Upper Sacramento River Winter Chinook Salmon Carcass Survey

2022 Annual Report

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Abstract

Since 1996 the U.S. Fish & Wildlife Service and the California Department of Fish and Wildlife have cooperated on an annual survey of the spawning area of Sacramento River winter-run Chinook Salmon *Oncorhynchus tshawytscha* in the upper Sacramento River. The upper Sacramento River winter Chinook Salmon spawning area survey is used to estimate annual spawner abundance and is the primary source of data used to evaluate the performance of the U.S. Fish and Wildlife Service's winter Chinook Salmon integrated-recovery supplementation program conducted at the Livingston Stone National Fish Hatchery. This report summarizes information from the 2022 winter Chinook Salmon spawning area survey pertinent to evaluation of this program at the Livingston Stone National Fish Hatchery.

An estimated 5,921 winter Chinook Salmon returned to the upper Sacramento River in 2022. The abundance of winter Chinook Salmon spawning in 2022 was less than that observed in 2019, representing a negative age-3 cohort replacement rate. Of the total winter Chinook Salmon returning to the upper Sacramento River in 2022, an estimated 642 originated at the Livingston Stone National Fish Hatchery. The modal recovery date of hatchery- and natural-origin carcasses in 2022 was near their respective 2001–2021 mean. However, the 2022 temporal distributions of these two population groupings differed, with natural-origin carcasses exhibiting a later peak abundance, as opposed to hatchery-origin carcasses that exhibited a peak more consistent with the historical average. Regarding spatial distributions, the greatest numbers of both natural- and hatchery-origin recoveries occurred within the uppermost river mile 301, followed by river mile 300 for natural-origin and river mile 297 for hatchery-origin carcasses. Similar to most years, hatchery-origin returns in 2022 were dominated by age-3 fish. However, in 2022, age-4 fish represented the largest proportion of returns since at least 2001. Length-at-age comparisons between hatchery- and natural-origin winter Chinook Salmon were not completed due to the lack of hatchery origin age-2 males and due to uncertainty in the ages of natural-origin fish. Length-at-age comparisons between hatchery- and natural-origin adult (age-3 or older) winter Chinook Salmon were not completed due to uncertainty in the ages of natural-origin fish. Consistent with all survey years, the recovery of female carcasses in 2022 substantially exceeded those of males and the number of salmon dying prior to spawning was low.

Introduction

The Sacramento River system in California supports four distinct races of Chinook Salmon *Oncorhynchus tshawytscha*: fall, late-fall, spring, and winter. Winter Chinook Salmon (WCS) enter the Sacramento River from November through June in an immature reproductive state. They migrate into the upper reaches of the Sacramento River, hold in cool waters released from Shasta Dam, and spawn from May through August between the city of Red Bluff (river mile [RM] 245) and Keswick Dam (RM 302), the upstream limit of migration. Most WCS spawn at age three, with the remainder spawning at ages two and four (Hallock and Fisher 1985).

Sacramento River WCS were listed as “threatened” under the Endangered Species Act in 1989 (54 FR 32085: August 4, 1989) and the listing was downgraded to “endangered” in 1994 (59 Federal Register 440). The endangered status was reaffirmed in status reviews conducted in 2005 (70 Federal Register 37160), 2011 (76 Federal Register 50447), and 2016 (81 Federal Register 33468). In 1989, the U.S. Fish and Wildlife Service began propagating Sacramento River WCS to supplement natural production. The WCS integrated-recovery supplementation program, hereafter referred to as “Supplementation Program”, was initially located at the Coleman National Fish Hatchery (NFH) on Battle Creek, a tributary of the upper Sacramento River. In 1998, the Supplementation Program was moved to the newly constructed Livingston Stone NFH, located at the base of Shasta Dam, to improve imprinting to the natural spawning area in the Sacramento River. A secondary hatchery propagation program (Jumpstart Program) was subsequently developed in 2017 to reintroduce WCS to Battle Creek, which is believed to have historically supported a natural spawning population of WCS.

This report uses information derived from the 2022 WCS spawning area survey, hereafter referred to as the Carcass Survey, to monitor the characteristics, status, and trends of WCS spawning escapement in the Sacramento River. The Carcass Survey is a primary source of information to evaluate the performance of the WCS Supplementation Program at the Livingston Stone NFH. Data collected on the Carcass Survey are used to compare important life history attributes of hatchery- and natural-origin WCS, including age and sex composition of the spawning population, pre-spawn mortality rates, and temporal and spatial distributions of spawning. Another primary objective of the Carcass Survey is to estimate the abundance of spawning WCS in the Sacramento River. Precise estimates of WCS abundance are necessary to monitor the status of the species and assess progress towards achieving the delisting recommendations, which are specified in the recovery plan for WCS (National Marine Fisheries Service 2014).

This report does not evaluate the Jumpstart Program associated with the reintroduction of WCS to Battle Creek. For this report, identifiable Jumpstart WCS encountered on the Carcass Survey are removed from all comparative analyses between hatchery- and natural-origin fish, with the intent of only considering WCS produced from the Supplementation Program and natural reproduction in the Sacramento River. Jumpstart fish are included in calculation of two whole-population metrics, including the total river population estimate by the California Department of Fish and Wildlife (CDFW; noted in report text when used and in Appendix A) and the estimate of Proportionate Natural Influence. Each of these calculations consider all Chinook Salmon encountered on the Carcass Survey. Currently, returning Jumpstart WCS consist of only hatchery-origin fish, which are identifiable by a pelvic-fin clip or a CWT code unique to that program. The first potential return of natural-origin Jumpstart WCS occurred in 2022. Beginning at that time, naturally produced WCS will not be differentiable based on their location of origin, and WCS originating naturally in Battle Creek and the Sacramento River are considered together in this Carcass Survey report.

Methods

Study Area & Sampling Protocol

The Carcass Survey was designed to encompass the temporal and spatial distributions of WCS spawning within the mainstem Sacramento River. The Carcass Survey generally begins the Monday nearest May 1st and continues until spawning of WCS has ceased, as evidenced by no new recoveries of taggable carcasses (jaw disc tags) for two complete 3-day survey cycles (described below). A separate escapement survey of late-fall Chinook Salmon is conducted by the CDFW prior to the WCS spawning season and includes the known WCS spawning area; therefore, this additional survey has the potential to observe any WCS carcasses that would appear prior to the start of the Carcass Survey.

The Carcass Survey was conducted on 26 miles immediately downstream of the Keswick Dam, encompassing the known spawning area of WCS in the Sacramento River. The survey area was divided into four reaches (Figure 1): reach 1 extended from the Keswick Dam (RM 302) to the Anderson-Cottonwood Irrigation District (ACID) Diversion Dam (RM 298.5), reach 2 extended from the ACID Diversion Dam to the Highway 44 Bridge in Redding, California (RM 296), reach 3 extended from the Highway 44 Bridge to above Bourbon Island (RM 288.5), and reach 4 extended from above Bourbon Island to just below Ash Creek Road Bridge (RM 276).

Daily surveys were conducted in repeating 3-day cycles: reach 4 was surveyed on the first day of each survey cycle, reach 3 on the second day, and reaches 2 and 1 on the third day. Daily surveys were conducted with two boats, each having one observer and one boat operator. Polarized glasses were used to reduce glare and eyestrain and improve visibility of underwater objects. Each boat surveyed from a shoreline to the middle of the river. Carcasses were recovered using an approximate 4.9-meter gig spear.

Data recorded from carcasses included: collection date and location (reach, RM, and latitude / longitude), carcass condition (fresh or non-fresh), sex, spawn status (spawned, unspawned, and unknown), fork length, and adipose fin status (absent, present, and unknown). The condition of a recovered carcass was assigned as fresh if it had at least one clear eye, relatively firm body texture, or pink gills, otherwise the condition was assigned as non-fresh. Each carcass received an externally visible disc tag with a unique color and number combination that was applied to the lower jaw or was cut in half (e.g., severely degraded or previously sampled and tagged carcasses) prior to placing it into the river near to where it was recovered. The externally visible tag enabled previously sampled fish to be identified, which is necessary for applying the Cormack-Jolly-Seber mark-recapture method to estimate spawner abundance. Estimation of spawner abundance is conducted by the CDFW (Doug Killam, CDFW, Red Bluff, CA, personal communication) and not discussed in detail in this report. Because length, sex, and spawn status can be determined more reliably on fresh carcasses, information in this report is based only on data from fresh carcasses, unless otherwise noted. Spawn status of females was defined as spawned (abdomen extremely flaccid and very few eggs remaining in the skein), unspawned (abdomen firm and swollen with many eggs remaining in the skein), or unknown (indeterminable spawn status, usually due to predation on the carcass). The spawn status of males was considered less likely to be ascertained based on visual observation and is, therefore, not considered in this report.

Carcasses that were not extremely decayed were considered for biological specimen sampling, including a small piece of fin tissue, sagittal otoliths, and a skin patch (scales). The rate at which carcasses were sampled was dependent on workload and specimen type but conducted at levels to ensure representation of all carcasses throughout the entire survey. All tissues were preserved by desiccation. Fin tissues were archived for potential future genetic analysis, typically conducted by the U.S. Fish and Wildlife Service's Abernathy Fish Technology Center. Ageing of WCS scales will be conducted by the CDFW scale-ageing program. Otoliths were collected for the University of California – Davis, for use in a separate study not directly related to the assessment of the Supplementation Program; these samples are not discussed further in this report.

In addition to the above samples, the head was collected from all carcasses identified as hatchery-origin. All juvenile hatchery-origin WCS are processed prior to release for removal of the adipose fin and insertion of a coded-wire tag (CWT) into their snout. Hatchery-origin was identified in returning adult carcasses through the absence of an adipose fin or the detection of a CWT in carcasses where the adipose fin status could not be determined. Recovered heads were transferred to the Red Bluff Fish and Wildlife Office where they were processed, including CWT extraction and decoding, using established protocols (U.S. Fish and Wildlife Service 2014). Carcasses with a fin status of unknown were subsequently considered to be hatchery-origin if they contained a CWT or natural-origin if no CWT was verified during CWT extraction.

Data Analysis

Recovered carcasses were assumed to be WCS, unless indicated otherwise by CWT data. Data associated with carcasses of any run other than WCS were excluded from analyses. Data analyses and report figures were completed using R Statistical Software (v4.1.2; R Core Team 2021). Comparisons were made between hatchery- and natural-origin carcasses for the following metrics: temporal and spatial distribution using the Anderson-Darling (A-D) k-sample test (R with kSamples package; Scholz and Zhu 2019), age composition using Cochran-Mantel-Haenszel Chi-square (R with samplesizeCMH package; Egeler 2017), length-at-age using Welch Two Sample t-test (R with stats package; R Core Team, 2021), and sex composition and pre-spawn mortality using Fisher exact test (R with stats package; R Core Team, 2021), Cochran-Mantel-Haenszel Chi-square, and Tietjen-Moore Test for Outliers (R with climtrend package; Gama 2016). The temporal and spatial distributions of female carcass recoveries were used to provide insights to the relative timing and location of spawning for hatchery- and natural-origin fish. To draw these inferences requires the assumption that female hatchery- and natural-origin WCS have the same behaviors and longevity after spawning. Comparisons of the age distribution of hatchery- and natural-origin WCS were based on age assignments. The age of hatchery-origin carcasses was determined by decoding the CWT and identifying the brood year relative to the return year. The age of natural-origin carcasses will be determined by scale pattern analysis; however, this work has not been completed at the time this report was drafted and this comparison will be updated as information from scale ageing becomes available. To compare age compositions of hatchery- and natural-origin WCS in the absence of scale ageing, it was assumed that age-2 natural-origin carcasses can be reliably distinguished from age-three and older carcasses using length-frequency analysis (Ney 1993). However, length-frequency histograms of WCS do not reliably differentiate between fishes older than age-2; therefore, comparison of age distributions in this report are limited to the relative frequencies of age-2 fish to those of combined older age classes (i.e., age-3 and older). For all metrics analyzed, comparisons to previous years utilized data collected since 2001, which was the first year of adult returns originating from Livingston Stone NFH juvenile WCS releases that began with brood year 1998.

The potential for hatchery-origin WCS to have adverse genetic effects on the integrated population comprised of hatchery- and natural-origin fish was assessed using a metric developed by the Hatchery Scientific Review Group (2004). The Proportionate Natural Influence (PNI) is a tool that assists in managing hatcheries and fish populations to reduce adverse effects that hatcheries can have on disrupting adaptation to the natural environment. The PNI is calculated by dividing the proportion of natural-origin fish used as broodstock in the Livingston Stone NFH Supplementation Program (pNOB) by the sum of pNOB and the proportion of hatchery-origin fish spawning in the escapement study area [pHOS; PNI = pNOB / (pNOB + pHOS)]. The recommended PNI value of ≥0.67 is applicable to natural populations considered essential for the recovery or viability of an ESU.

Genetic parentage analyses of fin tissues were not completed at the time this report was drafted; however, analysis of these tissues is expected to occur in the near future and will be provided as an addendum to this report.

Run Size Estimate of Hatchery-origin WCS

Estimation of hatchery contribution to WCS spawner abundance is based on the observation of adipose-fin clips and CWTs within the sampled population. The determination of whether a carcass has an intact adipose fin can be difficult on non-fresh carcasses due to tissue decomposition and degradation, and potentially leads to misidentification of origin (Mohr and Satterthwaite 2013). Furthermore, the retention of a CWT within a degraded carcass may be less than that of a carcass with minimal degradation. To account for these potential biases, we estimated the abundance of adipose-fin clipped (i.e. hatchery-origin) WCS carcasses based on the proportion of adipose-fin clipped fish using only fresh carcass recoveries (Appendix A). The estimate of hatchery-origin carcasses was then proportionally expanded to include non-fresh fish and the unsampled fraction based on the Cormack-Jolly-Seber mark-recapture population estimate (Doug Killam, CDFW, Red Bluff, CA, personal communication). Additional calculations were performed to account for carcasses for which carcass condition was not recorded, fish that did not receive an adequate fin clip when marked as juveniles (estimated from mark retention data collected from juvenile salmon prior to their release), and observations of hatchery-origin, non-WCS straying into the survey area.

Results

Carcass Recoveries

The 2022 Carcass Survey began May 2 and ended September 22. The Carcass Survey began before WCS initiated spawning, as evidenced by zero observations of spawned WCS during the CDFW's late-fall Chinook Salmon escapement survey. The total of 1,650 Chinook Salmon carcasses observed represented 27.9% of the 2022 estimated run size of 5,921 (Table 1, Appendix A). These observations include a total of one carcass that originated from the Battle Creek Jumpstart Program, which expanded to two fish in the final run-size estimate; these Jumpstart WCS are not considered further in this report unless otherwise noted. Of the remaining carcasses observed, 855 fresh carcasses were sampled for biological data, including 50 with a missing adipose fin, 796 with an intact adipose fin, and 9 with an adipose fin of indeterminable status. Considering both fresh and non-fresh carcass recoveries, a total of 95 had a clipped adipose fin, 1,540 had a present adipose fin, and 14 had an adipose fin with an indeterminable status.

Coded-Wire Tag Recoveries

Non-fresh carcasses are included in the summary of CWT recoveries. The head was collected from 109 carcasses that were identified as either having a clipped adipose fin (n = 95), or an adipose fin with an indeterminable status (n = 14). Of the carcasses with an indeterminable adipose fin, none contained a CWT and all were reclassified as natural-origin. From the total of 109 heads collected on the Carcass Survey, a readable CWT was recovered from 72 heads, 2 CWT were lost before the code could be determined, and a CWT was not detected in 35 heads (Appendix A Table 2). Each of the recovered CWTs contained a code associated with WCS from the Livingston Stone NFH. Finally, a total of 1,540 carcasses had an intact adipose fin suggesting they were natural-origin. The final count of collected carcasses was 95 assigned to hatchery-origin and 1,554 assigned to natural-origin.

Hatchery- and Natural-origin Run Composition

Including two strays from the Jumpstart Program, an estimated 642 hatchery-origin WCS returned to the upper Sacramento River in 2022, representing 10.8% of the total estimated spawner escapement (Table 1). The PNI value of 0.86 was above the recommended value of 0.67 for the first time since 2015. The proportion of natural-origin fish available for use as broodstock within the hatchery (pNOB = 0.40) was relatively low, but the rate that hatchery-origin fish contributed to the natural spawning population (pHOS = 0.06) was very low; below the recommended 30% maximum.

Temporal and Spatial Distribution

For both hatchery- and natural-origin WCS, the overall 2022 temporal distributions of female carcass recoveries were different than their respective distributions from 2001–2021 (Anderson-Darling [A-D] k-sample test: hatchery-origin, $P < 0.001$; natural-origin, $P = 0.001$). The modal collection date for hatchery-origin carcasses of July 9 was typical of previous observations (2001–2021 mean = July 13 and range = June 23 to July 25). The modal collection date of natural-origin carcasses was July 18 (Figure 2), which was within but near the tail end of the range of previous observations (2001–2021 mean = July 9 and range = June 26 to July 24). For return year 2022, hatchery-origin temporal distributions were significantly earlier than for natural-origin (A-D k-sample test: $P < 0.001$). Although, the biological significance of these peak distributions is unknown, especially given they both were within the range of previous yearly observations.

The 2022 spatial distributions of female hatchery- and natural-origin WCS carcasses were not significantly different (A-D k-sample test; $P = 0.098$; Figure 3). However, in 2022, the distributions of female hatchery-and natural-origin carcasses were different from their respective 2001–2021 distributions (A-D k-sample test: hatchery-origin $P < 0.001$; natural-origin $P = 0.001$). The peak carcass collection in 2022 for both hatchery- (32.1%) and natural-origin carcasses (30.1%) occurred at RM 301, whereas the average peak collection during 2001–2021 occurred at RM 297 for hatchery-origin (17.9%) and RM 300 for natural-origin carcasses (26.9%). Atypical of most years since 2001 (7 out of 22), but for the fifth consecutive year (2018–2022), a greater proportion of natural-origin carcasses (56.9%) were observed in the two most upstream river miles compared to hatchery-origin carcasses (39.3%).

Age Composition and Length-at-Age

In 2022, consistent with most survey seasons since 2001, hatchery-origin WCS were predominantly age-3 (55.5%; Table 2). However, a larger proportion of hatchery-origin fish returned as age-4 (40.3%) than previously observed from 2001–2021. Only 9.3% of the hatchery-origin males recovered were age-2 (2001–2021 mean = 23.4%) while no age-2 hatchery-origin females were collected in 2022 (2001–2021 mean = 2.0%). Twenty-five age-2 natural-origin males (Table 3) and two age-2 natural-origin females were collected in 2022. From 2001 through 2022, hatchery-origin males were more likely to return at age-2 than for natural-origin males (Cochran-Mantel-Haenszel Chi-square: $P < 0.001$; controlled for return year). Comparison of hatchery- and natural-origin age-2 females were not made due to low sample sizes across years.

Length-at-age comparisons between hatchery- and natural-origin age-2 fish were precluded by insufficient sample size of age-2 males. Length-at-age comparisons by origin of age-3 and older males and on all age classes of females were not possible due to the absence of well-defined modes in the length-frequency histograms, which precluded ageing by this method (Figure 4). Ageing of scales collected from WCS carcasses will be conducted by the CDFW Scale Ageing program, but this work has not been completed at the time this report was drafted. This information will be updated in supplemental reports as information from scale ageing becomes available.

Sex Ratio

Considering fresh and non-fresh carcasses, substantially more female than male carcasses were recovered in 2022, which is consistent with all previous survey years (Table 4). Hatchery-origin females outnumbered males 1.5 to 1 and natural-origin females outnumbered males 2.5 to 1; these ratios were significantly different from each other (Fisher exact test: $P = 0.025$). Considering return years 2001–2022, the proportion of females to males was significantly greater for hatchery-origin than for natural-origin WCS (Cochran-Mantel-Haenszel Chi-square test stratified on return year: $P = 0.001$).

Pre-spawn Mortality

In 2022, the proportion of natural-origin female salmon carcasses that were collected unspawned was 2.2% (13 out of 589), while no hatchery-origin female carcass was determined to be unspawned (0 out of 28; Table 5). For survey years 2001–2022, the proportion of unspawned females was significantly higher in hatchery-origin as compared to natural-origin fish (Cochran-Mantel-Haenszel Chi-square test stratified on return year: $P < 0.001$). In 2022, no unspawned hatchery-origin females were observed within the 28 carcasses collected; however, the proportion of unspawned natural-origin females in 2022 was not unusually high compared to the respective 2001–2021 observations (Tietjen-Moore Test for Outliers: $P < 0.05$).

TABLE 1.—Sacramento River winter Chinook Salmon estimated run size, hatchery-origin run component, carcasses observed, and river miles surveyed for return years 2001–2022.

Return Year	Total Estimated Run[a]	Hatchery origin Estimated Run[b]	Hatchery origin % of Total	Total Carcasses Observed	Percent of Total Estimated Run Observed	River miles Surveyed, From : To
2001	8,224	429	5.2	5,145	62.6	288 : 302
2002	7,441	566	7.6	4,959	66.6	288 : 302
2003	8,218	423	5.1	4,549	55.4	286 : 302
2004	7,869	636	8.1	3,280	41.7	273 : 302
2005	15,839	3,056	19.3	8,771	55.4	273 : 302
2006	17,296	2,386	13.8	7,698	44.5	275 : 302
2007	2,541	143	5.6	1,581	62.2	276 : 302
2008	2,830	170	6.0	1,409	49.8	276 : 302
2009	4,537	467	10.3	1,904	42.0	276 : 302
2010	1,596	199[c]	12.5	908	56.9	276 : 302
2011	827	82[c]	9.9	431	52.1	276 : 302
2012	2,671	809	30.3	1,348	50.5	276 : 302
2013	6,404	399	6.2	3,217	50.2	276 : 302
2014	3,015	705	23.4	1,389	46.1	276 : 302
2015	3,440	770	22.4	1,194	34.7	276 : 302
2016	1,547	467	30.2	297	19.2	276 : 302
2017	977	824	84.3	143	14.6	276 : 302
2018	2,639	2,177	82.5	1,126	42.7	276 : 302
2019	8,033	2,978	37.1	3,026	37.7	276 : 302
2020	6,392	2,909	45.5	3,678	57.5	276 : 302
2021	10,254	3,271	31.9	4,847	47.3	276 : 302
2022	5,921	642	10.8	1,650	27.9	276 : 302
Mean	5,841	1,114	19.1	2,843	48.7	276 : 302

[a] Estimates of Sacramento River winter Chinook Salmon spawning escapement (natural spawners and Livingston Stone NFH broodstock; excludes Jumpstart Program returning to Battle Creek). Estimated by the California Department of Fish and Wildlife and reported by that agency (https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381&inline=1) as part of the Sacramento River winter Chinook Salmon Carcass Survey effort. Recent estimates not reported online were provided by Doug Killam, California Department of Fish and Wildlife, Red Bluff, CA (personal communication).

[b] Calculation of this estimate utilizes the 'Total Estimated Run-size.' Data corrections have resulted in changes to the California Department of Fish and Wildlife 'Total Estimated Run-size' and the U.S. Fish and Wildlife Service 'Hatchery-Origin Estimated Run-size' for some years, from values reported in the corresponding yearly reports.

[c] This estimate is less than the actual count of hatchery-origin winter Chinook Salmon made at the Keswick Dam Fish Trap from February–July of the respective year.

TABLE 2.—Sacramento River winter Chinook Salmon percent at age by origin and sex[a,b,c], for return years 2001–2022.

Return Year	Natural origin, % at Age		Hatchery origin, % at Age[d]			
	Age-2	Age-3 and older	Age-2	Age-3	Age-4	Age-5
			Total			
2001	9.0	91.0	26.4	73.6	0.0	0.0
2002	6.5	93.5	10.0	88.3	1.6	0.0
2003	2.6	97.4	8.9	90.3	0.8	0.0
2004	12.4	87.6	36.6	62.2	1.2	0.0
2005	4.4	95.6	5.0	94.9	0.1	0.0
2006	1.3	98.7	0.2	95.5	4.4	0.0
2007	4.0	96.0	1.5	71.5	27.0	0.0
2008	3.5	96.5	15.8	79.8	2.2	2.1
2009	1.0	99.0	0.0	100.0	0.0	0.0
2010	1.7	98.3	1.1	85.0	13.9	0.0
2011	8.8	91.2	61.5	29.4	9.1	0.0
2012	5.8	94.2	0.3	99.7	0.0	0.0
2013	2.5	97.5	17.4	82.6	0.0	0.0
2014	8.3	91.7	7.2	88.5	4.3	0.0
2015	1.0	99.0	0.6	98.2	0.6	0.0
2016	5.8	94.2	57.5	38.1	4.3	0.0
2017	7.7	92.3	40.0	57.2	2.8	0.0
2018	39.0	61.0	17.6	82.2	0.2	0.0
2019	3.9	96.1	4.8	94.8	0.3	0.0
2020	6.4	93.6	5.3	94.5	0.2	0.0
2021	2.8	97.2	0.8	96.5	2.7	0.0
2022	3.4	96.7	4.2	55.5	40.3	0.0
			Female			
2001	0.2	99.8	5.0	95.0	0.0	0.0
2002	1.2	98.8	1.7	97.4	0.8	0.0
2003	0.2	99.8	0.0	99.0	1.0	0.0
2004	1.0	99.0	1.2	96.5	2.3	0.0
2005	0.3	99.7	0.1	99.9	0.0	0.0
2006	0.1	99.9	0.0	97.8	2.2	0.0
2007	0.6	99.4	0.0	74.9	25.1	0.0
2008	0.0	100.0	0.0	93.7	3.3	3.0
2009	0.0	100.0	0.0	100.0	0.0	0.0
2010	0.3	99.7	0.0	83.6	16.4	0.0
2011	3.4	96.6	60.5	34.1	5.3	0.0
2012	2.6	97.4	0.4	99.6	0.0	0.0
2013	1.5	98.5	5.4	94.6	0.0	0.0
2014	4.1	95.9	2.7	94.6	2.7	0.0
2015	0.3	99.7	0.0	100.0	0.0	0.0
2016	3.8	96.2	36.9	58.2	4.9	0.0

TABLE 2.—Continued.

Return Year	Natural origin, % at Age		Hatchery origin, % at Age[d]			
	Age-2	Age-3 and older	Age-2	Age-3	Age-4	Age-5
2017	9.1	90.9	34.3	64.6	1.2	0.0
2018	11.7	88.3	4.1	95.8	0.2	0.0
2019	0.9	99.1	1.4	98.6	0.0	0.0
2020	1.2	98.8	1.3	98.6	0.1	0.0
2021	0.4	99.6	0.4	98.7	1.0	0.0
2022	0.3	99.7	0.0	62.5	37.5	0.0
			Male			
2001	25.4	74.6	49.6	50.4	0.0	0.0
2002	21.1	78.9	59.2	34.5	6.2	0.0
2003	15.9	84.1	46.1	53.9	0.0	0.0
2004	40.1	59.9	77.6	22.4	0.0	0.0
2005	16.0	84.0	18.8	81.0	0.3	0.0
2006	4.0	96.0	0.6	89.2	10.3	0.0
2007	13.7	86.3	11.2	49.9	38.9	0.0
2008	14.0	86.0	50.8	49.2	0.0	0.0
2009	3.3	96.7	0.0	100.0	0.0	0.0
2010	7.0	93.0	3.7	88.1	8.2	0.0
2011	30.6	69.4	67.2	0.0	32.8	0.0
2012	24.0	76.0	0.0	100.0	0.0	0.0
2013	6.2	93.8	45.8	54.2	0.0	0.0
2014	19.7	80.3	17.2	75.1	7.7	0.0
2015	3.9	96.1	1.9	94.2	2.0	0.0
2016	20.0	80.0	86.3	10.1	3.6	0.0
2017	0.0	100.0	64.6	25.4	9.9	0.0
2018	75.6	24.4	45.9	53.8	0.4	0.0
2019	10.9	89.1	17.1	81.3	1.6	0.0
2020	25.7	74.3	29.7	69.2	1.1	0.0
2021	9.9	90.1	2.1	90.4	7.5	0.0
2022	11.6	88.4	9.3	46.9	43.8	0.0

[a] The number of age-2 natural-origin fish was estimated by looking for a logical break in the length-frequency analysis for each spawning season. Age-2 fish were considered less than or equal to the following fork lengths (cm), by return year, for females and males, respectively: 2001: 58, 69; 2002: 55, 68; 2003: 56, 67; 2004: 58, 69; 2005: 58, 67; 2006: 58, 67; 2007: 58, 68; 2008: 58, 68; 2009: 57, 67; 2010: 57, 67; 2011: 59, 68; 2012: 62, 66; 2013: 62, 68; 2014: 64, 68; 2015: 58, 67; 2016: 58, 68; 2017: 62, 71; 2018: 61, 69; 2019: 61, 67; 2020: 59, 67; 2021: 58, 69; 2022: 58, 66. Age of hatchery-origin carcasses was determined by coded-wire tag data.

[b] Age of carcasses was determined from those recovered at or above river mile 276 to maximize usable data and consistency among years.

[c] The percent at age for natural-origin fish are based on fresh carcasses. Due to the presence of a coded-wire tag in hatchery-origin fish, and the lower abundance of hatchery-origin fish, fresh and non-fresh carcasses were used.

[d] Based on expanded coded-wire tag recoveries using methods described in Appendix A.

TABLE 3.—Fork length (cm) of fresh age-2 male hatchery- and natural-origin Sacramento River winter Chinook Salmon carcasses, return years 2001–2022.

Return Year	Natural origin[a]					Hatchery origin				
	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
2001	162	56	5.9	40	69	24	54	6.1	39	65
2002	71	58	4.7	46	68	8	55	6.1	47	65
2003	56	52	5.1	41	65	10	52	5.3	42	58
2004[b]	164	58	5.3	43	68	35	54	4.7	44	63
2005	134	56	5.4	41	66	38	55	4.7	45	65
2006	20	56	5.7	44	64	1[c]	-	-	54	54
2007	25	55	5.8	44	67	1	-	-	55	55
2008	17	54	6.8	46	65	5	51	5.9	44	57
2009	7	56	4.8	50	64	0	-	-	-	-
2010	6	52	4.7	43	56	1[c]	-	-	48	48
2011	11	57	7.0	48	68	2	61	8.5	55	67
2012	18	53	5.3	43	66	0	-	-	-	-
2013	15	56	5.0	45	67	15	54	6.9	45	69
2014	25	58	5.6	45	68	4	53	4.8	49	60
2015	3	53	3.2	49	55	1[c]	-	-	59	59
2016	3	61	9.9	50	68	17	60	7.1	46	78
2017	0	-	-	-	-	10	61	4.9	54	71
2018	34	59	8.0	21	68	46	61	6.5	50	82
2019	30	56	5.3	47	66	20	56	5.0	46	68
2020	60	58	4.2	48	66	37	56	6.3	39	78
2021[b]	39	60	5.6	47	69	6	54	3.3	50	57
2022	24	59	3.5	51	64	1[c]	-	-	61	61

[a] The maximum length of natural-origin age two males was estimated through length-frequency analysis.

[b] The yearly age-2 fork lengths were significantly different (Welch's Two Sample t-test: 2004, *df* = 54.1, $P <$ 0.001; 2021, *df* = 10.3, $P = 0.002$). Low sample size of fresh hatchery-origin male carcasses precluded this analysis from return years 2006, 2007, 2009, 2010, 2012, 2015, 2017, and 2022.

[c] No fresh two year old male carcasses were collected; non-fresh carcass data presented if available.

TABLE 4.—Sex ratio of hatchery- and natural-origin Sacramento River winter Chinook Salmon carcasses, return years 2001–2022. Both fresh and non-fresh carcass recoveries at or above river mile 276 were used to maximize usable data and consistency among years.

Return Year[a]	Natural origin			Hatchery origin		
	Female (F)	Male (M)	F:M	Female (F)	Male (M)	F:M
2001[b]	1,950	1,007	1.9	84	67	1.3
2002[b]	1,379	460	3.0	175	28	6.2
2003	1,954	384	5.1	152	30	5.1
2004[b]	1,006	410	2.5	133	98	1.4
2005	2,451	841	2.9	1,114	375	3.0
2006[b]	1,017	463	2.2	658	225	2.9
2007[b]	521	184	2.8	70	12	5.8
2008	368	121	3.0	41	18	2.3
2009	493	220	2.2	100	37	2.7
2010	503	171	2.9	78	29	2.7
2011	234	81	2.9	28	4	7.0
2012[b]	577	112	5.2	284	78	3.6
2013	1,354	357	3.8	113	42	2.7
2014	476	180	2.6	130	64	2.0
2015[b]	462	135	3.4	135	60	2.2
2016[b]	139	38	3.7	45	32	1.4
2017	17	7	2.4	88	20	4.4
2018[b]	92	87	1.1	606	291	2.1
2019[b]	936	452	2.1	742	196	3.8
2020[b]	1,153	317	3.6	1,260	207	6.1
2021	1,514	517	2.9	871	301	2.9
2022[b]	748	298	2.5	57	38	1.5
Mean	879	311	2.8	317	103	3.1

[a] Controlling for year, sex ratios between hatchery- and natural-origin fish were different (Cochran-Mantel-Haenszel Chi-square: $P < 0.001$).

[b] The yearly hatchery- and natural-origin sex ratios were significantly different (Pearson's Chi-square: $df = 1$, $P \leq 0.05$).

TABLE 5.—Pre-spawn mortality of hatchery- and natural-origin female Sacramento River winter Chinook Salmon, return years 2001–2022.

	Natural origin			Hatchery origin		
Return year[a]	Total carcass	Number not spawned	Percent not spawned	Total carcass	Number not spawned	Percent not spawned
2001	1,177	10	0.8	62	0	0.0
2002	927	19	2.0	81	3	3.7
2003	1,915	11	0.6	98	0	0.0
2004[b]	995	7	0.7	74	4	5.4
2005[b]	2,419	36	1.5	600	24	4.0
2006[b]	1,918	25	1.3	324	23	7.1
2007	518	9	1.7	36	1	2.8
2008	361	6	1.7	25	0	0.0
2009	488	3	0.6	64	0	0.0
2010	321	1	0.3	40	1	2.5
2011	147	1	0.7	19	0	0.0
2012[b]	427	2	0.5	175	5	2.9
2013	977	8	0.8	62	2	3.2
2014	344	3	0.9	73	1	1.4
2015	325	7	2.2	74	1	1.4
2016	106	0	0.0	22	1	4.5
2017	11	1	9.1	49	0	0.0
2018	60	0	0.0	347	3	0.9
2019	661	6	0.9	434	7	1.6
2020	856	21	2.5	765	27	3.5
2021	1,161	62	5.3	505	30	5.9
2022	589	13	2.2	28	0	0.0
Mean	759	11	1.4	180	6	3.3

[a] Controlling for year, the proportion of spawned females was lesser for hatchery-origin than for natural-origin fish from return years 2001–2022 (Cochran-Mantel-Haenszel Chi-square: $P < 0.001$).

[b] The yearly hatchery- and natural-origin pre-spawn mortality ratios were significantly different (Pearson's Chi-square: $P \leq 0.050$).

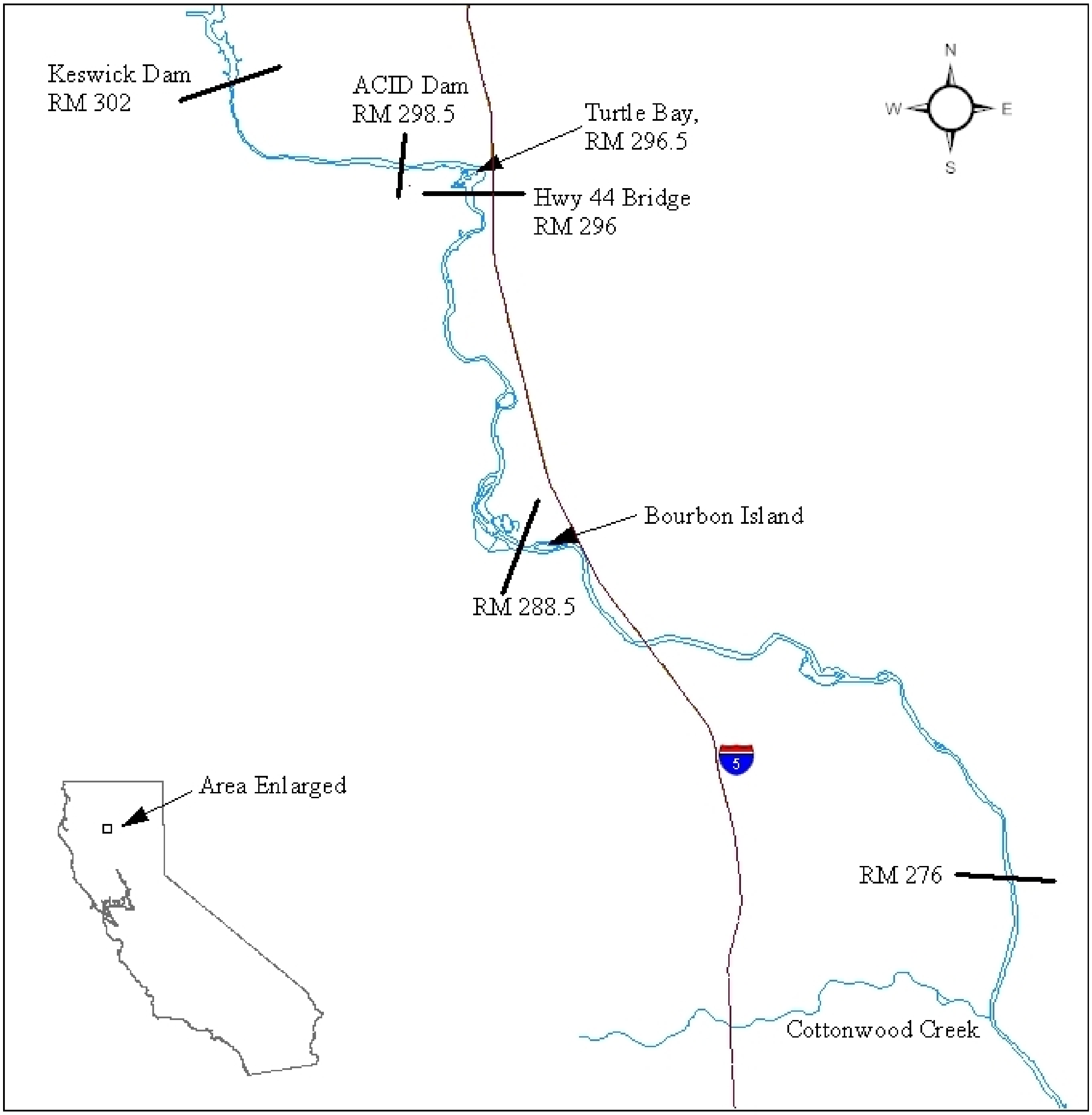

FIGURE 1.—Area included in the Sacramento River winter Chinook Salmon Carcass Survey for return year 2022. Survey reach boundaries are delineated by a solid black line and their respective river mile is indicated (see text for survey reach descriptions).

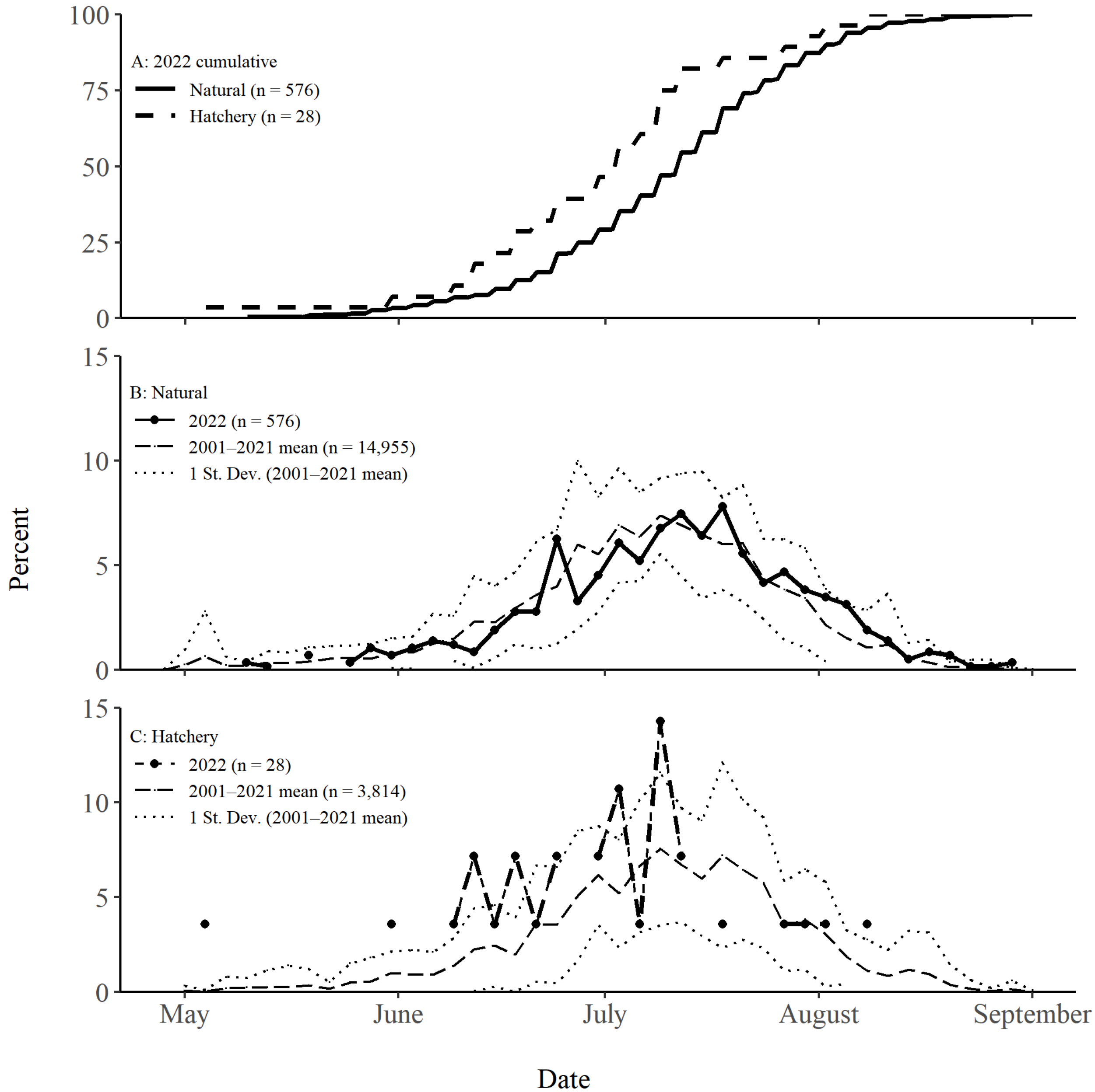

FIGURE 2.—Temporal distribution of fresh female Sacramento River winter Chinook Salmon carcass recoveries for return year 2022. Represented is (A) the cumulative percent of natural- and hatchery-origin winter Chinook Salmon recovered by date for return year 2022 (A-D k-sample test: $P < 0.001$) and a comparison of the total percent that returned by date with the mean observed for return years 2001–2021 for (B) natural- (A-D k-sample test: $P = 0.001$) and (C) hatchery-origin fish (A-D k-sample test: $P < 0.001$).

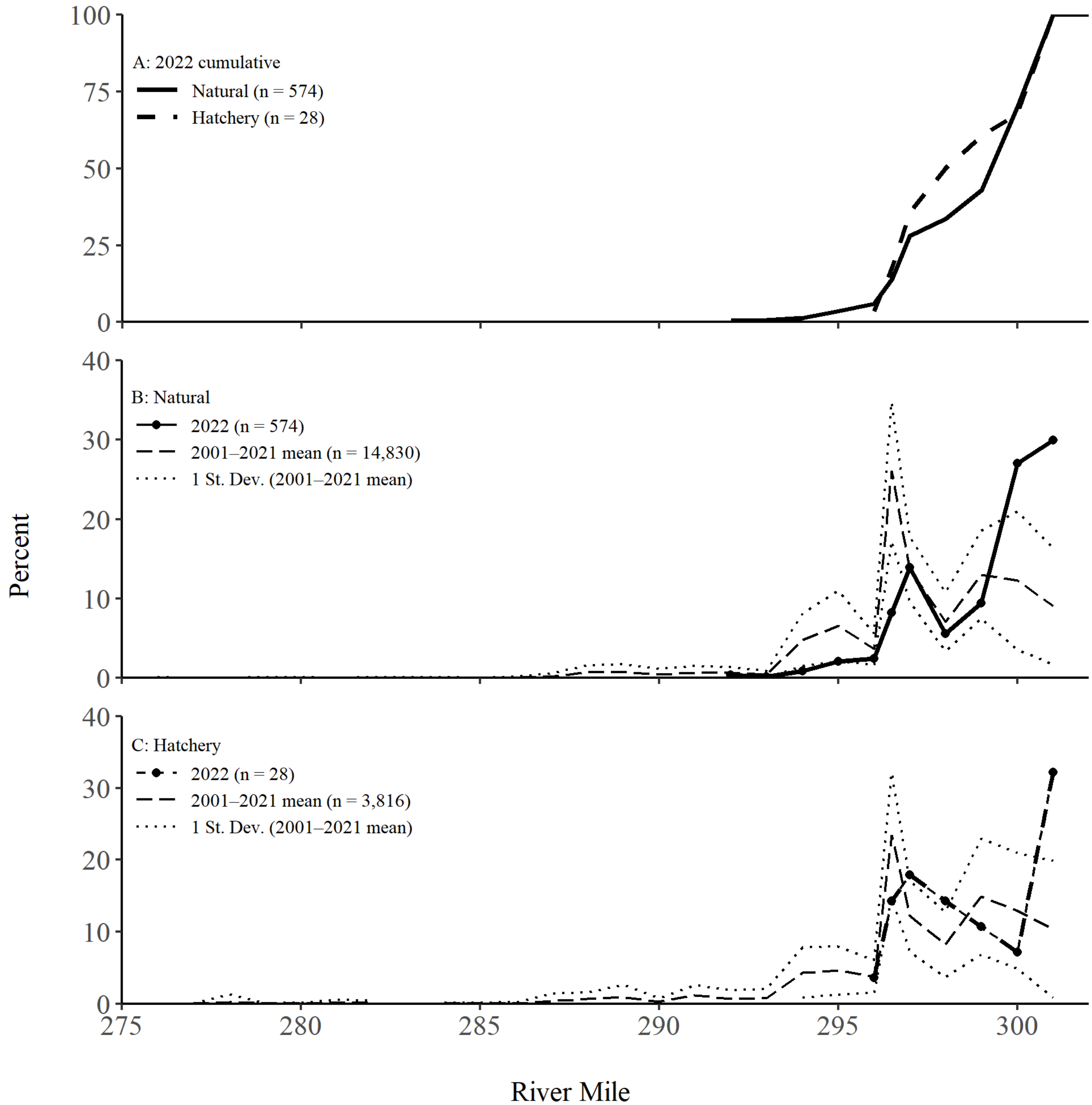

FIGURE 3.—Spatial distribution of spawned fresh female Sacramento River winter Chinook Salmon carcass recoveries for return year 2022. Represented are (A) the cumulative percent of natural- and hatchery-origin winter Chinook Salmon recovered by river mile for return year 2022 (A-D k-sample test: $P = 0.098$) and a comparison of the total percent recovered by river mile with the mean observed for return years 20012021 for (B) natural- (A-D k-sample test: $P = 0.001$) and (C) hatchery-origin fish (A-D k-sample test: $P < 0.001$).

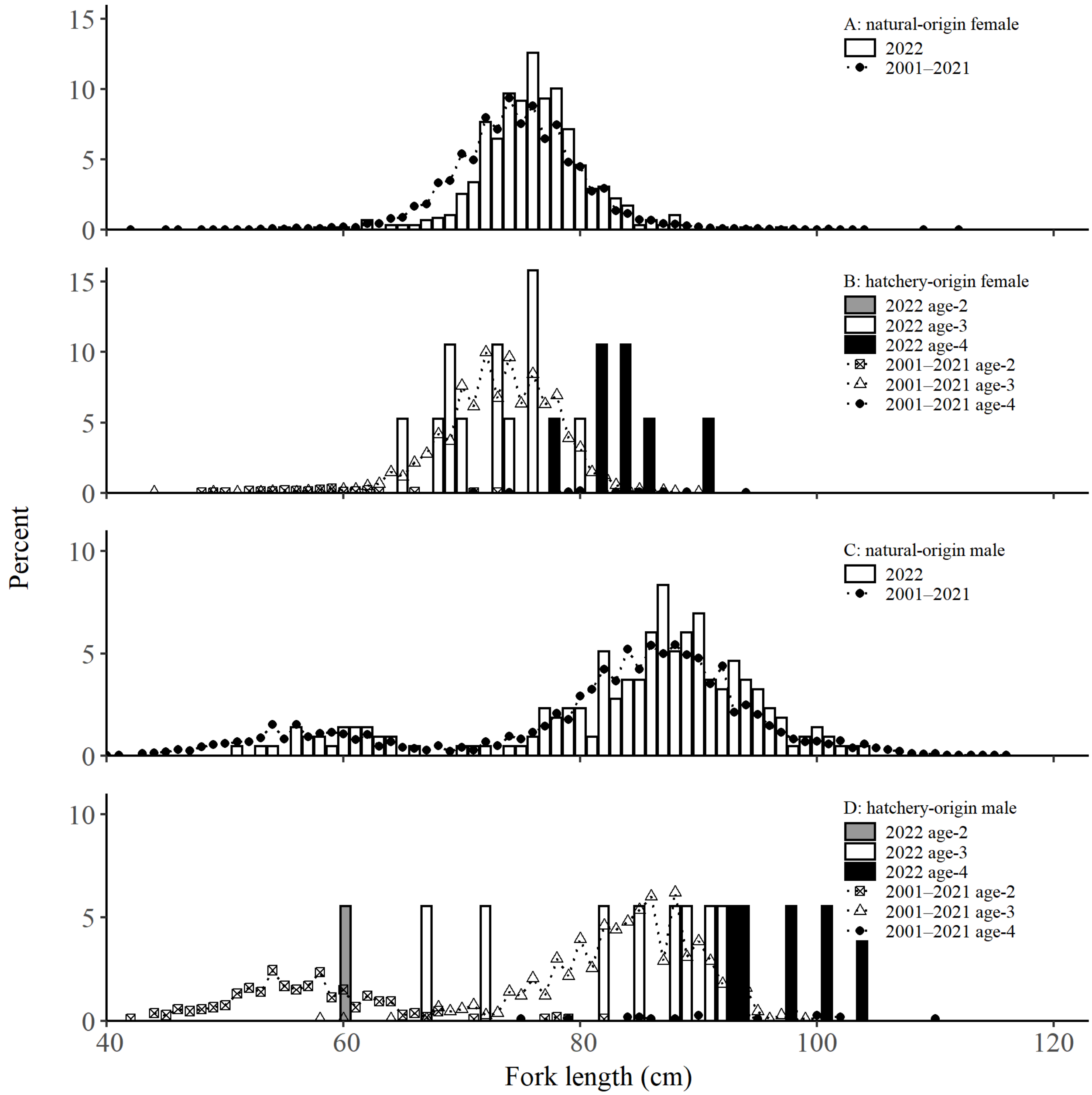

FIGURE 4.—Winter Chinook Salmon length-frequency distribution comparisons of fresh carcass recoveries for return year 2022 and the mean from return years 2001–2021.

Discussion

The upper Sacramento River WCS Carcass Survey is used to estimate the abundance of WCS spawners in the mainstem Sacramento River and is a principal source of information to evaluate the Supplementation Program at the Livingston Stone NFH. The WCS Supplementation Program is operated to increase the abundance of WCS in the Sacramento River while imposing a low risk of adverse impacts to the population. Hatchery-origin WCS are intended to mimic phenotypic characteristics of naturally produced WCS, such as spawn time and location, and to reproductively integrate with naturally produced WCS in the upper Sacramento River (U.S. Fish and Wildlife Service 2011). In 2022, the WCS Supplementation Program increased the number of WCS spawners in the Sacramento River and represented 10.8% of the estimated spawner abundance.

The positive effects of the Supplementation Program at increasing abundance and reducing the risk of extinction in the short term are accompanied by an increased level of long-term genetic risks to the WCS population due to domestication. The PNI is a tool to assist in managing hatcheries and fish populations to minimize adverse effects that hatcheries can have on the local adaptation of naturally spawning populations (Hatchery Scientific Review Group 2004). The PNI metric focuses on quantifying the relative influence of hatchery and natural environments to integrated salmon populations. It is generally desirable for the natural environment to have a greater influence on natural spawning salmon populations than the hatchery environment. For integrated populations that are considered essential for recovery or viability of an Evolutionarily Significant Unit (ESU), such as the Sacramento River WCS population, PNI is recommended to be greater than 0.67 and pHOS less than 0.30. In 2022, the PNI value for the WCS population (PNI = 0.86) was above this recommended value. Prior to 2022, the PNI had been below the recommended value for six consecutive years.

The lower PNI value for WCS from 2016–2021 resulted from the low numbers of natural-origin fish collected for use as hatchery broodstock (mean pNOB = 0.23) and the relatively high rate that hatchery fish contributed to the natural spawning population (mean pHOS = 0.50; as compared to a hatchery target of less than 0.10). Both factors were exacerbated by recent year-class failures of natural-origin WCS resulting from successive or recurrent conditions of severe drought and associated decisions to temporarily increase production in the Supplementation Program. Another factor contributing to the relatively low PNI value observed from 2016–2021 is the inability to collect sufficient numbers of natural-origin fish at the Keswick Dam Fish Trap for use as hatchery broodstock. For example, despite the presence of nearly 7,000 natural-origin spawners in the Sacramento River in 2021, and a trapping program and brood selection strategy oriented towards preferentially retaining up to 300 natural-origin WCS, a total of only 57 natural-origin WCS were trapped and retained as hatchery broodstock. This results because naturally produced WCS tend to develop redd sites downstream of Keswick Trap, so that they generally are not as susceptible to trapping at that location as hatchery-origin fish. Modifications to the brood collection strategy, potentially including a downstream trapping location nearer to the geographic center of the WCS spawning distribution, will be necessary to substantively improve pNOB and PNI for Sacramento River WCS in future years. While these concerns may have been alleviated in 2022 with acceptable PNI and pHOS values, it is likely to only be temporary as evidenced by the low return of age-2 and age-3 year classes in 2022.

While a reduced PNI presents a genetic risk to the population, there are also genetic risks associated with allowing year class failures that may result in substantially reduced WCS abundance (albeit with a higher PNI). If the decision had been made to forego increased hatchery production in years of drought, the abundance of WCS spawners would have fallen to critically low levels. For example, during 2017 an estimated total of only 151 naturally produced WCS were included in the total spawning escapement, indicating a general failure of the 2014 year class to produce age-2 recruits. Demographic factors become increasingly important as the population size decreases, potentially resulting in the permanent loss of genetic variation and reducing the ability of the population to adapt to environmental change. Both short-term and long-term genetic risks are cause for concern with WCS and resource managers should continue to consider both areas of risk when developing hatchery management strategies in future years. These concerns are amplified during period of drought, when the naturally spawning component of the population is expected to experience low reproductive success.

An estimated 642 hatchery-origin fish are included in the upper Sacramento River spawner estimate in 2022. The estimated number of hatchery-origin fish may be upwardly biased compared to previous survey seasons because of changes that were implemented in the retention of broodstock for the Livingston Stone NFH beginning in 2014. Prior to 2014, hatchery-origin WCS collected while trapping for hatchery broodstock were retained at a low rate (1998-2009) or released into the Sacramento River to spawn naturally (2010-2013). However, since 2014, due to the paucity of natural-origin WCS spawners and increased brood fish collection targets during years of expanded hatchery production, hatchery broodstock has consisted of a high proportion of hatchery-origin fish. This change of protocols for retaining broodstock may impart a bias to the estimated number of hatchery spawners. Per standard protocols, the estimate of abundance of naturally spawning WCS is based on the mark-recapture methods and fish retained as hatchery broodstock are added to the estimate of in-river spawners. Unpublished research has demonstrated, however, that Chinook Salmon released from the Keswick Dam Fish Trap are not typically observed on the Carcass Survey commensurate with the number released, thereby causing them to be underrepresented in estimates of escapement. Conversely, all WCS retained as Supplementation Program broodstock are directly added to the estimated number of natural spawners. This methodology results in an estimate of hatchery-origin fish which may be upwardly biased during years when many hatchery-origin WCS are retained for spawning. The potential for this bias is highest when a higher proportion of hatchery fish are retained for broodstock. In 2022, more than 50% of the total hatchery spawners were retained for broodstock, indicating circumstances existed that could exacerbate this potential bias within the estimation methodology.

In 2022, the peak date of female carcass recovery was different for hatchery- and natural-origin WCS and differed by nine days. Although, the peak spawn dates of 2022 for each group were within their respective range of annual variability observed during previous survey seasons. The temporal distributions being statistically different between natural- and hatchery-origin females likely resulted from the sensitivity of the statistical analyses and the low samples size of hatchery-origin females and may not be biologically meaningful. The modal abundance of both natural- and hatchery-origin carcasses coincided in July and the temporal distribution of carcasses overlapped substantially. Furthermore, an interannual trend towards earlier or later spawn timing isn't apparent for either hatchery- or natural-origin WCS. Improved resolution into the assessment of the temporal distribution of hatchery- and natural-origin WCS spawners may result from genetic parentage analyses, which is currently planned to begin in 2023.

Heavily utilized spawning area for WCS is mostly limited to within the same 5.5-mile stretch of the Sacramento River between RM 296.5 and the end of RM 301. The spatial distributions of carcass recoveries in 2022 were not statistically different between hatchery- and natural-origin WCS, though hatchery-origin were proportionally more abundant near river mile 297. In 2022, the spatial distributions of hatchery- and natural-origin WCS carcasses overlapped considerably, with greater than 94% of each overlapping within the same 5.5-mile stretch (RM 296.5–RM 301). Considering the similar temporal and spatial distributions observed between hatchery- and natural-origin fish, we consider it likely that there was a high level of reproductive integration of between hatchery and natural origin WCS in 2022. However, the 2022 spatial distributions of both hatchery- and natural-origin carcasses was statistically different from the aggregate (e.g., multi-year) 2001–2021 distribution. Annual variation in peak spawn location results in an aggregate spawn distribution that differed than the 2022 spawn distribution. The exact cause of the yearly variation is unknown, with possible factors such as normal biological variation, variable effectiveness of fish passage at the ACID Dam, variation in abundance of spawning substrate or water temperature, as influenced by management operations from Shasta and Keswick Dams.

Only one hatchery-origin grilse (age-2) male and no grilse females was observed in 2022, possibly indicating relatively poor survival of the 2020 year-class at the Livingston Stone NFH. The low number of age-2 males prevented any statistical comparison to natural-origin male recoveries. For both female and male recoveries, proportionally more age-4 hatchery-origin fish were observed in 2022 than in any previous year. The high proportion of age-4 WCS observed in 2022 is largely a result from a reduced return of age-2 and age-3 cohorts.

The sex ratio of WCS observed on the Carcass Survey in 2022 was similar to most previous survey seasons and appears to show a persistent bias against the collection of males. Consistent with this hypothesis, the proportion of males collected at the Keswick Dam Fish Trap is typically much higher than that observed on the carcass survey (U.S. Fish and Wildlife Service, Red Bluff FWO, unpublished data). The discrepancy in sex ratios between these locations likely results from sex-mediated differences in post-spawning behaviors, with females remaining near their redd site until they die and males moving about freely and searching for additional spawning opportunities. A bias against observing males at their true abundance is supported by the increased occurrence of male carcasses in downstream survey areas (U.S. Fish and Wildlife Service 2004) and frequent observations of male Chinook Salmon passively drifting downstream in a moribund state.

Pre-spawn mortality rates were low for both hatchery- and natural-origin females in 2022 and did not significantly differ. Considering the entirety of data collected on the Carcass Survey from 2001–2022, pre-spawn mortality rates of hatchery-origin winter Chinook Salmon were significantly higher than that of natural-origin winter Chinook Salmon for 4 of the 22 survey seasons, whereas pre-spawn mortality rates were not significantly different between hatchery and natural-origin winter Chinook Salmon for 18 of 22 survey seasons. Overall, the number and proportion of pre-spawn mortalities are low, and a trend of increasing rates of pre-spawn mortality rates across years is not apparent.

Multiple sources of information support that the spatial and temporal limits of the Carcass Survey were sufficient to encompass the location and duration of WCS spawning. Few carcasses were observed at the beginning and end of the survey season, suggesting that the survey season encompassed the vast majority of WCS spawning activity. Indications that the survey encompassed the entire area used for WCS spawning include observations of few carcasses in survey areas furthest downstream combined with information from aerial redd surveys, which showed no WCS redds downstream of the area encompassed by the Carcass Survey (CDFW unpublished data).

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Appendix A.—Estimated escapement of hatchery-origin winter Chinook Salmon in the upper Sacramento River for 2022.

Methods and Equations

Total abundance of hatchery-origin winter Chinook Salmon returning to the upper Sacramento River was estimated using a series of expansions to account for potential biases and difficulties in identifying hatchery-origin carcasses and recovering coded-wire tags. The number of fresh hatchery-origin Chinook Salmon carcasses observed on the spawning area survey was expanded to: 1. account for unrecognized fin clips and undetected coded-wire tags in non-fresh carcasses, 2. include carcasses not observed during the survey, 3. account for fish taken into Livingston Stone NFH for use as broodstock, 4. to include hatchery-origin fish that did not have a clipped adipose fin, and 5. subtraction of non-winter Chinook Salmon strays. Descriptions of these expansions follow:

Non-fresh hatchery-origin carcasses were expanded for decreased coded-wire tag recovery and fin clip recognition based on the recovery rate of fresh hatchery-origin carcasses ($H_{NF\text{-}Exp}$):

$$H_{NF\text{-}Exp} = (H_{F\text{-}Obs} \times T_{NF\text{-}Obs}) / T_{F\text{-}Obs} \qquad (1)$$

where,
$H_{F\text{-}Obs}$ = number of fresh hatchery-origin carcasses (adipose fin absent or adipose fin unknown with a valid CWT recovery),
$T_{NF\text{-}Obs}$ = total number of non-fresh hatchery- and natural-origin carcasses, and
$T_{F\text{-}Obs}$ = total number of fresh hatchery- and natural-origin carcasses recovered during the Carcass Survey. This includes fresh carcasses that were not sampled for biological data, other than freshness and sex, and tallied as “fresh chops” (indicating the carcass was compromised for biological data collection usually due to animal predation).

Expansions were made for adipose-fin clipped hatchery-origin carcasses believed to be present in the upper Sacramento River, but not observed during the survey (H_{Sac}). This expansion was based on the proportion of hatchery-origin carcasses observed during the Carcass Survey to the total estimated escapement of winter Chinook Salmon in the upper Sacramento River (this excludes fish retained as broodstock by the Livingston Stone NFH), based on the Cormack-Jolly-Seber population estimate ($N_{J\text{-}S}$):

$$H_{Sac} = (H_{NF\text{-}Exp} + H_{F\text{-}Obs} + H_{Unk}) / T_{Obs} \times N_{J\text{-}S} \qquad (2)$$

where,
H_{Unk} = number of hatchery-origin carcasses with an unknown “freshness” and
T_{Obs} = the total number of carcasses observed during the Carcass Survey (including fresh and non-fresh and hatchery- and natural-origin carcasses).

Hatchery-origin fish captured for use as broodstock at Livingston Stone NFH ($LSNFH_H$) were accounted for by adding them to H_{Sac}. Addition of these fish yielded the total number of adipose-fin clipped hatchery-origin fish present in the upper Sacramento River and at the Livingston Stone NFH (H_{Clip}):

$$H_{Clip} = H_{Sac} + LSNFH_H \tag{3}$$

To account for non-adipose-fin clipped hatchery-origin fish, H_{Clip} was expanded based on mark retention rates measured prior to release of juveniles.

- H_{Clip} was apportioned among each recovered tag code (CWT_{App}):

  $$CWT_{App} = H_{Clip} \times (CWT_{Rec} / CWT_T) \tag{4}$$

  where,
  CWT_{Rec} = the number of coded-wire tags recovered for an individual tag code and
  CWT_T = the total number of all coded-wire tags recovered.

- CWT_{App} was expanded to include all hatchery-origin fish without an adipose-fin clip (CWT_{Final}) based on tag retention rates measured prior to release of Chinook Salmon juveniles.

  $$CWT_{Final} = CWT_{App} / (J_{Clip} / J_{Obs}) \tag{5}$$

  where,
  J_{Clip} = the number of juveniles observed with an adipose-fin clip during tag retention studies prior to release, by individual tag code and
  J_{Obs} = the total number of juveniles observed during tag retention studies prior to release, by individual tag code.

The total hatchery-origin Chinook Salmon (H_{Total}) was obtained by summing CWT_{Final}:

$$H_{Total} = \Sigma\, CWT_{Total} \tag{6}$$

CWT_{Final} estimated from hatchery-origin strays ($CWT_{Final\text{-}Stray\ \text{“listed by tag code”}}$) were removed to produce the final hatchery-origin winter Chinook Salmon estimate.

$$H_{Final} = H_{Total} - CWT_{Final\text{-}Stray} \tag{7}$$

Data

Appendix A TABLE 1.—Data obtained during the 2022 winter Chinook Salmon Carcass Survey and Keswick Trap operations.

Count		Abbreviation		Description
50	=	$H_{F\text{-}Obs}$	=	Number of fresh hatchery-origin carcass recoveries
795	=	$T_{NF\text{-}Obs}$	=	Number of non-fresh hatchery- and natural-origin carcass recoveries
855	=	$T_{F\text{-}Obs}$	=	Number of fresh hatchery- and natural-origin carcass recoveries
1,650	=	T_{Obs}	=	Total carcasses observed during the Carcass Survey
5,437	=	$N_{J\text{-}S}$	=	Total naturally reproducing winter Chinook Salmon escapement estimated by the California Department of Fish and Wildlife
323	=	$LSNFH_H$	=	Hatchery-origin fish retained as Livingston Stone National Fish Hatchery broodstock
0	=	H_{Unk}	=	Total hatchery-origin fish with unknown carcass condition

Appendix A TABLE 2.—Coded-wire tag codes recovered during the 2022 run year, by recovery location, with juvenile tag retention data. Recovery locations include the area surveyed during the winter Chinook Salmon Carcass Survey (Survey), those collected for broodstock at the Livingston Stone National Fish Hatchery (LSNFH), and "lone heads" with a CWT (Other). For calculations using 'Juvenile Tag Retention Data': C = fish with an adipose-fin clip, NC = fish with no adipose-fin clip, T = fish with a coded-wire tag, NT = fish with no coded-wire tag.

CWT Code	CWT_{Rec}			Releases based on juvenile tag retention data			
	Survey	LSNFH	Other	T/C	NT/C	T/NC	NT/NC
055778	15	32	0	99,097	292	0	0
055883	4	9	0	49,710	323	0	0
055884	5	16	1	49,073	439	146	146
055885	5	9	1	50,554	299	150	0
055886	8	4	0	49,983	157	0	0
055887	2	9	0	51,783	453	340	113
055888	10	39	0	51,278	253	0	0
055889	13	46	0	45,058	226	226	0
055908	6	4	0	22,603	76	0	0
056532	1	16	0	43,696	109	0	0
056533	0	22	0	46,807	114	0	0
056534	0	11	0	47,056	119	0	0
056535	0	22	0	52,390	0	0	0
056536	1	31	0	53,551	129	0	0
056537	1	24	0	59,305	146	0	0
056284[a]	1	0	0	44,100	905	0	226
	72	292	2				

[a] Released into Battle Creek as part of the Livingston Stone NFH Jumpstart Program.

<u>Calculations</u>

1. Non-fresh carcass expansion based on fresh carcass recovery rate

$$\left(\underset{50}{\underline{H_{F\text{-}Obs}}} \times \underset{795}{\underline{T_{NF\text{-}Obs}}}\right) / \underset{855}{\underline{T_{F\text{-}Obs}}} = \underset{\mathbf{46.5}}{\underline{H_{NF\text{-}Exp}}}$$

2. Expansion to include carcasses not observed

$$\left(\underset{46.5}{\underline{H_{NF\text{-}Exp}}} + \underset{50}{\underline{H_{F\text{-}Obs}}} + \underset{0}{\underline{H_{Unk}}}\right) / \underset{1{,}650}{\underline{T_{Obs}}} \times \underset{5{,}437}{\underline{N_{J\text{-}S}}} = \underset{\mathbf{318.0}}{\underline{H_{Sac}}}$$

3. Addition of hatchery-origin fish retained for Livingston Stone NFH broodstock

$$\underset{318.0}{\underline{H_{Sac}}} + \underset{323}{\underline{LSNFH_H}} = \underset{\mathbf{641.0}}{\underline{H_{Clip}}}$$

4. Estimated number of hatchery-origin Chinook Salmon returning in 2022 by tag code, following expansions to account for coded-wire tag loss from non-fresh carcasses and carcasses present, but not observed.

CWTCode		H_{Clip}			CWT_{Rec}		CWT_T			CWT_{App}
055778	:	641.0	×	(	47	/	364	)	=	**82.8**
055883	:	641.0	×	(	13	/	364	)	=	**22.9**
055884	:	641.0	×	(	20	/	364	)	=	**35.2**
055885	:	641.0	×	(	13	/	364	)	=	**22.9**
055886	:	641.0	×	(	12	/	364	)	=	**21.1**
055887	:	641.0	×	(	11	/	364	)	=	**19.4**
055888	:	641.0	×	(	49	/	364	)	=	**86.3**
055889	:	641.0	×	(	59	/	364	)	=	**103.9**
055908	:	641.0	×	(	10	/	364	)	=	**17.6**
056532	:	641.0	×	(	17	/	364	)	=	**29.9**
056533	:	641.0	×	(	22	/	364	)	=	**38.7**
056534	:	641.0	×	(	11	/	364	)	=	**19.4**
056535	:	641.0	×	(	22	/	364	)	=	**38.7**
056536	:	641.0	×	(	32	/	364	)	=	**56.3**
056537	:	641.0	×	(	25	/	364	)	=	**44.0**
056284	:	641.0	×	(	1	/	364	)	=	**1.8**
										641.0

5 and 6. Estimated number of hatchery-origin Chinook Salmon returning in 2022 by tag code, following the final expansion to account for hatchery-origin fish without a clipped adipose fin.

CWTCode		CWT_{App}			J_{Clip}		J_{Obs}			CWT_{Final}
055778	:	82.8	/	(	99,389	/	99,389	)	=	**82.8**
055883	:	22.9	/	(	50,033	/	50,033	)	=	**22.9**
055884	:	35.2	/	(	49,512	/	49,804	)	=	**35.4**
055885	:	22.9	/	(	50,853	/	51,003	)	=	**23.0**
055886	:	21.1	/	(	50,140	/	50,140	)	=	**21.1**
055887	:	19.4	/	(	52,236	/	52,689	)	=	**19.5**
055888	:	86.3	/	(	51,531	/	51,531	)	=	**86.3**
055889	:	103.9	/	(	45,284	/	45,510	)	=	**104.4**
055908	:	17.6	/	(	22,679	/	22,679	)	=	**17.6**
056532	:	29.9	/	(	43,805	/	43,805	)	=	**29.9**
056533	:	38.7	/	(	46,921	/	46,921	)	=	**38.7**
056534	:	19.4	/	(	47,175	/	47,175	)	=	**19.4**
056535	:	38.7	/	(	52,390	/	52,390	)	=	**38.7**
056536	:	56.3	/	(	53,680	/	53,680	)	=	**56.3**
056537	:	44.0	/	(	59,451	/	59,451	)	=	**44.0**
056284	:	1.8	/	(	45,005	/	45,231	)	=	**1.8**
								H_{Total}	=	**641.9**

7. The estimated number of hatchery-origin winter Chinook Salmon returning in 2022 following the removal of hatchery-origin non-winter fish.

H_{Total}		$CWT_{Final\text{-}"no\ strays\ in\ 2022"}$		H_{Final}
641.9	-	0	=	**642**

- Of the estimated total 2022 hatchery-origin return, 640 originated from the Supplementation Program and 2 from the Jumpstart Program juvenile releases.