Upper Sacramento River Winter Chinook Salmon Carcass Survey

2012 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 principal spawning areas of Sacramento River winter Chinook salmon. The upper Sacramento River winter Chinook spawning area survey is the primary source of data to evaluate the performance of the U.S. Fish and Wildlife Service's winter Chinook salmon supplementation program conducted at the Livingston Stone National Fish Hatchery. This report summarizes information from the 2012 winter Chinook spawning area survey pertinent to evaluation of the supplementation program at the Livingston Stone National Fish Hatchery.

An estimated 2,676 winter Chinook returned in 2012, which was an increase over the previous two years but the sixth consecutive year with a cohort replacement rates less than one. An estimated 809 of the winter Chinook were of hatchery-origin, representing 30.2 percent of the total run. This is the highest percentage of hatchery-origin recorded for Sacramento River winter Chinook. The return rate for brood year 2009 hatchery-origin winter Chinook was near the long-term average, indicating that the high percentage of hatchery fish resulted from a relatively depressed rate of return of naturally produced fish. The return rate for brood year 2008 winter Chinook, which was concluded with recovery of age-4 fish in 2012, was the lowest observed since the winter Chinook program was moved to the Livingston Stone National Fish Hatchery in 1998. The modal recovery date of natural-origin carcasses in 2012 was the latest observed during the 2001-2012 surveys. For hatchery-origin fish, the modal recovery date was skewed towards a later return than the 2001-2011 average but the distribution was within the range previously observed. Spatial distributions of natural- and hatchery-origin winter Chinook were bi-modal, with modes at RM 296 and RM 299, consistent with previous years. However, the mode occurring at RM 299 was increased relative to the 2001-2011 average, indicating that the primary spawning area was shifted upstream in 2012. Consistent with most years from 2001-2011, age-3 fish dominated hatchery-origin returns. For hatchery-origin fish, only one age-2 (female) and no age-4 fish were collected. No age-2 males were collected in 2012, which was the lowest number observed during all surveys since 2001, but was consistent with generally low recoveries of age-2 winter Chinook in recent years. In 2012, consistent with all survey years and for both natural- and hatchery-origin recoveries, more female than male carcasses were observed and the number of pre-spawn female mortalities was small.

Introduction

The Sacramento River system supports four distinct "runs" of Chinook salmon (*Oncorhynchus tshawytscha*): fall, late-fall, spring, and winter. Winter Chinook salmon 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 winter Chinook salmon spawn at age three, with the remainder spawning at ages two and four (Hallock and Fisher 1985).

Sacramento River Winter Chinook were listed as "threatened" under the Endangered Species Act in 1989 and subsequently changed to "endangered" in 1994 (59 Federal Register 440). The endangered status was reaffirmed in status reviews conducted in 2005 (70 Federal Register 37160) and 2011 (76 Federal Register 50447). In 1989, the U.S. Fish and Wildlife Service (Service) began propagating Sacramento River Winter Chinook salmon to supplement natural production. The winter Chinook salmon 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 program was moved to the newly constructed Livingston Stone NFH, located at the base of Shasta Dam, to improve imprinting to natural spawning areas in the main stem Sacramento River.

The winter Chinook spawning areas survey, hereafter referred as the winter Chinook carcass survey or simply "carcass survey", is the primary source of information to monitor status and trends of the species and to evaluate the performance of the winter Chinook supplementation program at the Livingston Stone NFH. A primary objective of the winter Chinook carcass survey is to estimate the abundance of winter Chinook in their only known spawning areas of the upper Sacramento River. Estimates of winter Chinook abundance are listed in the electronic CDFW GrandTab population file (Azat 2013). Precise estimates of winter Chinook abundance are necessary to meet the delisting recommendations for the species, which are specified in the draft recovery plan for winter Chinook salmon (National Marine Fisheries Service 2009). The Service and the California Department of Fish and Wildlife (CDFW) initiated the carcass survey in 1996 to improve the precision of population estimates, which had previously been based on extrapolation of fish counts at the Red Bluff Diversion Dam. Additional objectives of the carcass survey are to (1) collect information on several important life history attributes of winter Chinook, including: age and sex composition of the spawning population, pre-spawning mortality rate, and temporal and spatial distributions of spawning, and (2) collect data useful in evaluating the winter Chinook supplementation program at the Livingston Stone NFH.

Methods

Study Area & Sampling Protocol

The 2012 carcass survey was conducted on the Sacramento River, California and was designed to encompass the primary spawning areas of winter Chinook salmon. The survey area covered approximately 27 miles of the Sacramento River and 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 (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 downstream of Ash Creek Road Bridge (RM 276). The carcass survey was designed to include the duration of winter Chinook spawning and was 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. The order that reaches were sampled was consistent throughout the survey.

Typically, daily surveys were conducted with at least two boats, each having one observer and one operator. Each boat surveyed from a shoreline to the middle of the river. Carcasses were recovered using a 4.9 meter pole with a five-pronged gig attached. Carcass condition was estimated as "fresh" or "non-fresh." A carcass was considered fresh if it had at least one clear eye, relatively firm body texture, or pink gills. Fresh carcasses were generally more intact than non–fresh carcasses and parameters such as length, sex, and spawn status could be determined more reliably. As a result, morphometric and other information in this report are based only on data from fresh carcasses unless otherwise noted.

Data gathered from carcasses included: collection date and location (reach, RM, and latitude / longitude), sex, spawn status (spawned, unspawned, and unknown), fork length, and adipose fin status (absent, present, and unknown). Each carcass received an externally visible tag or was cut in half to ensure that the carcass was not resampled at a later date. Spawn status of females was defined as spawned (abdomen extremely flaccid or very few eggs remaining), unspawned (abdomen firm and swollen or many eggs remaining), or unknown (indeterminable spawn status, usually due to predation on the carcass). The spawn status of males was always categorized as unknown. Carcasses with an intact adipose fin were considered to be natural-origin and those with a missing adipose fin were considered to be hatchery-origin. The head was collected from all hatchery-origin carcasses so that the coded-wire tag (CWT) could be extracted and read at a later date (all hatchery-origin winter Chinook receive a CWT as juveniles prior to release). Additionally, the head was collected from carcasses with an adipose fin status of "unknown" so it could be examined for the presence of a CWT. Carcasses with fin status unknown were subsequently considered to be hatchery-origin if they contained a CWT; if they did not, their classification remained "unknown." However, the CDFW changed these to natural-origin for population estimate calculations (Doug Killam, personal communication). Biological specimen collections consisted of a small piece of fin tissue and skin patch (scales) from all carcasses not extremely decayed (all fresh and most non-fresh). Fin tissues were preserved in 100% ethanol and skin patches were preserved by air desiccation.

Data Analysis

Spatial and temporal distribution, age composition, sex composition, and pre-spawn mortality were compared between natural-origin and hatchery-origin carcasses. Age two natural-origin carcasses were separated from age three and age four carcasses using length-frequency analysis (Ney 1993). The age of hatchery-origin carcasses was determined by decoding the CWT and identifying the brood year relative to the return year.

Run Size Estimate of Hatchery-origin Winter Chinook

The number of non-fresh hatchery-origin winter Chinook salmon carcasses was estimated based on the proportion of fresh adipose fin clipped carcasses to the total fresh carcass recoveries

(Appendix 1). The estimate of non-fresh hatchery-origin carcasses was added to the number of fresh hatchery-origin carcasses recovered, and then expanded to include the unsampled fraction based on the Jolly-Seber mark-recapture estimate produced by the CDFW (Doug Killam, personal communication). Additional calculations were performed to account for carcasses for which "freshness" was not recorded, fish that did not receive an adequate fin clip when marked as juveniles (estimated from mark retention data), and observations of hatchery-origin Chinook straying into the survey area (i.e., non-winter Chinook).

Results

Carcass Recoveries

The survey was conducted from 30 April 2012 through 2 September 2012. We observed 1,348 carcasses during the 2012 survey, representing 50.4% of the estimated run size (Table 1). A total of 736 fresh Chinook carcasses was recovered and sampled for biological data (229 hatchery-origin, 500 natural-origin, and 7 of unknown origin). The CDFW estimated the total 2012 escapement of winter Chinook to be 2,676.

Coded-Wire Tag Recoveries

Non-fresh carcasses were included in the CWT analysis. A head was collected from 388 carcasses that were identified as having a clipped adipose-fin (n = 346) or for which the status of the adipose-fin was indeterminable (n = 42). A readable CWT was recovered from 312 of the heads collected, tags were not detected in 75 heads, and one head was not processed due to predation on the snout (Appendix Table 1). None of the carcasses with an indeterminable adipose-fin contained a CWT. All 312 of the recovered tags were from winter Chinook released from the Livingston Stone NFH

Hatchery-origin Returns

An estimated 809 hatchery-origin winter Chinook returned in 2012, representing 30.2 percent of the total run (Table 1). Age three hatchery-origin fish (brood year 2009) were the primary contributors, representing all but one of recovered tags (n = 311). One age-2 hatchery-origin winter Chinook was recovered during the survey (Table 2). Eighteen of the 19 CWT groups released from brood year 2009 (age-3) were represented (Table 3).

Temporal and Spatial Distribution

The modal collection date of natural-origin carcasses was 24 July (Figure 2), which is later than all previous survey years (2001-2011 average = 7 July and range = 26 June to 15 July). This marks the second consecutive year that the modal collection date for natural-origin winter Chinook was later than previously observed. The modal collection date for hatchery-origin carcasses of 12 July, was within the range typically observed (2001-2011 average = 10 July and range = 23 June to 23 July). Although the mode and range of spawn dates for hatchery-origin carcasses was typical in respect to previous years, the overall distribution was skewed towards a late spawn.

Consistent with recent survey seasons, most winter Chinook carcasses were observed at two general locations, RM 296 (including Turtle Bay) and RM 299 (Figure 3). However, the relative

abundance of both natural- and hatchery-origin carcasses was increased at RM 299 relative to previous survey seasons. A higher proportion of hatchery-origin winter Chinook was observed further upstream; however the distribution of spawning areas of natural- and hatchery-origin fish overlapped and did not significantly differ (KS two sample test; $p = 0.953$).

Age Composition and Length-at-Age

Hatchery-origin winter Chinook were primarily age-3 based on CWT data (Table 2). One CWT was recovered from an age-2 (female) winter Chinook and none from age-4. The proportion of natural-origin age-2 males (20.3%) was consistent with the average observed since 2001 (17.2%, Table 3). However, no age-2 hatchery-origin males were recovered in 2012 (2001-2012: average 29.8%, range 0.0% - 79.2%).

Length-at-age comparisons between natural- and hatchery-origin fish were not conducted in 2012. For age-2 fish, a comparison could not be made due to the absence of age-2 hatchery-origin fish (Table 4). For age three and older natural-origin winter Chinook, we could not estimate age using length-frequency analysis because of the absence of well-defined modes in the length-frequency histogram (Figure 4). Comparison of length-at-age between natural-origin and hatchery-origin carcasses was not possible without knowing the age of natural-origin fish.

Sex Ratio

Considering all carcass recoveries in 2012, and consistent with previous years, substantially more female than male carcasses were recovered (Table 5). Among natural-origin fish, females outnumbered males 5.67 to 1 and among hatchery-origin fish, females outnumbered males 3.24 to 1. The cumulative 2001-2012 sex ratio was not statistically different between natural- and hatchery-origin fish (Yate's corrected Chi-square: $p = 0.869$, $df = 1$).

Pre-spawning Mortality

The percentage of pre-spawn mortalities was small for both natural- (0.5%) and hatchery-origin females (2.9%; Table 6). This rate was greater for hatchery-origin females in 2012 (Yate's corrected Chi-square: $p = 0.044$, $df = 1$) and when considering all recoveries from 2001-2012 (Yate's corrected Chi-square: $p < 0.001$, $df = 1$).

TABLE 1.—Sacramento River winter Chinook salmon estimated run size, hatchery-origin run component, carcasses observed, and river miles surveyed for return years 2001 – 2012.

Return Year	Total Estimated Run-size[a]	Hatchery Origin Run-size	% of Run Hatchery Origin	Total Carcasses Observed	Percent of Run Observed	River miles Surveyed, From : To
2001	8,224	513	6.2	5,145	62.6	288 : 302
2002	7,441	570	7.7	4,971	66.8	288 : 302
2003	8,218	423	5.1	4,531	55.1	286 : 302
2004	7,869	636	8.1	3,276	41.6	273 : 302
2005	15,839	3,056	19.3	9,047	57.1	273 : 302
2006	17,296	2,380	13.8	7,699	44.5	275 : 302
2007	2,541	140	5.5	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	824	80[c]	9.7	431	52.3	276 : 302
2012	2,676	809	30.2	1,348	50.4	276 : 302
Mean	6,658	787	11.8	3,521	52.9	

[a] Estimated by the California Department of Fish and Wildlife and reported by that agency (http://www.calfish.org/tabid/213/Default.aspx) as part of the Sacramento River winter Chinook salmon carcass survey effort.

[b] Calculation of this estimate utilizes the 'Total Estimated Run-size'. California Department of Fish and Wildlife corrections to the 'Total Estimated Run-size' has resulted in the U.S. Fish and Wildlife Service making changes to the 'Hatchery Origin Run-size' estimate 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], return years 2001 – 2012.

Return Year	Natural-origin, % at Age		Hatchery-origin, % at Age			
	Age 2	Ages 3 & 4	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	2.7	97.3	8.9	90.3	0.8	0.0
2004	12.4	87.6	36.6	62.2	1.2	0.0
2005	4.3	95.7	5.0	94.9	0.1	0.0
2006	1.5	98.5	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	1.5	98.5	1.1	85.0	13.9	0.0
2011	7.9	92.1	61.5	29.4	9.1	0.0
2012	5.2	94.8	0.7	99.3	0.0	0.0
Mean	5.0	95.0	13.5	81.4	5.0	0.2
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	3.5	96.5	60.5	34.2	5.3	0.0
2012	2.6	97.4	0.9	99.1	0.0	0.0
Mean	0.8	99.2	5.8	89.3	4.6	0.3
Male						
2001	25.4	74.6	49.6	50.4	0.0	0.0
2002	21.2	78.8	59.2	34.5	6.2	0.0
2003	15.9	84.1	46.1	53.9	0.0	0.0
2004	39.8	60.2	77.6	22.4	0.0	0.0
2005	15.9	84.1	18.8	81.0	0.3	0.0
2006	4.3	95.7	0.6	89.2	10.3	0.0
2007	13.7	86.3	11.2	49.9	38.9	0.0
2008	14.2	85.8	50.8	49.2	0.0	0.0
2009	3.3	96.7	0.0	100.0	0.0	0.0

TABLE 2.—Continued.

Return Year	Natural-origin, % at Age		Hatchery-origin, % at Age			
	Age 2	Ages 3 & 4	Age 2	Age 3	Age 4	Age 5
			Male			
2010	5.8	94.2	3.7	88.1	8.2	0.0
2011	26.5	73.5	67.2	0.0	32.8	0.0
2012	20.3	79.7	0.0	100.0	0.0	0.0
Mean	17.2	82.8	29.8	60.8	9.4	0.0

[a] The number of age 2 natural-origin fish was estimated using length-frequency analysis. Age 2 fish were considered less than or equal to the following fork lengths (mm), by return year, for females and males, respectively: 2001: 580, 690; 2002: 550, 680; 2003: 560, 670; 2004: 580, 690; 2005: 580, 670; 2006: 580, 670; 2007: 580, 680; 2008: 580, 680; 2009: 570, 670; 2010: 570,670; 2011: 590, 680; 2012: 620, 660. 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 288 (consistency among years).

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

TABLE 3.—Winter Chinook salmon returns by brood year, coded-wire tag (CWT) groups contributing to return, return rate, and returns at age for brood years 1998 – 2010. Hatchery-origin groups using captive broodstock or cryo-preserved sperm are not included in this summary.

Brood year	Number of CWT groups. contributing to:		Average number of family groups. per CWT group	Number Released[a]	Total CWTs Recovered[b]	Return Rate (%)[c]	CWT Returns at Age[d,e]		
	Release	Return					Age 2	Age 3	Age 4
1998	21	19	5.7	147,004	108	0.073	8	98	2
1999	17	17	1.0	26,135	153	0.585	30	117	1
2000	28	27	5.6	151,858	129	0.085	16	112	1
2001	27	21	3.7	181,205	94	0.052	6	87	1
2002	32	32	2.7	154,922	1,041	0.672	46	971	24
2003	30	30	3.0	145,872	598	0.410	44	534	19
2004	16	16	4.2	124,862	49	0.039	1	47	1
2005	17	16	5.8	151,321	41	0.027	1	40	0
2006	18	18	6.9	149,060	124	0.083	6	108	9
2007	9	9	5.1	69,119	79	0.114	0	77	2
2008	13	4	6.8	133,760	7	0.005	1	6	0
2009	19	18[f]	6.6	183,676	328	0.179[f]	15	313	Na[g]
2010	28	Na[g]	4.0	227,818	2	Na[g]	1	Na[g]	Na[g]

[a] Number released reflects only those with a CWT and clipped adipose fin as estimated from tag retention data collected prior to release.

[b] Some coded wire tags were recovered from fish of age-1 or greater than age-4.

[c] Return rate (%) was calculated by dividing (number of CWTs recovered) by the (number of CWTs released), multiplied by 100.

[d] Adult returns are based on all CWT returns including fresh and non-fresh carcasses from all sampling activities (including those other than the carcass survey).

[e] Fish return as: Age 2 (Brood year + 2 years), Age 3 (Brood year + 3 years), and Age 4 (Brood year + 4 years).

[f] Based on recoveries through age-3.

[g] Data not final, returns not yet complete or not yet available.

TABLE 4.—Fork length (mm) of fresh age two male Sacramento River winter Chinook salmon carcasses by origin, return years 2001 – 2012.

Return Year	Natural-origin[a]					Hatchery-origin				
	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
2001	162	563	59	400	690	24	539	61	390	650
2002	71	578	47	460	680	8	550	61	470	650
2003	56	521	51	410	650	10	518	53	420	580
2004	162	581	53	430	680	35	545	47	440	630
2005	132	555	54	410	660	38	551	47	450	650
2006	20	556	57	440	640	1[b]	-	-	540	540
2007	25	555	58	440	670	1	-	-	550	550
2008	17	542	68	460	650	5	512	59	440	570
2009	7	559	48	500	640	0	-	-	-	-
2010	5	534	23	510	560	1[b]	-	-	480	480
2011	9	583	70	500	680	2	610	85	550	670
2012	15	539	51	460	660	0	-	-	-	-

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

[b] No fresh two year old male carcasses were collected, non-fresh carcass data presented.

TABLE 5.—Sex ratio of Sacramento River winter Chinook salmon carcasses by origin, return years 2001 – 2012.

Return Year	Natural-origin			Hatchery-origin		
	Female (F)	Male (M)	F:M	Female (F)	Male (M)	F:M
2001	1,180	639	1.85	62	51	1.22
2002	928	335	2.77	81	22	3.68
2003	1,899	352	5.39	98	23	4.26
2004	1,009	472	2.14	74	56	1.32
2005	2,452	885	2.77	600	205	2.93
2006	1,905	738	2.58	324	102	3.18
2007	534	203	2.63	36	5	7.20
2008	378	135	2.80	25	7	3.57
2009	486	225	2.16	64	19	3.37
2010	312	86	3.63	40	20	2.00
2011	146	41	3.56	18	4	4.50
2012	425	75	5.67	175	54	3.24
Mean	971	349	2.78	133	47	2.81

TABLE 6.—Pre-spawn mortality of female Sacramento River winter Chinook salmon by origin, return years 2001 – 2012.

	Natural-origin			Hatchery-origin		
Return year	Total carcasses	Number not fully spawned[a]	Percent not fully spawned	Total carcasses	Number not fully spawned[a]	Percent not fully spawned
2001	1,177	10	0.8	62	0	0.0
2002	926	19	2.1	81	3	3.7
2003	1,899	11	0.6	98	0	0.0
2004	988	7	0.7	74	4	5.4
2005	2,392	35	1.5	600	24	4.0
2006	1,905	25	1.3	324	23	7.1
2007	513	9	1.8	36	1	2.8
2008	361	6	1.7	25	0	0.0
2009	482	3	0.6	64	0	0.0
2010	312	1	0.3	40	1	2.5
2011	146	1	0.7	18	0	0.0
2012	425	2	0.5	175	5	2.9
Mean	961	11	1.1	133	5	3.8

[a] "Not fully spawned" includes female carcasses classified as "unspawned" and "partially spawned".

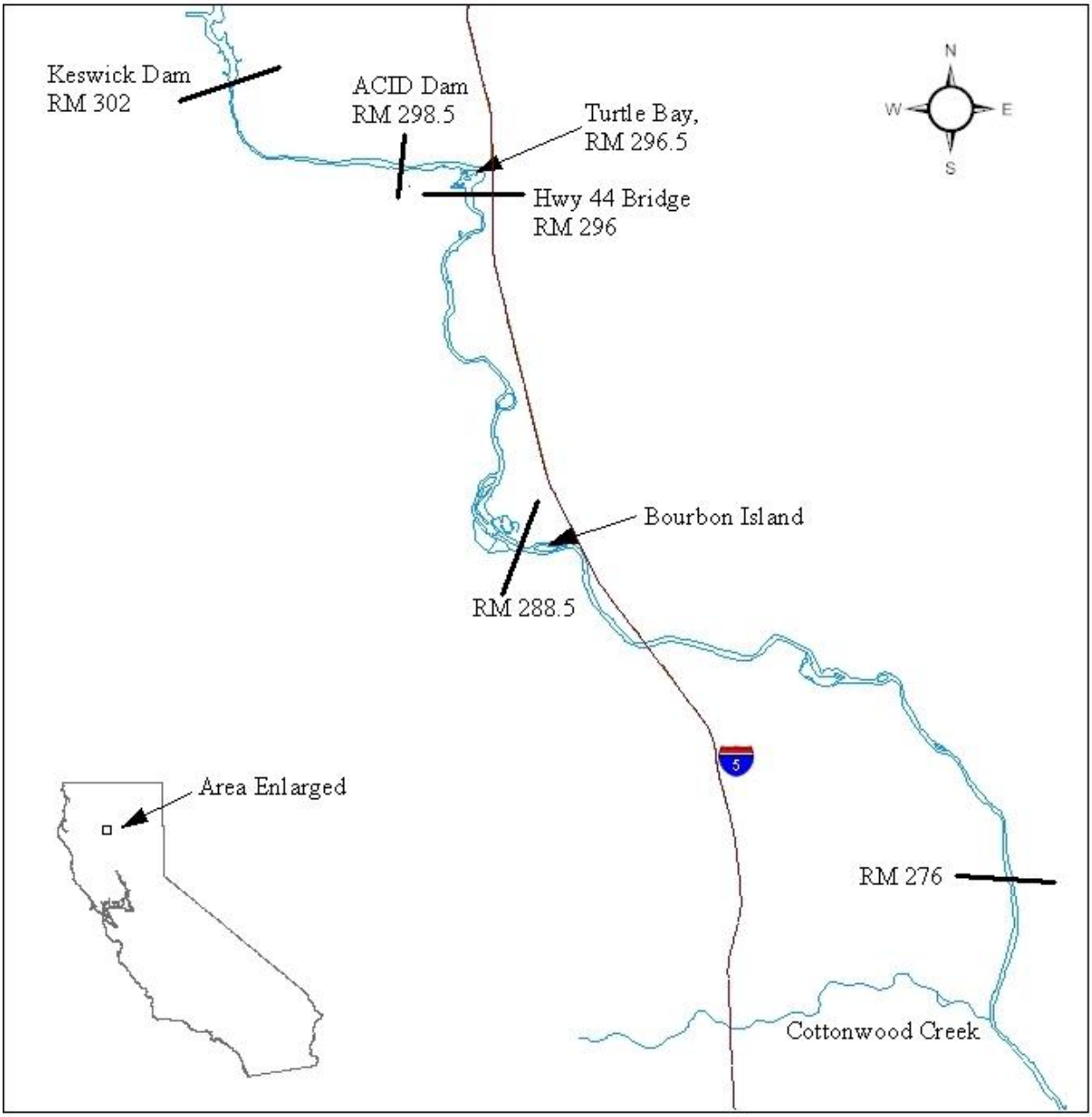

FIGURE 1.—Area included in the Sacramento River winter Chinook salmon carcass survey for return year 2012. Reach 1 extended from the Keswick Dam (RM 302) to the Anderson-Cottonwood Irrigation District (ACID) Diversion Dam (RM 298.5); reach 2 extended from the ACID Diversion Dam to the Highway 44 Bridge 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). Turtle Bay (RM 296.5) is the primary carcass collection area.

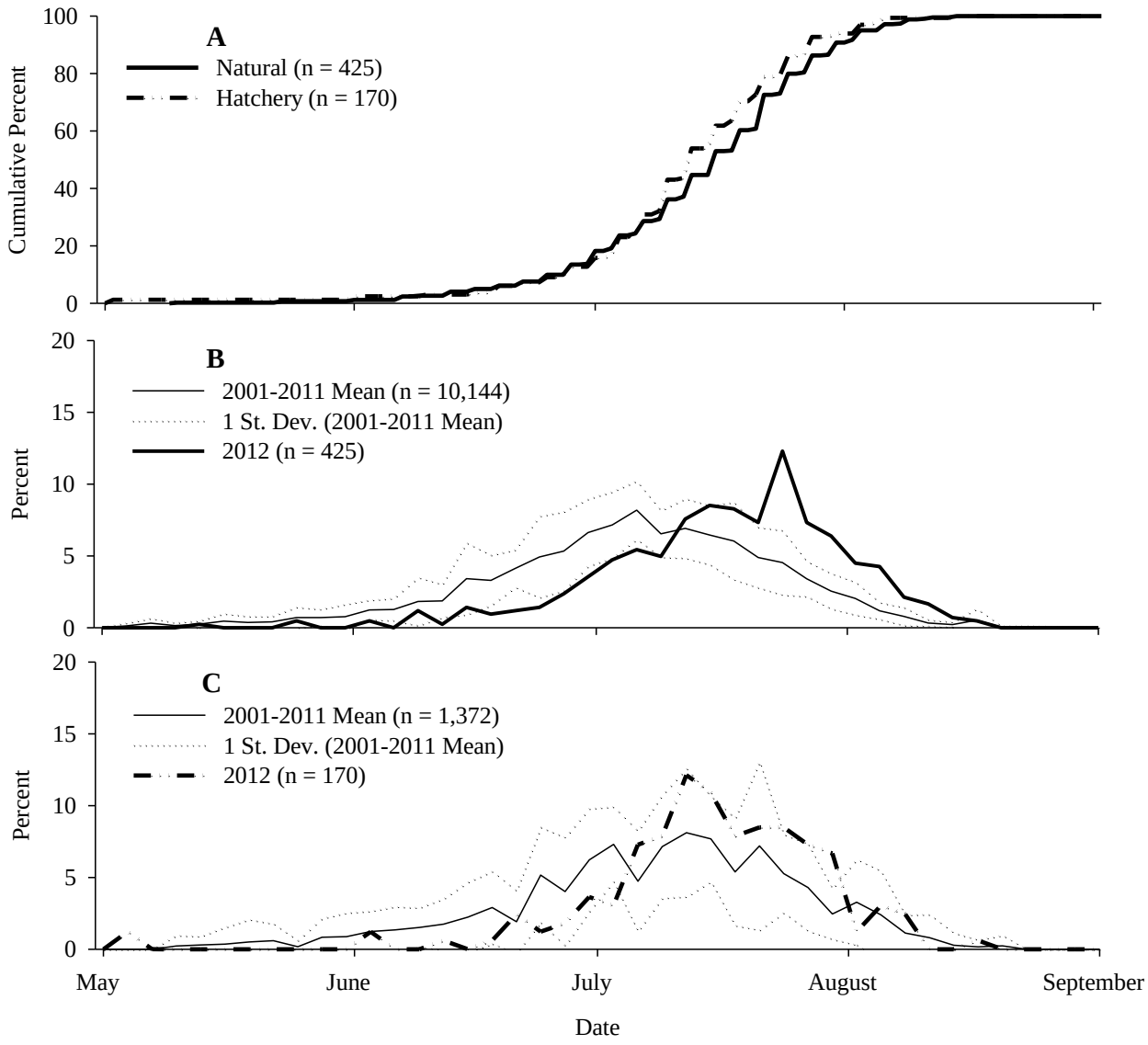

FIGURE 2.—Temporal distribution of fresh female Sacramento River winter Chinook salmon carcass recoveries for return year 2012. Represented is (**A**) the cumulative percent of natural- and hatchery-origin winter Chinook salmon recovered by date for return year 2012 and a comparison of the total percent that returned by date with the mean observed for return years 2001 – 2011 for (**B**) natural- and (**C**) hatchery-origin fish.

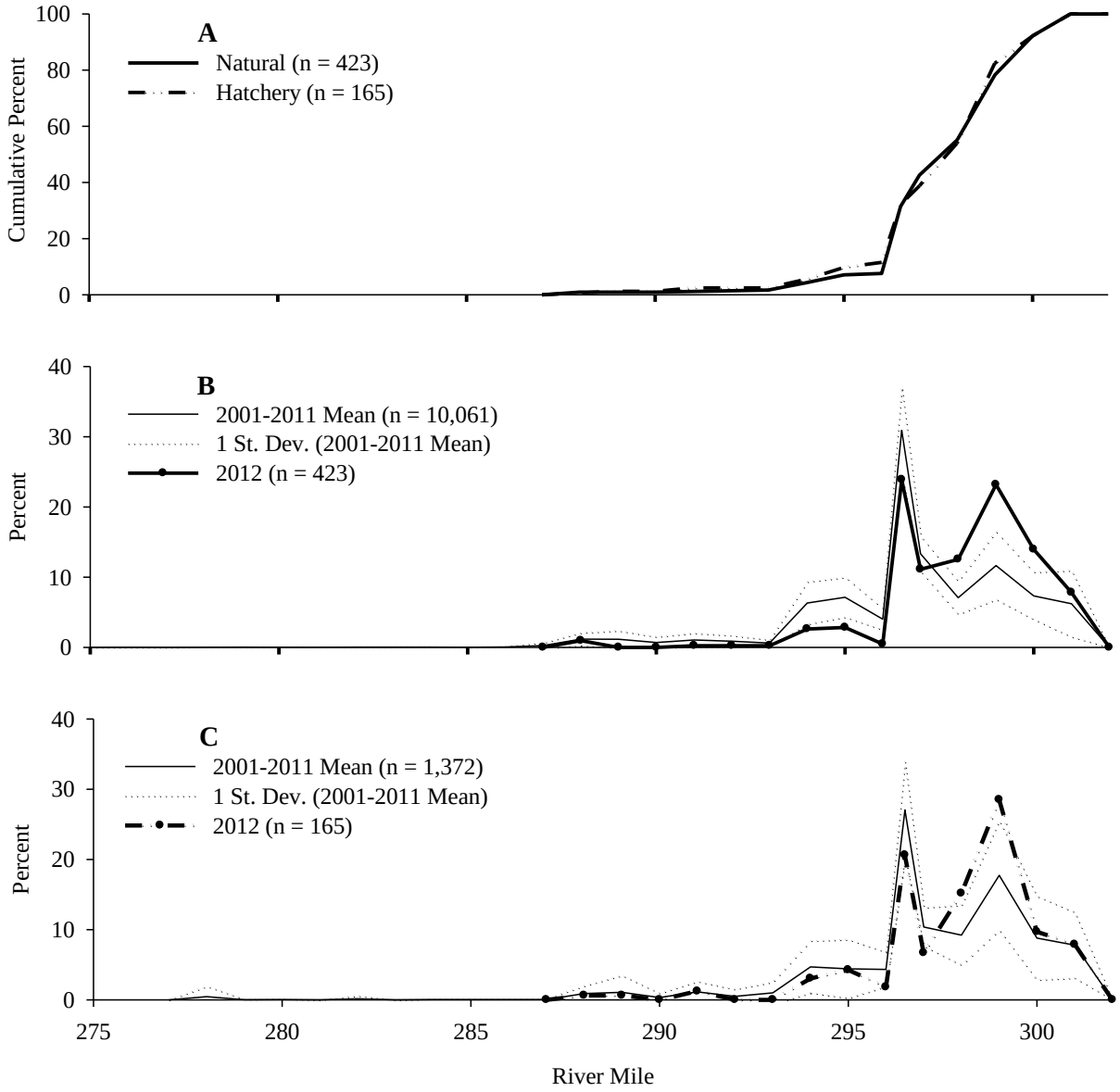

FIGURE 3.—Spatial distribution of fresh female Sacramento River winter Chinook salmon carcass recoveries for return year 2012. Represented is (A) the cumulative percent of natural- and hatchery-origin winter Chinook salmon recovered by river mile for return year 2012 and a comparison of the total percent recovered by river mile with the mean observed for return years 2001 – 2011 for (B) natural- and (C) hatchery-origin fish.

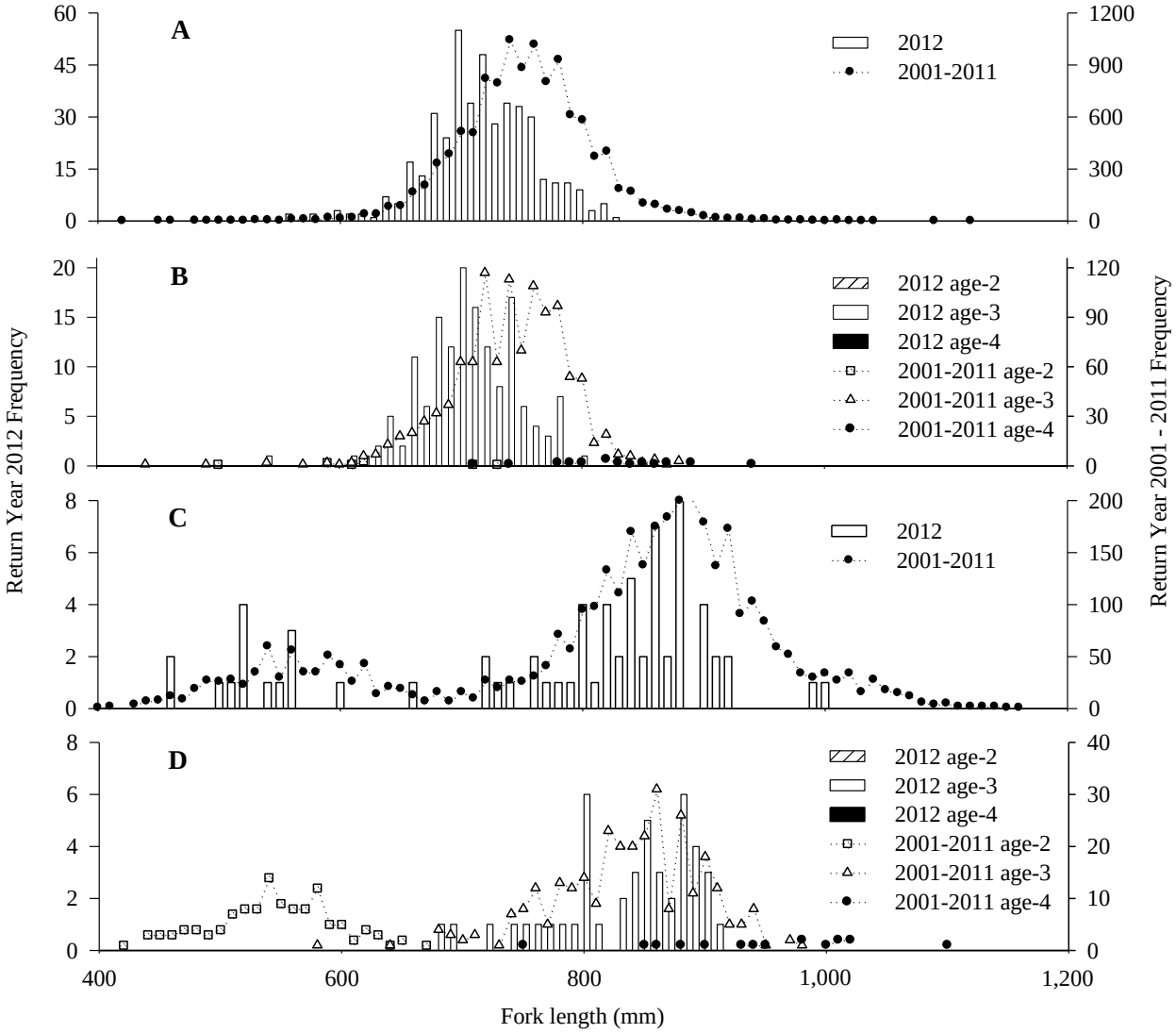

FIGURE 4—Winter Chinook salmon length-frequency distribution comparison of fresh carcass recoveries for return year 2012 and the mean from return years 2001 – 2011: (A) natural-origin females, (B) hatchery-origin females, (C) natural-origin males, and (D) hatchery-origin males.

Discussion

The estimated abundance of winter Chinook within spawning areas of the upper Sacramento River was 2,676 and included 809 hatchery-origin fish, representing 30.2 percent of the total run in 2012. The percentage of hatchery-origin winter Chinook observed in 2012 was considerably larger than all years since the supplementation program was initiated at the Livingston Stone NFH. Age-3 winter Chinook from brood year 2009 were the primary contributor to the return of hatchery-origin fish in 2012. The return rate of brood year 2009 hatchery-origin winter Chinook through age-3 (0.179%) was near to the average return rate for age-3 hatchery-origin winter Chinook since brood year 1998 (0.188%), indicating that survival of brood year 2009 hatchery-origin fish was about average. Therefore, the higher than average proportion of hatchery-origin fish observed in 2012 was a result of the relatively poorer survival experienced by naturally produced winter Chinook. The overall (i.e., hatchery plus natural-origin) cohort replacement rate for winter Chinook salmon returning in 2012 was less than one for the sixth consecutive year, indicating a trend of declining abundance.

Adult returns of brood year 2008 were completed in 2012. Only seven CWT recoveries, representing four of the thirteen family group combinations from brood year 2008, were observed on the spawning grounds from 2009 through 2012. From brood year 1998 to 2007, 95% of the family groups released from the Livingston Stone NFH were observed on the spawning grounds. The return rate of brood year 2008 releases from the Livingston Stone NFH (0.005%) was substantially lower than any rate previously observed for that program (average: 0.195, range: 0.027-0.672).

Winter Chinook spawning occurred within the range of dates typically observed; however, the modal spawn date for natural-origin fish was 17 days later than the average. The modal spawn date for hatchery-origin fish was consistent with those observed from 2001-2011; however, the 2012 distribution of spawn timing was skewed towards a later-than-average spawn date. Spatial distributions of natural- and hatchery-origin winter Chinook were generally similar. River mile 296, including Turtle Bay, was still a major carcass recovery area along with RM 299, which is located just downstream of the Keswick Dam canyon area.

Substantially more female carcasses than male carcasses were recovered in 2012, consistent with previous survey years. Amongst hatchery-origin winter Chinook, age-3 females comprised the majority of recoveries in 2012, consistent with observations from 2001 to 2012 (except for 2011, which was dominated by age-2 fish). No age-4 and only one age-2 hatchery-origin winter Chinook was observed in 2012. Pre-spawning mortality was greater for hatchery-origin females in 2012 and when considering all recoveries from 2001-2012.

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Appendix A-1.—Estimated escapement of hatchery-origin winter Chinook salmon in the upper Sacramento River for 2012.

Methods and Equations

Total abundance of hatchery-origin winter Chinook salmon returning to the upper Sacramento River was estimated following a series of expansions to account for potential biases and difficulties in identifying hatchery-origin carcasses and recovering coded-wire tags. The number of hatchery-origin Chinook carcasses 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 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 ($H_{NF\text{-}Exp}$):

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

where,

$H_{F\text{-}Obs}$ = number of fresh hatchery-origin carcasses,

$T_{NF\text{-}Obs}$ = 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 Jolly-Seber population estimate ($N_{J\text{-}S}$):

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

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}):

$$H_{Clip} = H_{Sac} + LSNFH_H \quad (3)$$

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}):

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

  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 juveniles.

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

  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}:

$$H_{Total} = \Sigma\, CWT_{Total} \quad (6)$$

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

$$H_{Final} = H_{Total} - CWT_{Final\text{-}Stray} \quad (7)$$

Data

Appendix Table 1.—Data obtained during the 2012 winter Chinook carcass survey and Keswick Trap operations.

Count	Abbreviation	Description
229	$H_{F\text{-}Obs}$	Number of fresh hatchery carcass recoveries
612	$T_{NF\text{-}Obs}$	Number of non-fresh hatchery and natural carcass recoveries
736	$T_{F\text{-}Obs}$	Number of fresh hatchery and natural carcass recoveries
1,348	T_{Obs}	Total carcasses observed during the carcass survey
2,581	$N_{J\text{-}S}$	Total naturally reproducing winter Chinook salmon escapement estimated by the California Department of Fish and Wildlife
2	$LSNFH_H$	Hatchery fish retained as Livingston Stone National Fish Hatchery broodstock
0	H_{Unk}	Total hatchery fish with unknown carcass condition

Appendix Table 2.—Coded-wire tag codes recovered during the 2012 run year, by recovery location, with juvenile tag retention data. Recovery locations include the area surveyed during the winter Chinook carcass survey (Survey) and those collected for broodstock at the Livingston Stone National Fish Hatchery (LSNFH). 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_{Rec}		Juvenile tag retention data			
CWT Code	Survey	LSNFH	T/C	NT/C	T/NC	NT/NC
054086	23	1	373	24	0	0
054087	16	0	374	14	0	0
054088	30	0	374	14	4	0
054164	16	0	365	25	3	0
054165	16	0	372	9	0	0
054166	15	0	355	41	0	0
054168	10	1	348	45	0	2
054169	18	0	334	60	0	0
054170	15	0	142	0	0	0
054977	29	0	386	5	5	0
054978	17	0	358	30	5	0
054979	17	0	382	9	0	0
054980	14	0	373	9	2	0
054981	14	0	389	4	4	1
054982	12	0	359	17	3	0
054983	4	0	356	27	1	0
054985	19	0	155	45	0	0
054988	26	0	174	26	0	0
055271	1	0	341	58	1	0
	312	2				

Calculations

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

$$\left(\frac{H_{F\text{-}Obs}}{229} \times \frac{T_{NF\text{-}Obs}}{612}\right) / \frac{T_{F\text{-}Obs}}{736} = \frac{H_{NF\text{-}Exp}}{\mathbf{190}}$$

2. Expansion to include carcasses not observed

$$\left(\frac{H_{NF\text{-}Exp}}{190} + \frac{H_{F\text{-}Obs}}{229} + \frac{H_{Unk}}{0}\right) / \frac{T_{Obs}}{1{,}348} \times \frac{N_{J\text{-}S}}{2{,}581} = \frac{H_{Sac}}{\mathbf{803}}$$

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

$$\frac{H_{Sac}}{803} + \frac{LSNFH_H}{2} = \frac{H_{Clip}}{\mathbf{805}}$$

4. Estimated number of hatchery-origin Chinook salmon returning in 2012 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}
054086	:	804.9555	×	(	24	/	314	)	=	**61.5**
054087	:	804.9555	×	(	16	/	314	)	=	**41.0**
054088	:	804.9555	×	(	30	/	314	)	=	**76.9**
054164	:	804.9555	×	(	16	/	314	)	=	**41.0**
054165	:	804.9555	×	(	16	/	314	)	=	**41.0**
054166	:	804.9555	×	(	15	/	314	)	=	**38.5**
054168	:	804.9555	×	(	11	/	314	)	=	**28.2**
054169	:	804.9555	×	(	18	/	314	)	=	**46.1**
054170	:	804.9555	×	(	15	/	314	)	=	**38.5**
054977	:	804.9555	×	(	29	/	314	)	=	**74.3**
054978	:	804.9555	×	(	17	/	314	)	=	**43.6**
054979	:	804.9555	×	(	17	/	314	)	=	**43.6**
054980	:	804.9555	×	(	14	/	314	)	=	**35.9**
054981	:	804.9555	×	(	14	/	314	)	=	**35.9**
054982	:	804.9555	×	(	12	/	314	)	=	**30.8**
054983	:	804.9555	×	(	4	/	314	)	=	**10.3**
054985	:	804.9555	×	(	19	/	314	)	=	**48.7**
054988	:	804.9555	×	(	26	/	314	)	=	**66.7**
055271	:	804.9555	×	(	1	/	314	)	=	**2.6**
										805.0

5 and 6. Estimated number of hatchery-origin Chinook salmon returning in 2012 by tag code, following the final expansion to account for hatchery-origin fish without an adipose fin clip.

CWTCode		CWT_{App}			J_{Clip}		J_{Obs}			CWT_{Final}
054086	:	61.5253	/	(	397	/	397	)	=	**61.5**
054087	:	41.0168	/	(	388	/	388	)	=	**41.0**
054088	:	76.9066	/	(	388	/	392	)	=	**77.7**
054164	:	41.0168	/	(	390	/	393	)	=	**41.3**
054165	:	41.0168	/	(	381	/	381	)	=	**41.0**
054166	:	38.4533	/	(	396	/	396	)	=	**38.5**
054168	:	28.1991	/	(	393	/	395	)	=	**28.3**
054169	:	46.1439	/	(	394	/	394	)	=	**46.1**
054170	:	38.4533	/	(	142	/	142	)	=	**38.5**
054977	:	74.3430	/	(	391	/	396	)	=	**75.3**
054978	:	43.5804	/	(	388	/	393	)	=	**44.1**
054979	:	43.5804	/	(	391	/	391	)	=	**43.6**
054980	:	35.8897	/	(	382	/	384	)	=	**36.1**
054981	:	35.8897	/	(	393	/	398	)	=	**36.3**
054982	:	30.7626	/	(	376	/	379	)	=	**31.0**
054983	:	10.2542	/	(	383	/	384	)	=	**10.3**
054985	:	48.7075	/	(	200	/	200	)	=	**48.7**
054988	:	66.6524	/	(	200	/	200	)	=	**66.7**
055271	:	2.5636	/	(	399	/	400	)	=	**2.6**
							H_{Total}		=	**808.6**

7. The estimated number of hatchery-origin winter Chinook salmon returning in 2012 following the removal of hatchery-origin non-winter fish.

H_{Total}		$CWT_{Final\text{-}"no\ strays\ in\ 2012"}$		H_{Final}
809	-	0	=	**809**