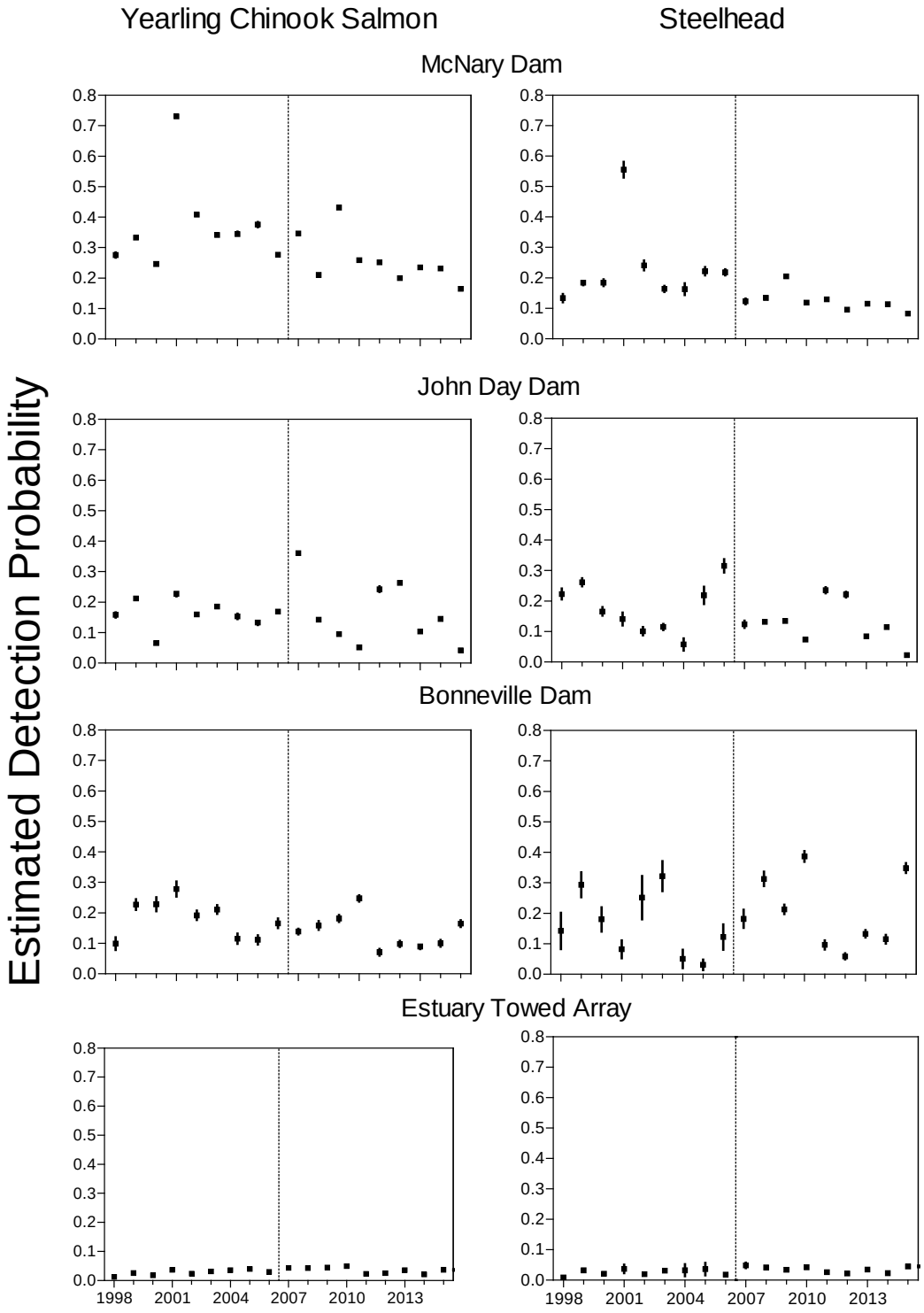

Figure 9. Annual average detection probability estimates at Columbia River dams and the towed estuary array for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. The vertical dashed line represents the change in spill regime that started in the 2007 migration season.