Upper Sacramento River Winter Chinook Salmon Carcass Survey

2011 Annual Report

Prepared by

U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office
Red Bluff, California 96080

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Red Bluff, California 96080

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Abstract

Since 1996, the U.S. Fish & Wildlife Service and the California Department of Fish and Game have cooperated on an annual survey of the principal spawning area for Sacramento River winter Chinook salmon. The U.S. Fish & Wildlife Service's participation in the survey is focused on collecting data to evaluate the winter Chinook salmon supplementation program at the Livingston Stone National Fish Hatchery. Provided in this report is a summary of data from the 2011 Sacramento River winter Chinook carcass survey pertinent to evaluation of the winter Chinook supplementation program.

An estimated 824 winter Chinook returned in 2011, which is the smallest return since the historically low return of 1994. An estimated 80 of the winter Chinook were of hatchery-origin, representing 9.8 percent of the total run. This estimated number of hatchery-origin spawners, which is based on standard methodology using information collected during the carcass survey, is known to be at least 228% lower than the actual number of hatchery-origin fish returning to spawn based on the number of fish encountered during broodstock collection activities. Hatchery-origin carcasses are typically recovered at age-3 but, in 2011 most were age-2. The peak return date of natural- and hatchery-origin fish was later than the 2001-2010 average with the natural-origin peak being the latest ever recorded. Spatial distributions of natural- and hatchery-origin winter Chinook were similar to each other but differed from most previous years in that there was an increased proportion of carcasses collected in the upstream canyon area (RM300 and RM301). The ratio of females to males was greater for hatchery-origin than natural-origin fish. The number of pre-spawn mortalities was small for both natural- and hatchery-origin females.

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).

Winter Chinook salmon were listed as "threatened" under the Endangered Species Act in 1989 and their status was changed to "endangered" on 4 January 1994 (59 Federal Register 440). The endangered status was reaffirmed 28 June 2005 (70 Federal Register 37160) with a five-year review on 15 August 2011 concluding the status should remain unchanged (76 Federal Register 50447). In 1989, the U.S. Fish and Wildlife Service (Service) began propagating 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 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.

A primary objective of the winter Chinook carcass survey is to estimate the abundance of returning winter Chinook. 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 Game (CDFG) 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. Population estimates derived from the carcass survey are listed in the electronic CDFG GrandTab population file or were provided by Doug Killam (CDFG – Red Bluff, CA; personal communication).

Additional objectives of the carcass survey are to (1) collect information on several important life history attributes of winter Chinook, including: age and gender 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. The following report was prepared by the Service to address these objectives.

Methods

Study Area & Sampling Protocol

The 2011 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 entire winter Chinook spawning period 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. In 2011, due to scheduling conflicts and mechanical breakdowns, multiple daily surveys were conducted using just one boat with two observers. Single-boat surveys were only used during periods and reaches that few carcasses were expected to be recovered and focused on areas most likely to harbor carcasses based on observations made in previous survey cycles. 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, gender, 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), gender, 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 CDFG changed these to natural-origin for population estimate calculations (Doug Killam, pers. com.). 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). Preservation of specimens consisted of 100% ethanol for fin tissues and air desiccation of skin patches. Tissue samples were subsequently transferred to the Service's Fish Conservation Genetics Laboratory in Longview, Washington for a genetic grandparentage analysis and scales were transferred to the DFG Salmon Ageing Project for age determination.

Data Analysis

Spatial and temporal distribution, age composition, gender 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. Longevity of natural-origin fish after spawning was assumed to be equal to that of hatchery-origin fish. This assumption allowed for the relative comparison of spawn timing between the two groups based on the timing of carcass recovery.

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 method used by the CDFG (Doug Killam, personal communication). Additional calculations were performed to adjust 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 straying into the survey area of non-winter Chinook hatchery fish.

Results

Carcass Recoveries

The survey was conducted from 2 May 2011 through 1 September 2011. A total of 431 carcasses was observed during the 2011 survey, representing 52% of the estimated run size (Table 1). A total of 214 fresh Chinook carcasses was recovered and sampled for biological data (23 hatchery-origin, 187 natural-origin, and 4 of unknown origin). There was no information to indicate that hatchery-origin winter Chinook strayed within or outside of typical spawning areas in the upper Sacramento River basin.

Coded-Wire Tag Recoveries

A head was collected from 42 fresh and non-fresh carcasses (31 hatchery-origin and 11 unknown-origin) and a readable CWT was recovered from 21 of the heads (tags were not detected in 21 heads and no tags or heads were lost prior to being read; Appendix Table 1). None of the unknown-origin carcasses contained a CWT. All 21 of the recovered tags were from winter Chinook released from the Livingston Stone NFH

Hatchery-origin Returns

An estimated 80 hatchery-origin winter Chinook returned in 2011 (please see “Discussion” for further comments regarding this estimate), representing 9.8 percent of the total run (Table 1). Age two hatchery-origin fish (brood year 2009) were the primary contributors to the 2011 hatchery estimate representing nearly 62% (n = 13) of recovered tags. The age-2 rate for females was larger than an order of magnitude from the previous observed high rate (Table 2). However, too few males were recovered for a meaningful analysis. Six of the 19 CWT groups released from brood year 2009 were represented but only 3 of the 13 groups released from brood year 2008 (age-3) were represented. Six age-3 and 2 age-four hatchery-origin winter Chinook were recovered during the survey.

Temporal and Spatial Distribution

The peak collection date of 15 July (Figure 3) for natural-origin carcasses is the latest observed in previous years; 2001-2010 average = 6 July and range = 26 June to 14 July. The peak collection date of 18 July for hatchery-origin carcasses was within the range typically observed; 2001-2010 average = 9 July and range = 23 June to 23 July. The greater range of peak collection dates for hatchery-origin carcasses likely results from low sample sizes.

The spatial distributions of natural- and hatchery-origin carcasses were mostly increased in the canyon area (RM 300 and 301) compared to previous years (Figure 4). Similar to most previous years, both natural- and hatchery-origin carcass recoveries generally increased as the RM increased with a peak collection occurring at Turtle Bay (RM 296.5).

Age Composition and Length-at-Age

Age of recovered hatchery-origin fish consisted primarily of age-2 which has not been previously documented; typically age-3 dominates (Table 3). Also, these fish were predominantly female which typically don't return at age-2. Only three hatchery-origin males were collected with 2 at age-2 and 1 at age-4 (Table 2).

Carcasses of age three and older natural-origin winter Chinook could not be distinguished using length-frequency analysis (Figure 5). For natural-origin fish, the absence of well-defined modes in the length-frequency histogram precluded the ability to unambiguously distinguish between fish of age three, four, and five. Comparison of length-at-age between natural-origin and hatchery-origin carcasses was not possible without knowing the age of natural-origin fish.

Gender Ratio

Considering all recoveries in 2011, substantially more female than male carcasses were recovered (Table 4). Among natural-origin fish observed in 2011, females outnumbered males 3.56 to 1 and among hatchery-origin fish, females outnumbered males 4.50 to 1. The cumulative 2001-2011 gender ratio was not statistically different between natural- and hatchery-origin fish (Paired t-test: $p = 0.276$, $df = 1$).

Pre-spawning Mortality

In 2011, the overall percentage of female pre-spawn mortalities was small for both natural and hatchery fish. The percentage of natural-origin female carcasses categorized as "not fully spawned" was larger than that of hatchery-origin carcasses (Table 5). However, there is no statistical difference for the 2001-2011 total pre-spawn mortality (Paired t-test: $p = 0.495$, $df = 1$).

Table 1.—Sacramento River winter Chinook salmon estimated run size, hatchery-origin run component, carcasses observed, and river miles surveyed for return years 2001 – 2011.

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	7,464	921	12.3	4,946	66.3	288 : 302
2003	8,218	474	5.8	4,536	55.2	286 : 302
2004	7,869	633	8.0	3,279	41.7	273 : 302
2005	15,839	3,092	19.5	8,772	55.4	273 : 302
2006	17,205	2,382	13.8	7,699	44.7	275 : 302
2007	2,542	189	7.4	1,581	62.2	276 : 302
2008	2,830	170	6.0	1,409	49.8	276 : 302
2009	4,537	467	10.3	1,902	41.9	276 : 302
2010	1,596	199[b]	12.5	908	56.9	276 : 302
2011	824	80[b]	9.7	431	52.3	276 : 302
Mean	7,013	829	10.1	3,692	53.5	

[a] Run size was estimated by the California Department of Fish and Game and was reported by that agency as part of the Sacramento River winter Chinook salmon carcass survey effort (objective three).

[b] Please see "Discussion" for further comments regarding this estimate.

Table 2.—Sacramento River winter Chinook salmon percent at age by origin and gender[a,b,c], return years 2001 – 2011.

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	34.6	64.1	1.4	0.0
2005	4.3	95.7	4.5	95.4	0.1	0.0
2006	1.5	98.5	0.2	95.7	4.2	0.0
2007	4.0	96.0	0.0	74.7	25.3	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	1.2	84.1	14.7	0.0
2011	7.9	92.1	59.5	30.9	9.6	0.0
Mean	4.9	95.1	14.6	79.7	5.4	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	1.3	96.4	2.4	0.0
2005	0.3	99.7	0.1	99.9	0.0	0.0
2006	0.1	99.9	0.0	97.9	2.1	0.0
2007	0.6	99.4	0.0	76.2	23.8	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	83.1	16.9	0.0
2011	3.5	96.5	60.5	34.2	5.3	0.0
Mean	0.7	99.3	6.2	88.4	5.1	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	79.2	20.8	0.0	0.0
2005	15.9	84.1	18.1	81.6	0.3	0.0
2006	4.3	95.7	0.6	89.0	10.4	0.0
2007	13.7	86.3	0.0	63.1	36.9	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
2010	5.8	94.2	4.2	86.6	9.2	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			
2011	26.5	73.5	49.7	0.0	50.3	0.0
Mean	16.9	83.1	32.5	57.2	10.3	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. 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 – 2009. Hatchery-origin groups using captive broodstock or cryo-preserved sperm are not included in this summary.

Brood year	Number of CWT groups. contributing to: Release	Number of CWT groups. contributing to: Return	Average number of family groups. per CWT group	Number Released[a]	Total CWTs Recovered	Return Rate (%)[b]	CWT Returns at Age[c,d]: Age 2	CWT Returns at Age[c,d]: Age 3	CWT Returns at Age[c,d]: 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	Na[e]	5.1	133,760	7	Na[e]	1	6	Na[e]
2009	19	Na[e]	6.8	183,676	15	Na[e]	15	Na[e]	Na[e]

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

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

[c] 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).

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

[e] 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 – 2011.

	Natural-origin[a]					Hatchery-origin				
Return Year	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

[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.—Gender ratio of Sacramento River winter Chinook salmon carcasses by origin, return years 2001 – 2011.

Return	Natural-origin			Hatchery-origin		
Year	Female (F)	Male (M)	F:M	Female (F)	Male (M)	F:M
2001	1,179	639	1.85	62	51	1.22
2002	927	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
Mean	1,021	374	2.73	129	47	2.77

Table 6.—Pre-spawn mortality of female Sacramento River winter Chinook salmon by origin, return years 2001 – 2011.

	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	1,176	10	0.9	62	0	0.0
2002	925	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
Mean	1,009	12	1.1	129	5	3.9

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

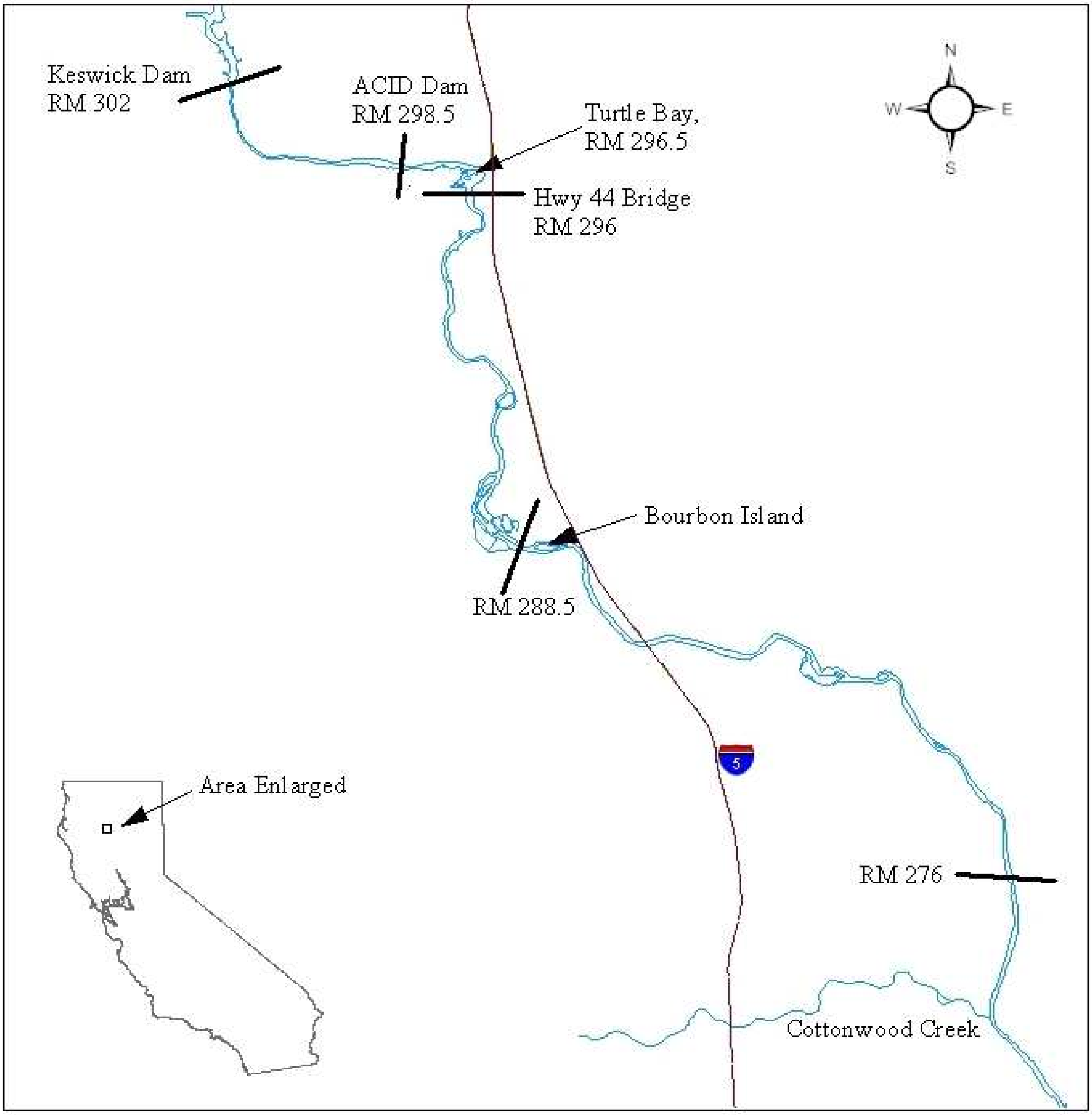

Figure 1.—Sampling area of the Sacramento River winter Chinook salmon carcass survey for return year 2011. Reach 1 extended from the Keswick Dam (RM 302) to the Anderson-Cottonwood Irrigation District (ACID) Diversion Dam (RM 298.5); reach 2 extended from the ACID Diversion Dam to the Highway 44 Bridge 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.

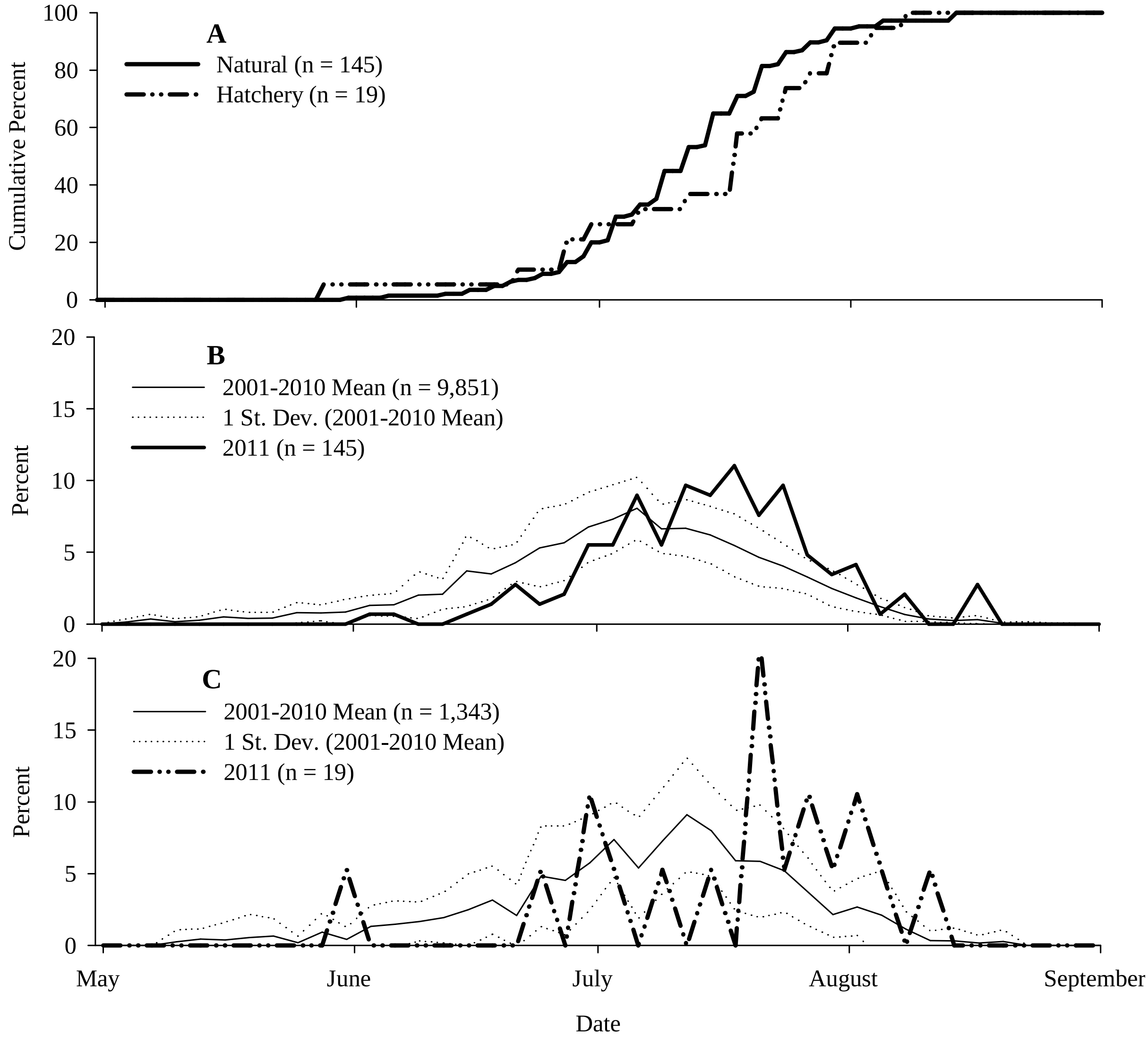

Figure 2.—Temporal distribution of fresh female Sacramento River winter Chinook salmon carcass recoveries for return year 2011. Represented is (**A**) the cumulative percent of natural- and hatchery-origin winter Chinook salmon recovered by date for return year 2011 and a comparison of the total percent that returned by date with the mean observed for return years 2001 – 2010 for (**B**) natural- and (**C**) hatchery-origin fish.

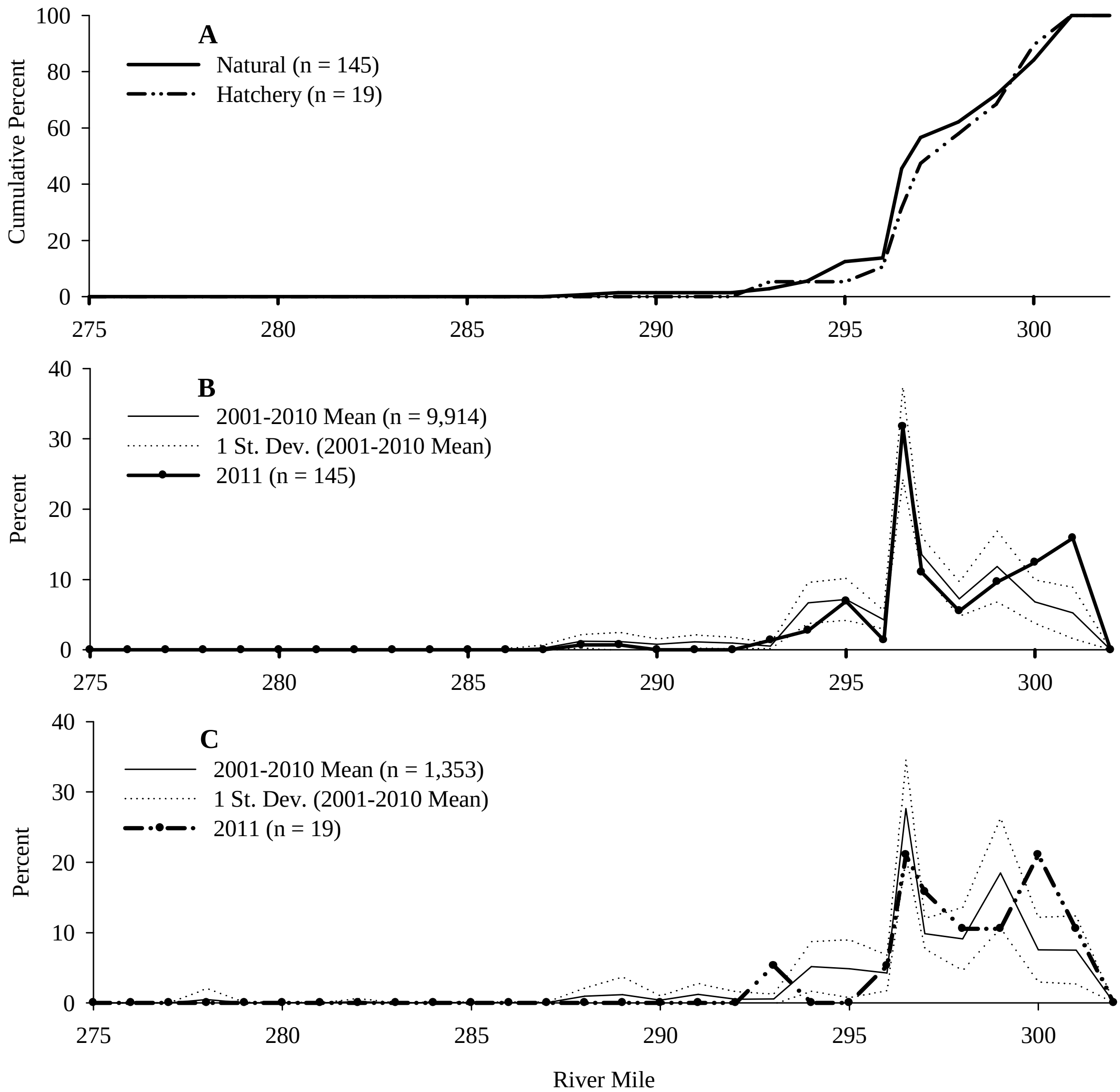

Figure 3.—Spatial distribution of fresh female Sacramento River winter Chinook salmon carcass recoveries for return year 2011. Represented is (A) the cumulative percent of natural- and hatchery-origin winter Chinook salmon recovered by river mile for return year 2011 and a comparison of the total percent recovered by river mile with the mean observed for return years 2001 – 2010 for (B) natural- and (C) hatchery-origin fish.

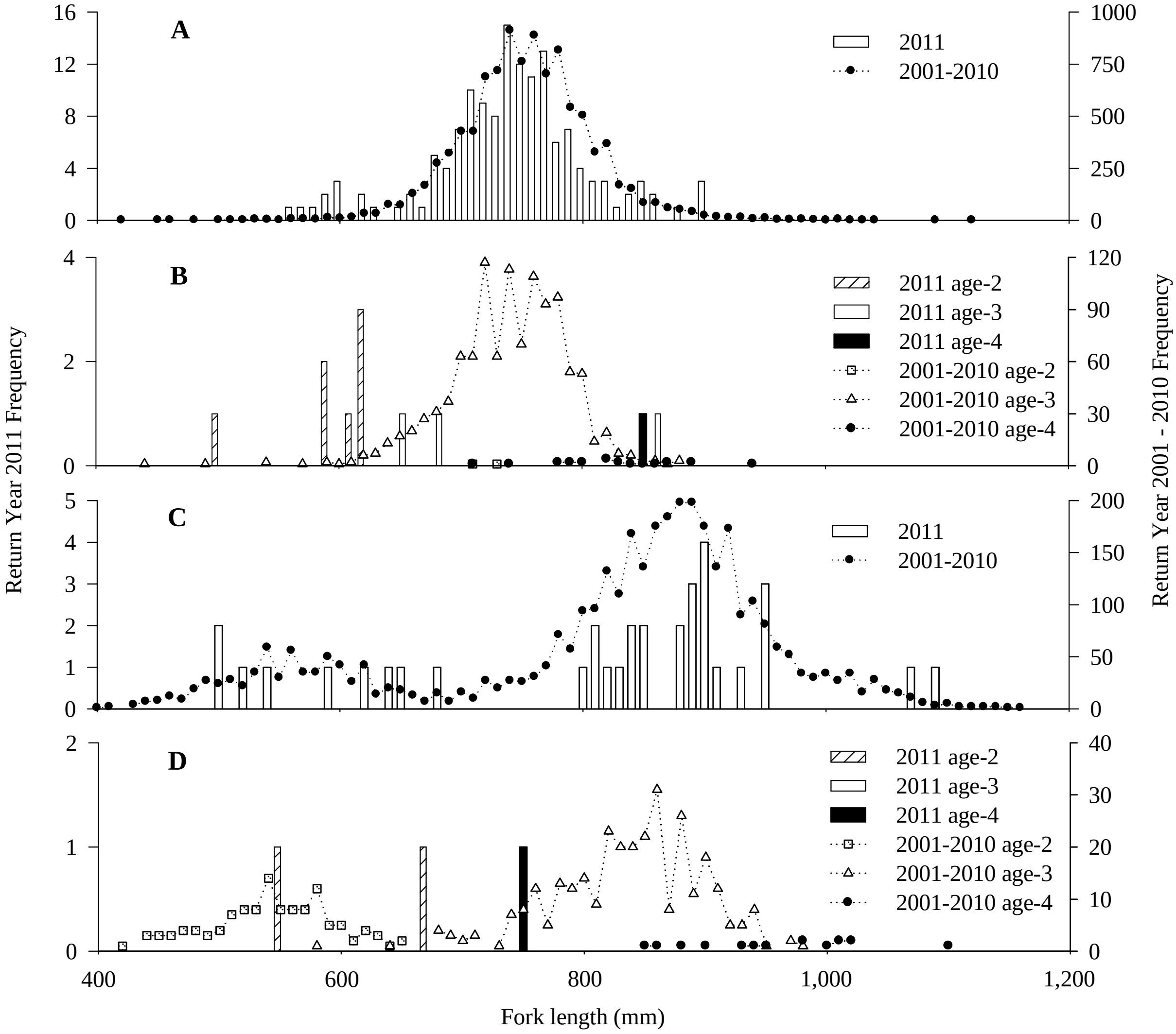

Figure 4—Winter Chinook salmon length-frequency distribution comparison of fresh carcass recoveries for return year 2011 and the mean from return years 2001 – 2010: (A) natural-origin females, (B) hatchery-origin females, (C) natural-origin males, and (D) hatchery-origin males.

Discussion

Using information collected during the winter Chinook carcass survey, the estimated winter Chinook salmon run size in 2011 was 824 and included 80 hatchery-origin fish, representing 9.8 percent of the total run (Appendix A). The 2011 return was the smallest run on record since the historically smallest return of 1994 (n = 186). However, the number of hatchery-origin winter Chinook salmon collected while trapping broodstock for the Service's winter Chinook supplementation program was larger than the hatchery-origin estimate that was derived from data collected during the carcass survey. The Service collected winter Chinook salmon for the supplementation program at the Livingston Stone NFH from 18 January 2011 through 26 July 2011 using a fish trap at the Keswick Dam (RM 302). Trapped fish that were not retained for broodstock, including all hatchery-origin winter Chinook (n = 262), were tissue sampled (caudal fin punch), double Floy tagged near the dorsal fin, and released at either Posse Grounds boat ramp (RM 298.5) or Caldwell Park boat ramp (RM 299) in Redding, CA. The two Floy tags and a hole-punched caudal fin of released fishes provide a reliable indication of Chinook that are either recaptured at the Keswick Dam fish trap or sampled during the carcass survey. The number of hatchery-origin winter Chinook trapped at the Keswick Dam fish trap and released in to the Sacramento River during 2011 was 228% larger than the estimated abundance of hatchery-origin winter Chinook based on the carcass survey. This anomaly first occurred in 2010 with a difference of 78% prompting the Service to initiate further, and ongoing, studies into this pattern.

The number of hatchery-origin winter Chinook encountered at the Keswick Dam fish trap should be considered a minimal estimate of the actual number of hatchery-origin winter Chinook spawners, since the fish trap at Keswick Dam is known to be less than 100% effective at attracting and capturing fish returning to the upper Sacramento River. For estimating winter Chinook abundance in the 2011 spawning season, we suggest that the number of fish observed at the Keswick Dam fish trap provides the most accurate minimal estimate of abundance of hatchery-origin fish, whereas, the estimate based on carcass survey data provide the best information on trends of abundance for the total population.

The discrepancy between the number of hatchery-origin winter Chinook trapped at the Keswick Dam fish trap and the number estimated based on carcass mark-and-recapture methods highlights that there is inaccuracy and perhaps a lack of precision in the carcass survey methodology, which may also affect the estimate of natural-origin winter Chinook salmon. Current methods used to estimate the abundance of hatchery- and natural-origin spawners based on carcass mark-and recapture methods require the acceptance of several untested assumptions, which could greatly affect both the accuracy and precision of estimates. The magnitude of the error observed in the estimated number of hatchery-origin spawners underscores the need for additional research into the accuracy and precision of the current methodology. To address these uncertainties, the authors recommend two complementary research projects; (1) acoustic or radio tagging of live salmon to observe their movements prior to spawning (initiated in 2012), and (2) conducting a mark-and-recapture estimate using live (pre-spawn) winter Chinook salmon.

The timing of peak recovery of natural-origin carcasses was the latest recorded among the eleven years of recorded data. Although the peak for hatchery-origin carcass recovery was within the range observed in previous years, it was among the latest dates recorded in previous years.

Spatial distributions of natural- and hatchery-origin winter Chinook were generally similar. Turtle Bay was still a major carcass recovery area; however, compared to previous years a larger proportion of carcasses was recovered in the canyon area (RM 300 and RM 301). Hatchery-origin fish consisted primarily of age-2 fish. In comparison, Age-3 fish comprised the majority of recoveries since at least 2001. Also, nearly all age-2 fish have previously been male. In 2011, age-2 females comprised nearly 61% of female recoveries compared to the 2001-2010 average of just 0.3%. Too few males were collected to effectively determine age composition; although, 2 out of the 3 male recoveries were age-2. In addition, fork lengths of age-2 males were among the longest ever recorded for both natural- and hatchery-origin fish. Overall, substantially more female carcasses were recovered than males and the ratio of female to male was greater for hatchery-origin fish. Considering yearly data, this ratio is more often greater for hatchery-origin fish. Although, there is no statistical difference for the 2001-2011 average female to male ratio. Pre-spawning mortality was low for both natural- and hatchery-origin fish.

Literature Cited

Hallock, R.J. and F. W. Fisher. 1985. Status of winter-run Chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento River. California Department of Fish and Game, Anadromous Fisheries Branch, January 25, 1985 office report, 28 pp.

National Marine Fisheries Service. 2009. Public Draft Recovery Plan for the Evolutionary Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead. Sacramento Protected Resources Division. October 2009.

Ney, J. J. 1993. Practical use of biological statistics. Pages 137-156 *in* C.C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

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Appendix A-1.—Estimated escapement of hatchery-origin winter Chinook salmon in the upper Sacramento River for 2011.

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 gender, 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.

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

<u>Data</u>

Appendix Table 1.—Data obtained during the 2011 winter Chinook carcass survey and Keswick Trap operations.

Count	Abbreviation	Description
23	$H_{F\text{-}Obs}$	Number of fresh hatchery carcass recoveries
217	$T_{NF\text{-}Obs}$	Number of non-fresh hatchery and natural carcass recoveries
214	$T_{F\text{-}Obs}$	Number of fresh hatchery and natural carcass recoveries
431	T_{Obs}	Total carcasses observed during the carcass survey
738	$N_{J\text{-}S}$	Total naturally reproducing winter Chinook salmon escapement estimated by the California Department of Fish and Game
1	$LSNFH_H$	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 2011 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
054608	1	0	411	20	0	0
054610	1	0	533	28	0	0
054026	1	0	518	62	0	0
054028	4	0	487	51	0	0
054172	1	0	326	72	0	0
054087	2	0	374	14	0	0
054088	1	0	374	14	4	0
054165	1	0	372	9	0	0
054166	2	0	355	41	0	0
054170	2	0	142	0	0	0
054988	5	0	174	26	0	0
	21	0				

Calculations

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

$$\left(\underset{23}{H_{F\text{-}Obs}} \times \underset{217}{T_{NF\text{-}Obs}} \right) / \underset{214}{T_{F\text{-}Obs}} = \underset{\mathbf{23}}{H_{NF\text{-}Exp}}$$

2. Expansion to include carcasses not observed

$$\left(\underset{23}{H_{NF\text{-}Exp}} + \underset{23}{H_{F\text{-}Obs}} + \underset{0}{H_{Unk}} \right) / \underset{431}{T_{Obs}} \times \underset{738}{N_{J\text{-}S}} = \underset{\mathbf{79}}{H_{Sac}}$$

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

$$\underset{79}{H_{Sac}} + \underset{1}{LSNFH_{H}} = \underset{\mathbf{80}}{H_{Clip}}$$

4. Estimated number of hatchery-origin Chinook salmon returning in 2011 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}
054608	:	80.3	×	(	1	/	21	)	=	**3.8**
054610	:	80.3	×	(	1	/	21	)	=	**3.8**
054026	:	80.3	×	(	1	/	21	)	=	**3.8**
054028	:	80.3	×	(	4	/	21	)	=	**15.3**
054172	:	80.3	×	(	1	/	21	)	=	**3.8**
054087	:	80.3	×	(	2	/	21	)	=	**7.6**
054088	:	80.3	×	(	1	/	21	)	=	**3.8**
054165	:	80.3	×	(	1	/	21	)	=	**3.8**
054166	:	80.3	×	(	2	/	21	)	=	**7.6**
054170	:	80.3	×	(	2	/	21	)	=	**7.6**
054988	:	80.3	×	(	5	/	21	)	=	**19.1**
										80.3

5 and 6. Estimated number of hatchery-origin Chinook salmon returning in 2011 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}
054608	:	3.8	/	(	431	/	431	)	=	**3.8**
054610	:	3.8	/	(	561	/	561	)	=	**3.8**
054026	:	3.8	/	(	580	/	580	)	=	**3.8**
054028	:	15.3	/	(	538	/	538	)	=	**15.3**
054172	:	3.8	/	(	398	/	398	)	=	**3.8**
054087	:	7.6	/	(	388	/	388	)	=	**7.6**
054088	:	3.8	/	(	388	/	392	)	=	**3.9**
054165	:	3.8	/	(	381	/	381	)	=	**3.8**
054166	:	7.6	/	(	396	/	396	)	=	**7.6**
054170	:	7.6	/	(	142	/	142	)	=	**7.6**
054988	:	19.1	/	(	200	/	200	)	=	**19.1**
							H_{Total}		=	**80.4**

7. The estimated number of hatchery-origin winter Chinook salmon returning in 2011 following the removal of hatchery-origin non-winter fish.

H_{Total}		$CWT_{Final\text{-}"no\ strays\ in\ 2011"}$		H_{Final}
80	-	0	=	**80**

*** Please see "Discussion" for further comments regarding this estimate.**