Upper Sacramento River Winter Chinook Salmon Carcass Survey

2010 Annual Report

Prepared by

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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 2010 Sacramento River winter Chinook carcass survey pertinent to evaluation of the winter Chinook supplementation program.

An estimated 1,596 winter Chinook returned in 2010, which is the smallest since return year 2000. An estimated 199 of the winter Chinook were of hatchery-origin, representing 12.5 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 52% lower than the actual number of hatchery-origin fish returning to spawn based on the number of fish encountered during broodstock collection activities. Most hatchery-origin carcasses recovered in 2010 were age-3. The peak return date of natural- and hatchery-origin fish was very near the average previously observed. 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 upstream of the Anderson-Cottonwood Irrigation District diversion dam. The ratio of females to males was greater for natural-origin than hatchery-origin fish whereas, from 2005 to 2009, this ratio was greater for hatchery-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" in 1994 (59 Federal Register 440). 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 requirements for the species, which are specified in the draft recovery plan for winter Chinook salmon (National Marine Fisheries Service 1997). 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; pers. com.).

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 2010 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 2010, 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." 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, pers. com.). 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 3 May 2010 through 27 August 2010. A total of 908 carcasses was observed during the 2010 survey, representing 57% of the estimated run size (Table 1). This was among the highest percent observed in recent survey years and likely resulted from the clear condition of the Sacramento River in 2010. Although visibility was as shallow as four feet at times, the vast majority of the survey season was at or above 15 feet visibility (Secchi depth: average = 12.5 feet). A total of 472 fresh Chinook carcasses were recovered and sampled for biological data (64 hatchery-origin, 398 natural-origin, and 10 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 137 fresh and non-fresh carcasses (112 hatchery-origin and 25 unknown-origin) and a readable CWT was recovered from 95 of the heads (tags were not detected in 35 heads and seven tags were lost prior to being read; Appendix Table 1). The seven lost tags consisted of two heads lost prior to CWT extraction attempts, one lost tag during extraction, one lost tag after extraction but prior to reading, one lost tag during reading, and two tags reclassified from no tag detected to lost. All heads are initially run through a R9500 tunnel detector (Northwest Marine Technology, Shaw Island, WA). Of the heads believed to contain a CWT based on positive indication from the tunnel detector, two were later processed with no tag detected. It was assumed that the tunnel detector was 100% accurate in indicating the presence of a CWT. None of the unknown-origin carcasses contained a CWT. Ninety of the recovered tags were from winter Chinook released from the Livingston Stone NFH, three were spring Chinook salmon reared at the CDFG Feather River Hatchery, and two were late-fall Chinook salmon reared at the Service's Coleman NFH. Data associated with the non-winter fish were removed from all analyses in this report unless otherwise noted.

Hatchery-origin Returns

An estimated 199 (please see "Discussion" for further comments regarding this estimate) hatchery-origin winter Chinook returned in 2010, representing 12.5 percent of the total run (Table 1). Age three hatchery-origin fish (brood year 2007) were the primary contributors to the 2010 return (n = 77) and all 9 CWT groups released from this brood year were represented (Table 2). Twelve age-four hatchery-origin winter Chinook were recovered during the survey. One age-two hatchery-origin carcass was recovered (male; non-fresh carcass).

Temporal and Spatial Distribution

The peak collection date of July 2 (Figure 3) for natural-origin carcasses was within the range observed in previous years; 2001-2009 average = July 5 and range = June 26 to July 14. The peak collection date of July 11 for hatchery-origin carcasses was within the range typically observed; 2001-2009 average = July 11 and range = June 23 to July 23. 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 was similar to that observed in 2009 with a higher than average occurrence in the area proximate and upstream of the ACID dam, RM 298 (Figure 4). Similar to previous years, both natural- and hatchery-origin carcass recoveries generally increased as the RM increased with a major collection occurring at Turtle Bay (RM 296.5). However, compared to previous years, both natural- and hatchery-origin recoveries were decreased at Turtle Bay and had a noticeable increase at RM 299 and RM 301.

Age Composition and Length-at-Age

Age of all recovered hatchery-origin fish consisted primarily of age-3 with one age-2 male (Table 3). Age-4 hatchery-origin fish represented a much larger than average proportion for both female and male recoveries (Table 2). Carcasses of age three and older natural-origin winter Chinook could not be distinguished using length-frequency analysis (Figure 5).

The frequency at length for all age-3 return year 2010 fresh hatchery-origin carcass recoveries was generally consistent with the average for return years 2001 – 2009. 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 2010, substantially more female than male carcasses were recovered (Table 4). Among natural-origin fish observed in 2010, females outnumbered males 3.63 to 1 and among hatchery-origin fish, females outnumbered males 2.00 to 1.

Pre-spawning Mortality

In 2010, the overall percentage of female pre-spawn mortalities was small for both natural and hatchery fish. The percentage of hatchery-origin female carcasses categorized as "not fully spawned" was larger than that of natural-origin carcasses; however, the sample size was low (Table 5).

Table 1.—Sacramento River winter Chinook salmon estimated run size, hatchery-origin run component, carcasses observed, and river miles surveyed for return years 2001 – 2010.

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	5,145.0	62.6	288 : 302
2002	7,464	921	12.3	4,946.0	66.3	288 : 302
2003	8,218	474	5.8	4,536.0	55.2	286 : 302
2004	7,869	633	8.0	3,279.0	41.7	273 : 302
2005	15,839	3,092	19.5	8,772.0	55.4	273 : 302
2006	17,205	2,382	13.8	7,699.0	44.7	275 : 302
2007	2,542	189	7.4	1,581.0	62.2	276 : 302
2008	2,830	170	6.0	1,409.0	49.8	276 : 302
2009	4,537	467	10.3	1,902.0	41.9	276 : 302
2010	1,596	199[1]	12.5	908.0	56.9	276 : 302
Mean	7,632	904	11.8	4,018	52.6	

[1] Please see “Discussion” for further comments regarding this estimate.

Table 2.—Sacramento River winter Chinook salmon percent at age by origin and gender, return years 2001 – 2010.

Return Year	Natural-origin, % at Age[b]		Hatchery-origin, % at Age[c]			
	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
Mean	5.1	94.9	6.2	91.4	2.4	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	1.3	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
Mean	0.4	99.6	0.3	97.6	2.0	0.0
			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
Mean	18.2	81.8	22.9	73.5	3.6	0.0

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 1999 – 2008. Adult returns in 2010 were from brood years 2006 (age four fish), 2007 (age three fish), and 2008 (age two fish).

Brood year[b]	Number of CWT groups. contributing to:		Average number of family groups. per CWT group.	Number Released[d]	Total CWTs Recovered	CWT Returns at Age[a]		
	Release[c]	Return				Age 2[b]	Age 3[b]	Age 4[b]
1998	21	19	5.7	137,368	108	8	98	2
1999	17	17	1.0	26,135	153	30	117	1
2000	28	27	5.6	152,143	129	16	112	1
2001	27	21	3.7	181,205	94	6	87	1
2002	32	32	2.7	154,922	1041	46	971	24
2003	30	30	3.0	145,774	598	44	534	19
2004	16	16	4.2	124,862	49	1	47	1
2005	17	16	5.8	151,321	41	1	40	0
2006	18	18	6.9	149,060	124	6	108	9
2007	9	NA[e]	5.1	69,119	77	0	77	NA[e]
2008	13	NA[e]	6.8	133,760	1	1	NA[e]	NA[e]

a. 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). Recoveries from groups using captive broodstock or cryo-preserved sperm are not included.
b. Fish return as: Age 2 (Brood year + 2 years), Age 3 (Brood year + 3 years), and Age 4 (Brood year + 4 years).
c. Releases using captive broodstock or cryo-preserved sperm are not included.
d. Number released reflects only those with a CWT and clipped adipose fin as estimated from tag retention data collected prior to release. Recoveries of groups using captive broodstock or cryo-preserved sperm are not included.
e. Return rate 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 – 2010.

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

Table 5.—Gender ratio of Sacramento River winter Chinook salmon carcasses by origin, return years 2001 – 2010.

Return Year	Natural-origin			Hatchery-origin		
	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
Mean	1,197	443	2.70	152	54	2.78

Table 6.—Pre-spawn mortality of female Sacramento River winter Chinook salmon by origin, return years 2001 – 2010.

	Natural-origin			Hatchery-origin		
Return year	Total carcasses	Number not fully spawned[1]	Percent not fully spawned[1]	Total carcasses	Number not fully spawned[1]	Percent not fully spawned[1]
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
Mean	1,095	13	1.2	140	6	4.0

1 "Not fully spawned" includes female carcasses classified as "unspawned" and "partially spawned".

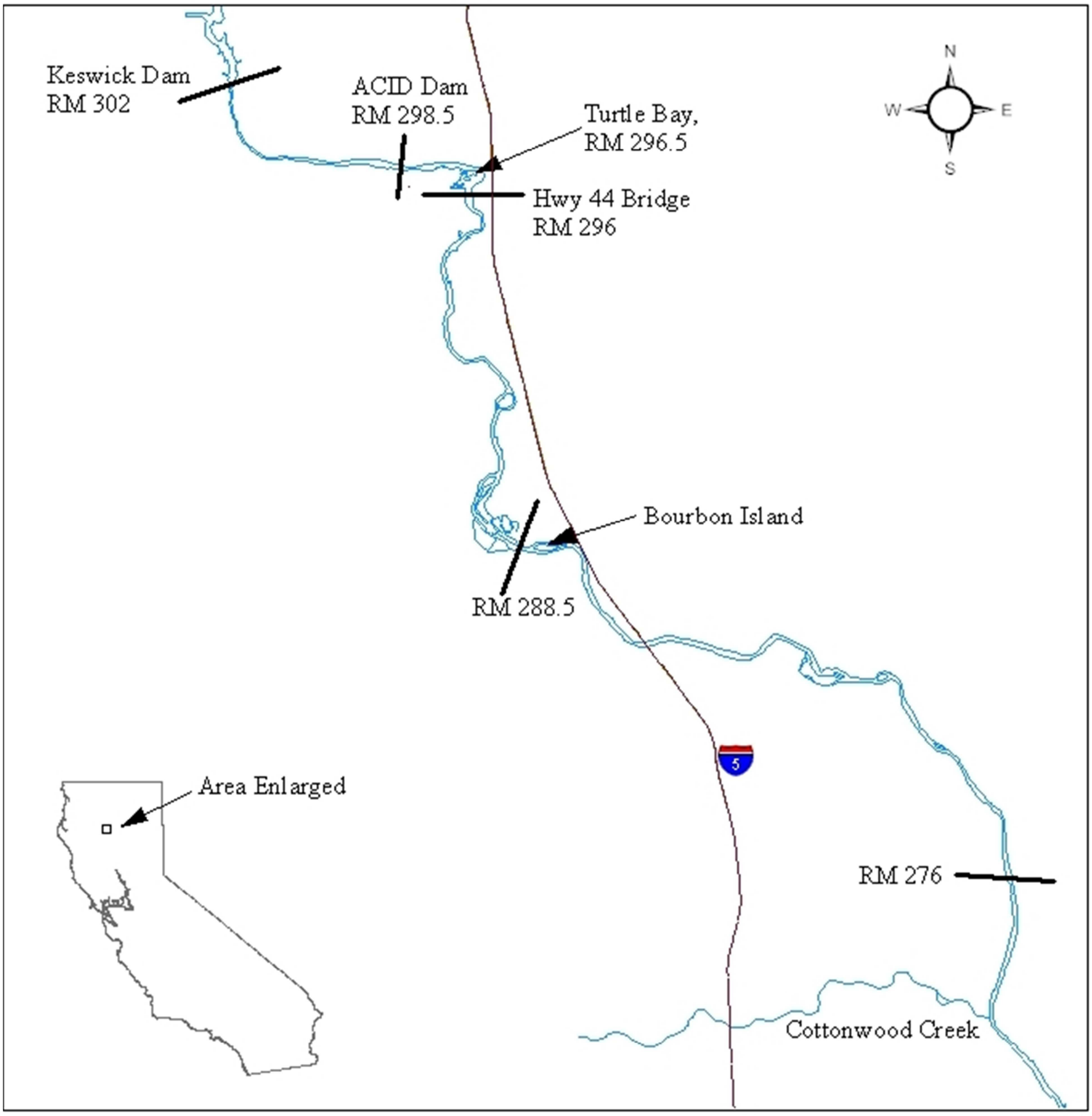

Figure 1.—Sampling area of the Sacramento River winter Chinook salmon carcass survey for return year 2010. Reach 1 extended from the Keswick Dam (RM 302) to the Anderson-Cottonwood Irrigation District (ACID) Diversion Dam (RM 298.5); reach 2 extended from the ACID Diversion Dam to the Highway 44 Bridge 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.

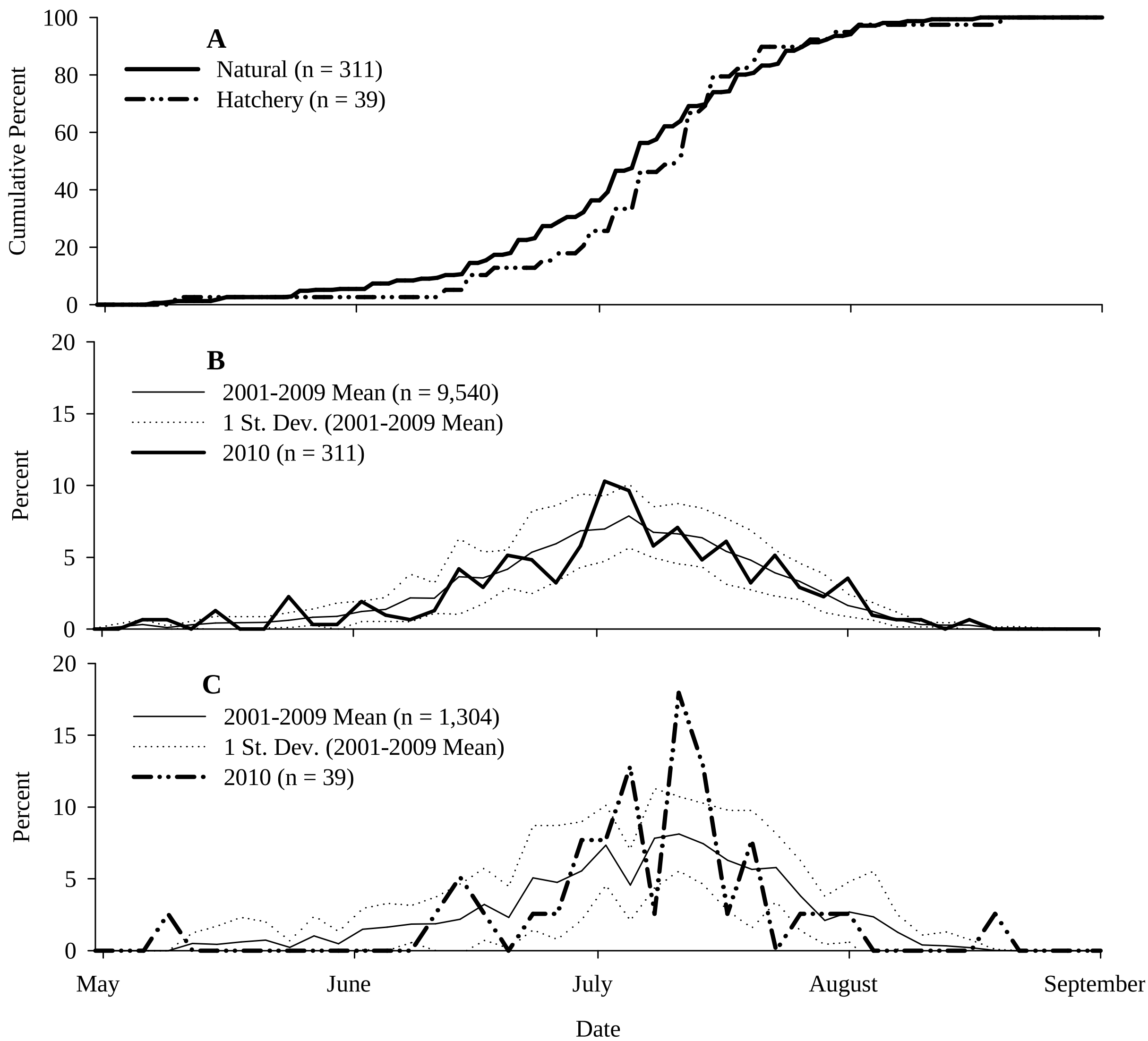

Figure 2.—Temporal distribution of fresh female Sacramento River winter Chinook salmon carcass recoveries for return year 2010. Represented is (**A**) the cumulative percent of natural- and hatchery-origin winter Chinook salmon recovered by date for return year 2010 and a comparison of the total percent that returned by date with the mean observed for return years 2001 – 2009 for (**B**) natural- and (**C**) hatchery-origin fish.

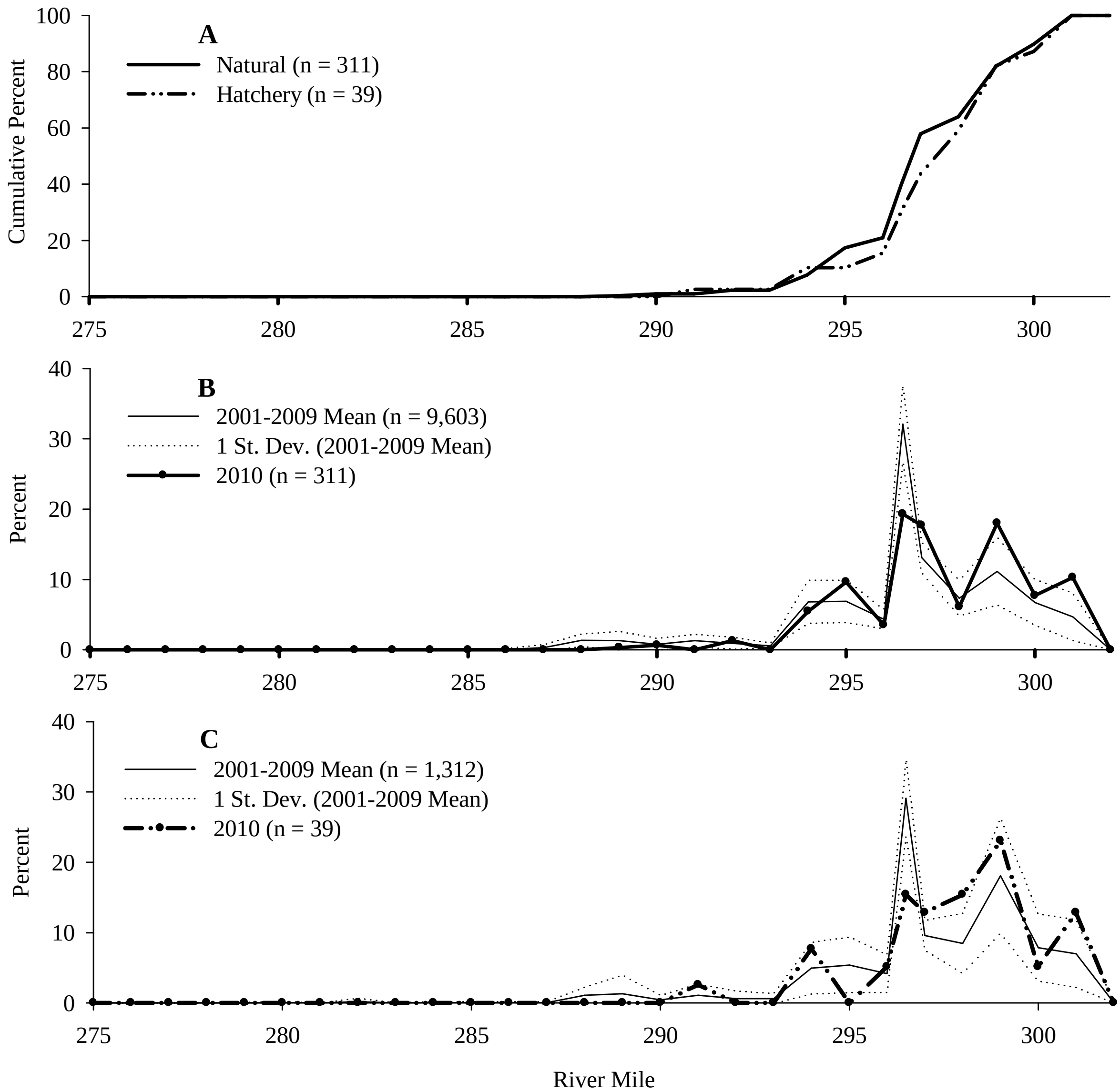

Figure 3.—Spatial distribution of fresh female Sacramento River winter Chinook salmon carcass recoveries for return year 2010. Represented is (A) the cumulative percent of natural- and hatchery-origin winter Chinook salmon recovered by river mile for return year 2010 and a comparison of the total percent recovered by river mile with the mean observed for return years 2001 – 2009 for (B) natural- and (C) hatchery-origin fish.

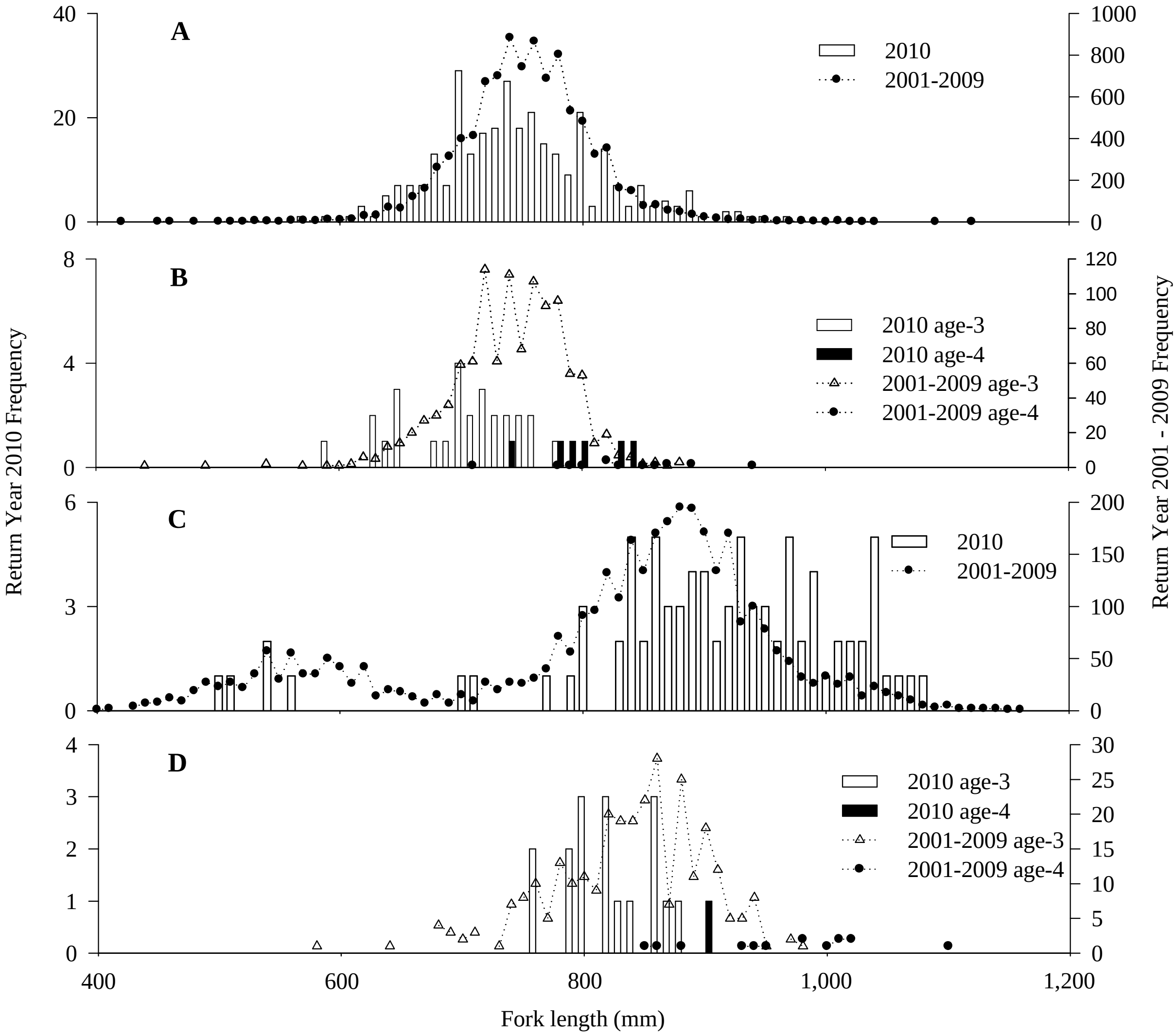

Figure 4—Winter Chinook salmon length-frequency distribution comparison of fresh carcass recoveries for return year 2010 and the mean from return years 2001 – 2009: (A) natural-origin females, (B) hatchery-origin females, (C) natural-origin males, and (D) hatchery-origin males.

Discussion

Using information collected during the winter Chinook carcass survey, the estimated winter Chinook salmon run size in 2010 (1,596) was the smallest observed since return year 2000 and included 199 hatchery-origin fish, representing 12.5 percent of the total run (Appendix A). 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 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 5 January 2010 through 29 July 2010 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=303), 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 2010 was 52% larger than the estimated abundance of hatchery-origin winter Chinook based on the carcass survey. 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. The collection of more hatchery-origin winter Chinook at the Keswick Dam fish trap than were estimated using the carcass survey has not previously occurred. For estimating winter Chinook abundance in the 2010 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, including; (1) acoustic or radio tagging of live salmon to observe their movements prior to spawning, and (2) conducting a mark-and-recapture estimate using live (pre-spawn) winter Chinook salmon.

Approximately 57 percent of the estimated run was handled in 2010, which is among the highest in recent survey years and is likely due to the relatively clear river condition during most of return year 2010. The timing of peak recovery of natural-and hatchery-origin carcasses was similar to 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 proximately upstream of the ACID dam. Overall, substantially more female carcasses were recovered than males and the ratio of female to male was greater for natural-origin fish. Pre-spawning mortality was low for both natural- and hatchery-origin fish.

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Appendix A-1.—Estimated escapement of hatchery-origin winter Chinook salmon in the upper Sacramento River for 2010.

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 brood stock, 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 ($H_{NF\text{-}Exp}$):

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

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 brood stock by the Livingston Stone NFH), based on the Jolly-Seber population estimate ($N_{J\text{-}S}$):

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

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 brood stock 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 2009 winter Chinook carcass survey and Keswick Trap operations.

64	=	$H_{F\text{-}Obs}$	=	Number of fresh hatchery carcass recoveries
436	=	$T_{NF\text{-}Obs}$	=	Number of non-fresh hatchery and natural carcass recoveries
472	=	$T_{F\text{-}Obs}$	=	Number of fresh hatchery and natural carcass recoveries
908	=	T_{Obs}	=	Total carcasses observed during the carcass survey
1,533	=	$N_{J\text{-}S}$	=	Total naturally reproducing winter Chinook salmon escapement
2	=	$LSNFH_H$	=	Hatchery fish retained for LSNFH broodstock
0	=	H_{Unk}	=	Total hatchery fish with unknown carcass condition

Appendix Table 2.—Coded-wire tag codes recovered during the 2009 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 brood stock 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
062474	2	0	194	6	0	0
068009	1	0	378	9	0	0
051680	1	0	185	15	0	0
051697	1	0	189	10	1	0
052368	3	0	366	18	8	2
052490	1	0	162	38	0	0
052491	1	0	175	22	2	1
052492	3	0	185	15	0	0
052493	1	0	192	6	0	2
053386	1	0	197	3	0	0
053468	1	0	183	17	0	0
053990	1	0	200	0	0	0
054553	10	0	525	19	0	0
054554	10	0	519	21	0	1
054604	7	0	658	46	0	0
054605	6	0	345	14	0	0
054606	2	0	448	18	1	0
054607	15	0	596	10	1	0
054608	6	0	411	20	0	0
054609	7	0	470	10	0	0
054610	14	0	533	28	0	0
053465	1	0	345	20	0	0
	95	0				

Calculations

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

	$H_{F\text{-}Obs}$		$T_{NF\text{-}Obs}$		$T_{F\text{-}Obs}$		$H_{NF\text{-}Exp}$
(	64	×	436	) /	472	=	**59**

2. Expansion to include carcasses not observed

	$H_{NF\text{-}Exp}$		$H_{F\text{-}Obs}$		H_{Unk}		T_{Obs}		$N_{J\text{-}S}$		H_{Sac}
(	59.1186	+	64	+	0	) /	908	×	1,533	=	**208**

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

H_{Sac}		$LSNFH_H$		H_{Clip}
207.86	+	2	=	**210**

4. Estimated number of hatchery-origin Chinook salmon returning in 2009 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}
062474	:	209.8644	× (	2	/	95	) =	**4.4**
068009	:	209.8644	× (	1	/	95	) =	**2.2**
051680	:	209.8644	× (	1	/	95	) =	**2.2**
051697	:	209.8644	× (	1	/	95	) =	**2.2**
052368	:	209.8644	× (	3	/	95	) =	**6.6**
052490	:	209.8644	× (	1	/	95	) =	**2.2**
052491	:	209.8644	× (	1	/	95	) =	**2.2**
052492	:	209.8644	× (	3	/	95	) =	**6.6**
052493	:	209.8644	× (	1	/	95	) =	**2.2**
053386	:	209.8644	× (	1	/	95	) =	**2.2**
053468	:	209.8644	× (	1	/	95	) =	**2.2**
053990	:	209.8644	× (	1	/	95	) =	**2.2**
054553	:	209.8644	× (	10	/	95	) =	**22.1**
054554	:	209.8644	× (	10	/	95	) =	**22.1**
054604	:	209.8644	× (	7	/	95	) =	**15.5**
054605	:	209.8644	× (	6	/	95	) =	**13.3**
054606	:	209.8644	× (	2	/	95	) =	**4.4**
054607	:	209.8644	× (	15	/	95	) =	**33.1**
054608	:	209.8644	× (	6	/	95	) =	**13.3**
054609	:	209.8644	× (	7	/	95	) =	**15.5**
054610	:	209.8644	× (	14	/	95	) =	**30.9**
053465	:	209.8644	× (	1	/	95	) =	**2.2**
								210

5 and 6. Estimated number of hatchery-origin Chinook salmon returning in 2009 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}
062474	:	4.4182	/ (	200	/	200	) =	**4.4**
068009	:	2.2091	/ (	387	/	387	) =	**2.2**
051680	:	2.2091	/ (	200	/	200	) =	**2.2**
051697	:	2.2091	/ (	199	/	200	) =	**2.2**
052368	:	6.6273	/ (	384	/	394	) =	**6.8**
052490	:	2.2091	/ (	200	/	200	) =	**2.2**
052491	:	2.2091	/ (	197	/	200	) =	**2.2**
052492	:	6.6273	/ (	200	/	200	) =	**6.6**
052493	:	2.2091	/ (	198	/	200	) =	**2.2**
053386	:	2.2091	/ (	200	/	200	) =	**2.2**
053468	:	2.2091	/ (	200	/	200	) =	**2.2**
053990	:	2.2091	/ (	200	/	200	) =	**2.2**
054553	:	22.0910	/ (	544	/	544	) =	**22.1**
054554	:	22.0910	/ (	540	/	541	) =	**22.1**
054604	:	15.4637	/ (	704	/	704	) =	**15.5**
054605	:	13.2546	/ (	359	/	359	) =	**13.3**
054606	:	4.4182	/ (	466	/	467	) =	**4.4**
054607	:	33.1365	/ (	606	/	607	) =	**33.2**
054608	:	13.2546	/ (	431	/	431	) =	**13.3**
054609	:	15.4637	/ (	480	/	480	) =	**15.5**
054610	:	30.9274	/ (	561	/	561	) =	**30.9**
053465	:	2.2091	/ (	365	/	365	) =	**2.2**
						H_{Total}	=	**210**

7. The estimated number of hatchery-origin winter Chinook salmon returning in 2009 following the removal of hatchery-origin non-winter fish.

H_{Total}		$CWT_{Final\text{-}062474,068009,053386,053990}$		H_{Final}
210	-	11	=	**199***

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