Upper Sacramento River Winter Chinook Salmon Carcass Survey

2006 Annual Report

A U.S. Fish & Wildlife Service Report

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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 winter Chinook salmon returning to the upper Sacramento River. The U.S. Fish & Wildlife Service's objective for participation in the survey is to collect 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 2006 Sacramento River winter Chinook carcass survey pertinent to evaluation of the supplementation program.

Return year 2006 was the largest return of winter Chinook salmon since 1981, with an estimated 17,298 winter Chinook returning to the survey area. An estimated 2,382 of the winter Chinook were of hatchery-origin, representing approximately 14% of the total run. Return year 2006 marked the completion of brood year 2002 returns, which had the highest survival rate of any of the brood years propagated at the Livingston Stone National Fish Hatchery. The percentage of age two males in the 2006 return was very low relative to recent years; whereas, the percentage of age four hatchery-origin fish was much higher. Temporal and spatial distributions of natural-origin and hatchery-origin fish, and gender ratios, were similar. Prespawning mortality was low for natural-origin fish, but higher for hatchery-origin fish.

Introduction

The Sacramento River supports four distinct "runs" of Chinook salmon (*Oncorhynchus tshawytscha*): fall-run, late-fall-run, spring-run, and winter-run. Winter-run salmon leave the ocean and 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 increase returns to the mainstem 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, and explained in further detail in a complementary report from the CDFG (Killam 2006).

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 2006 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 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 RM 275 just downstream of Balls Ferry Road bridge.

The carcass survey was designed to include the entire winter Chinook spawning period and was conducted daily from May 1, 2006 through August 25, 2006 in 3-day cycles: reach 4 on the first day; 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.

The survey was 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. During the peak time of carcass recovery, up to four boats were used for sampling. Carcasses were recovered using a 4.6 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: date, location (reach, RM, and latitude / longitude), gender, spawn status (spawned, unspawned, and unknown), fork length, and adipose fin status (absent, present, and unknown). After data were collected, the 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 are coded-wire tagged 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 coded-wire tag. These carcasses were counted as hatchery-origin if they contained a coded-wire tag; if they did not, their classification remained "unknown". A small piece of fin tissue was taken and preserved for future genetic analysis from all hatchery-origin fish. When few natural-origin carcasses were present, such as during May and August, a fin tissue sample was taken from all fresh natural-origin carcasses. Natural-origin carcasses were subsampled when large numbers of carcasses were present, such as in June and July.

Data Analysis

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 fish's brood year relative to the return year. Spatial and temporal distribution, age composition, gender composition, and pre-spawn mortality were compared between hatchery-origin and natural-origin carcasses. It was assumed that longevity of natural-origin and hatchery-origin fish after spawning was the same. 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 expanded based on the proportion of fresh, hatchery-origin carcass among all fresh carcass recoveries (Appendix 1). The estimate of non-fresh hatchery-origin carcasses was added to the number of fresh hatchery-origin carcass recovered, and then expanded to include carcasses believed to have been present, but not observed, based on the Jolly-Seber mark-recapture method used by the California Department of Fish and Game (Killam 2006). Additional calculations were performed to accommodate 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 hatchery-origin fish that were removed from the natural spawning population for use as brood stock at Livingston Stone NFH.

Results

Carcass Recoveries

A total of 7,699 carcasses were observed during the 2006 survey (45% of the estimated run size; Table 1), and 3,570 were sampled for biological data (3,084 of the carcasses sampled were fresh). Tissue samples were collected from 1,695 fresh carcasses (421 hatchery-origin, 1,256 natural-origin, and 18 of unknown origin).

No non-winter hatchery-origin Chinook carcasses (i.e. hatchery-origin strays) were recovered during the survey, and there is no information to indicate that hatchery-origin winter Chinook strayed outside of the upper Sacramento River basin. Six hatchery-origin winter Chinook adults (4 females and 2 males) were recovered from the Battle Creek watershed (the Battle Cr. watershed drains into the upper Sacramento River at RM 271) during activities outside the scope of the carcass survey. These fish were collected during December 2005 and March, April, and May 2006.

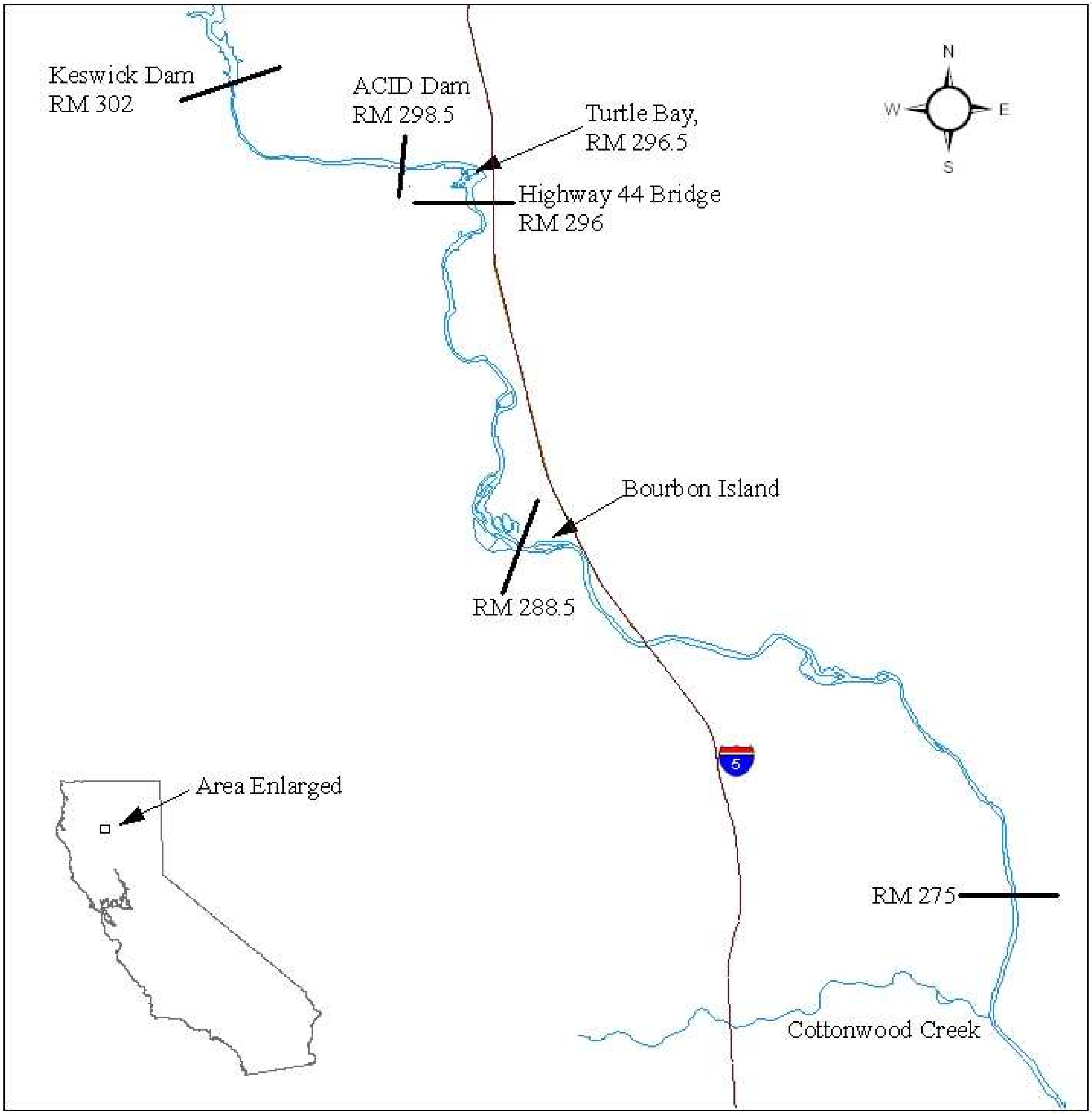


Figure 1. Sampling area of Sacramento River winter Chinook salmon carcass survey for return year 2006. Reach 1 extended from the Keswick Dam (RM 302) to the Anderson-Cottonwood Irrigation District (ACID) Diversion Dam (RM 298.5); reach 2 extended from the ACID Dam to the Highway 44 Bridge in Redding, 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 RM 275.

Coded-Wire Tag Recoveries

Heads were collected from 916 carcasses (867 hatchery-origin and 49 unknown-origin) and readable coded-wire tags were recovered from 767 of the heads (tags were not detected in 135 heads, 11 tags were lost, and three tags were unreadable; Appendix Table 1). Fifteen of the 49 carcasses of unknown-origin contained a coded-wire tag and were reclassified as hatchery-origin.

Hatchery-origin Returns

An estimated 2,382 hatchery-origin winter Chinook returned in 2006. Age three fish (brood year 2003) were the primary contributors to the 2006 return, and all of the 31 CWT groups released from this brood year were represented in the 2006 return (Table 2). Thirty-three age four hatchery-origin winter Chinook were recovered during the survey, representing approximately 4% of the total hatchery returns. Four percent is a substantially higher percentage of age four returns compared to previous years (Tables 1 and 2). In combination with recoveries made over the past two years, the brood year 2002 release had the highest overall rate of return of winter Chinook from Livingston Stone NFH (Table 2). Only one age-two hatchery-origin carcass was recovered in 2006 (Table 2).

Temporal and Spatial Distribution

The temporal distributions of natural-origin and hatchery-origin carcasses in 2006 were nearly identical and within the range observed in previous years (Figure 2). The spatial distributions of natural-origin and hatchery-origin carcasses were also nearly identical in 2006 (Figure 3).

Age Composition and Length-at-Age

Only one age two hatchery-origin carcass was recovered and it was a male (Table 3). The percentage of age two males, natural-origin and hatchery-origin, in the 2006 return was much lower than in previous years. Length-at-age comparisons between natural-origin and hatchery-origin age two males could not be conducted due to the small sample sizes available.

Age three fish accounted for most of the hatchery-origin returns of winter Chinook salmon. Carcasses of age three and age four natural-origin winter Chinook could not be distinguished using length-frequency analysis (Figure 4). More age four hatchery-origin carcasses were recovered in 2006 than in return years 2001 – 2005 combined (Table 1) and length-frequency histograms of hatchery-origin carcasses showed the presence of larger carcasses, especially among males, than what has occurred in previous years for hatchery-origin fish (Figure 4). The absence of well-defined modes in the length-frequency histograms of natural-origin carcasses precluded distinguishing carcasses of age three and age four fish. Additionally, comparison of length-at-age between natural-origin and hatchery-origin carcasses was precluded by uncertainties regarding age at return for these two groups.

Table 1. Sacramento River winter Chinook salmon estimated run size, carcasses observed, and percent at age by origin and gender, return years 2001 – 2006.

Total

Return Year	Total Estimated Runsize[a]	Hatchery-origin Runsize	% of Run Hatchery-origin	Total Carcasses Observed	Percent of Run Observed	River miles Surveyed, From : To	Natural-origin, % at Age[b]		Hatchery-origin, % at Age[b]		
							Age 2	Ages 3 & 4	Age 2	Age 3	Age 4
2001	8,224	513	6.2	5,145	62.6	288 : 302	9.0	91.0	23.0	77.0	0.0
2002	7,464	921	12.3	4,946	66.3	288 : 302	6.5	93.5	7.7	90.4	1.9
2003	8,218	474	5.8	4,536	55.2	286 : 302	2.7	97.3	8.5	90.6	0.9
2004	7,869	633	8.0	3,279	41.7	273 : 302	12.3	87.7	27.3	71.1	1.6
2005	15,839	3,092	19.5	8,772	55.4	273 : 302	4.4	95.6	4.9	95.0	0.1
2006	17,205	2,382	13.8	7,699	44.7	273 : 302	4.3	95.7	0.1	95.5	4.3
Average	10,803	1,338	12.4	5,730	53.0	.	6.5	93.5	11.9	86.6	1.5

Females

Return Year	Natural-origin, % at Age[b]		Hatchery-origin, % at Age[b]		
	Age 2	Ages 3 & 4	Age 2	Age 3	Age 4
2001	0.2	99.8	3.2	96.8	0.0
2002	1.2	98.8	0.0	98.8	1.2
2003	0.2	99.8	0.0	98.9	1.1
2004	0.9	99.1	0.0	97.3	2.7
2005	0.3	99.7	0.0	100.0	0.0
2006	0.1	99.9	0.0	97.7	2.3
Average	0.5	99.5	0.5	98.2	1.2

Males

Return Year	Natural-origin, % at Age[b]		Hatchery-origin, % at Age[b]		
	Age 2	Ages 3 & 4	Age 2	Age 3	Age 4
2001	25.4	74.6	47.1	52.9	0.0
2002	21.2	78.8	36.4	59.1	4.5
2003	15.9	84.1	43.5	56.5	0.0
2004	39.7	60.3	64.8	35.2	0.0
2005	15.8	84.2	19.5	80.0	0.5
2006	4.3	95.7	0.5	89.8	9.7
Average	20.4	79.6	35.3	62.3	2.5

[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] 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, females and males, respectively: 2001: 580, 690; 2002: 550, 680; 2003: 560, 670; 2004: 580, 690; 2005: 580, 670; 2006: 580, 670. Age of hatchery-origin carcasses was determined by coded-wire tag.

Table 2. Winter Chinook salmon returns by brood year, coded-wire tag groups contributing to return, return rate, and returns at age for brood years 1999 – 2004. Returns in 2006 were from brood years 2002 (age four fish), 2003 (age three fish), and 2004 (age two fish).

Brood year[b]	No. of CWT grps. contributing to Release[c]	No. of CWT grps. contributing to Return	Avg. family grps. per CWT grp.	Number Released[d]	Total CWTs Recovered	Return Rate (%)[e]	CWT Returns at Age[a] Age 2[b]	CWT Returns at Age[a] Age 3[b]	CWT Returns at Age[a] Age 4[b]
1999	17	17	1.0	30,367	162	0.533	32	129	1
2000	30	29	3.2	162,198	138	0.085	17	119	2
2001	27	21	3.7	241,812	123	0.051	12	110	1
2002	32	32	2.7	212,808	1313	0.617	59	1221	33
2003	31	31	3.0	216,577	803	0.371[f]	67	736	NA[f]
2004	17	NA[f]	4.3	144,075	1	NA[f]	1	NA[g]	NA[g]

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

[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 from the captive broodstock program are not included.

[d] Number released reflects only those with CWTs as estimated from tag retention data prior to release.

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

[f] Return rate not final, returns not yet complete.

[g] Not available.

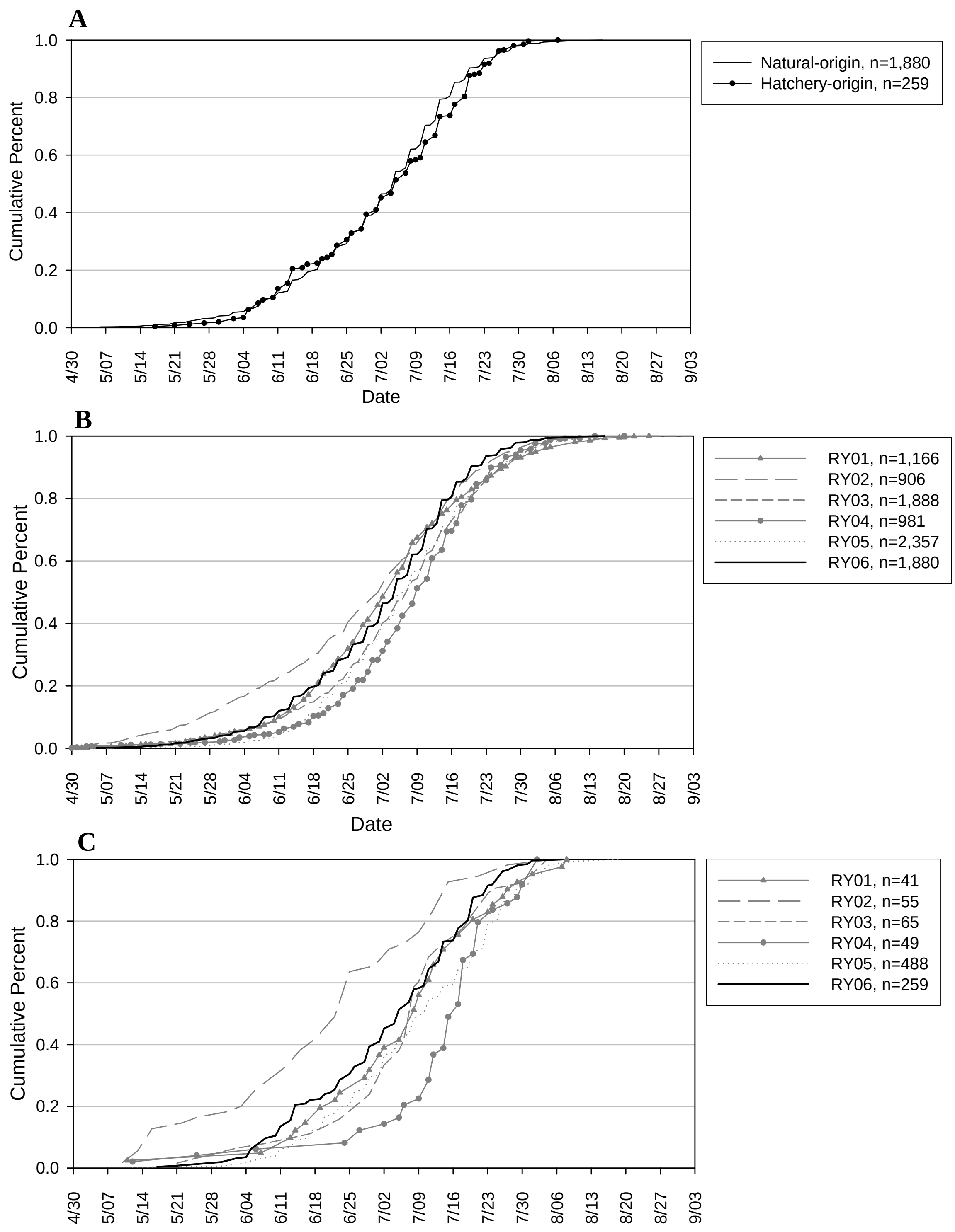


Figure 2. Temporal distribution of fresh, female Sacramento River winter Chinook salmon carcasses, **A**: natural-origin and hatchery-origin, return year 2006; **B**: natural-origin, return years 2001-2006; and **C**: hatchery-origin, return years 2001 – 2006.

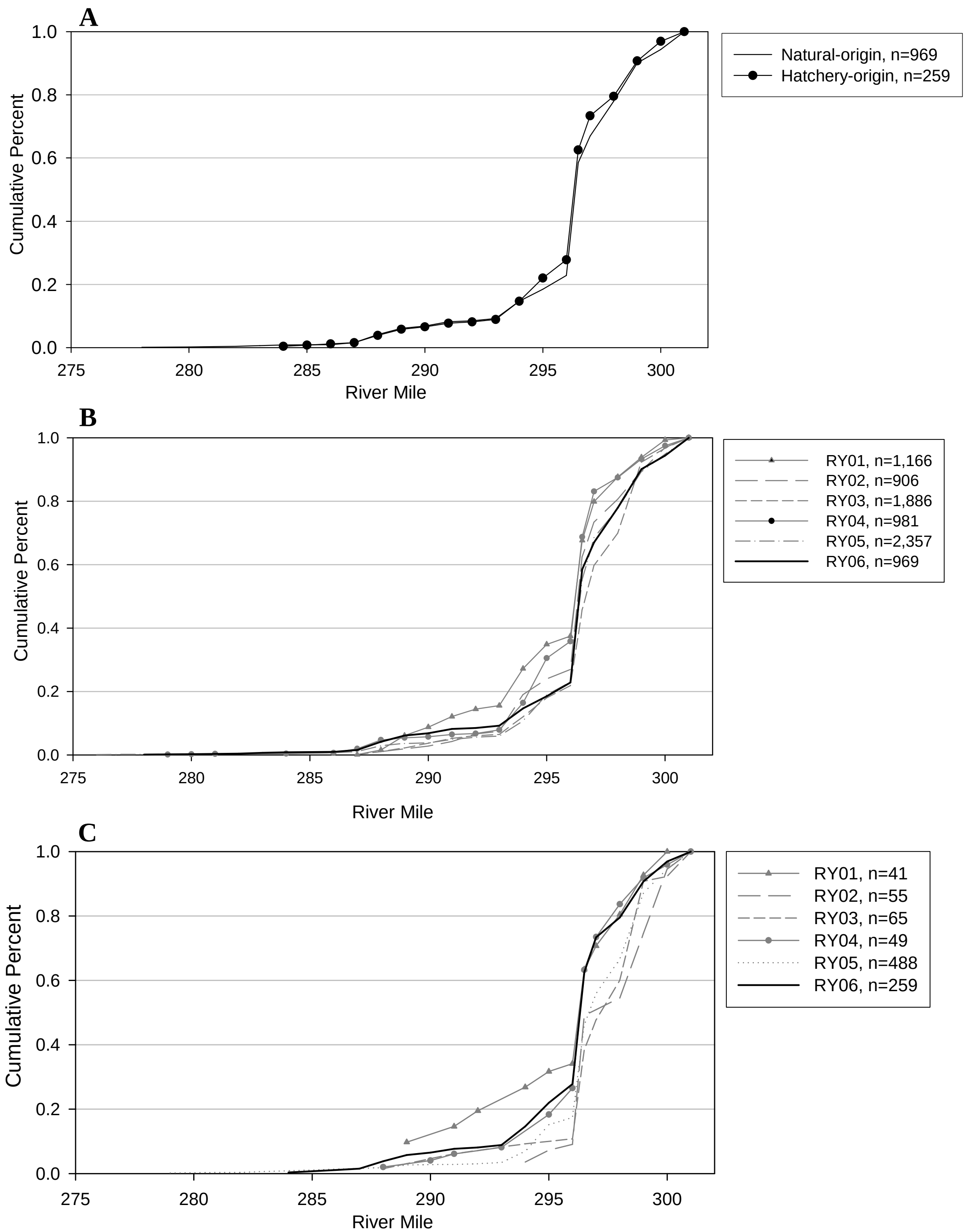
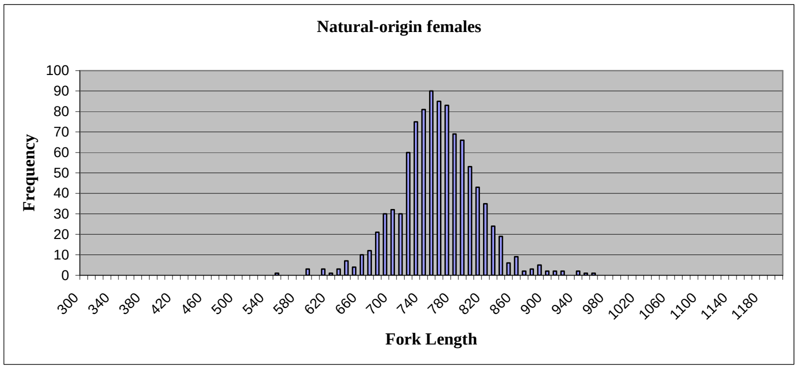


Figure 3. Spatial distribution of fresh, female Sacramento River winter Chinook salmon carcasses, **A**: natural-origin and hatchery-origin, return year 2006; **B**: natural-origin, return years 2001-2006, and **C**: hatchery-origin, return years 2001-2006.

A



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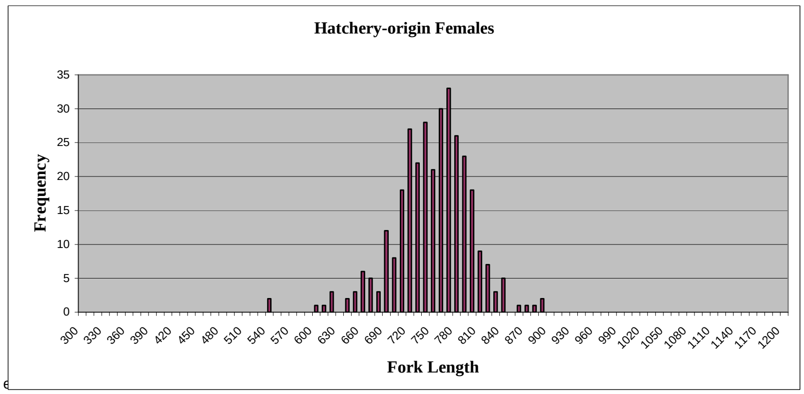

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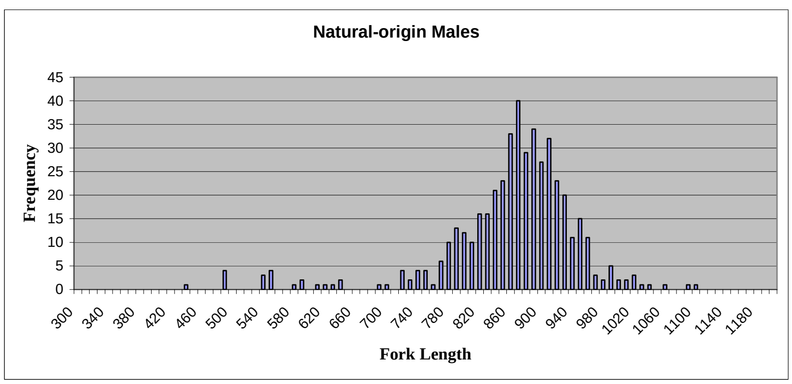

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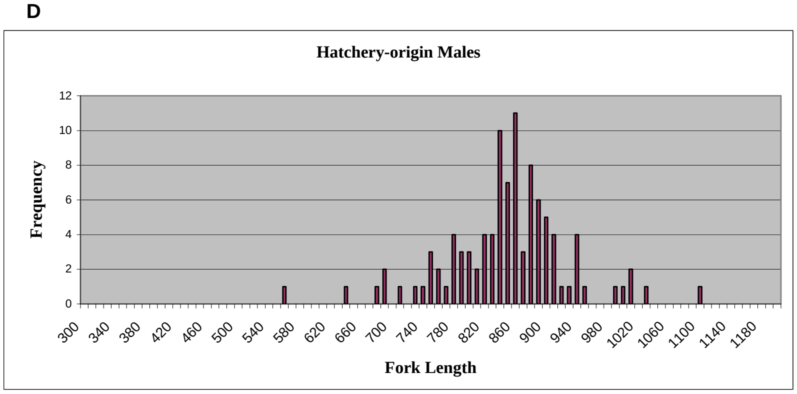

Figure 4. Length-frequency distributions of fresh winter Chinook salmon carcasses recovered in 2006, by origin: natural-origin females (A), hatchery-origin females (B), natural-origin males (C), and hatchery-origin males (D).

Table 3. Fork length (mm) of age two male Sacramento River winter Chinook salmon by origin, return years 2001 – 2006.

Return Year	Natural-origin Age 2 Male Fork Length[a]				Hatchery-origin Age 2 Male Fork Length			
	n	Avg	Min	Max	n	Avg	Min	Max
2001	162	563	400	690	24	539	390	650
2002	71	578	460	680	8	550	470	650
2003	54	524	440	650	10	518	420	580
2004	128	581	430	680	30	544	441	630
2005	116	557	410	662	35	550	450	645
2006	20	556	440	640	1[b]	.	540	540

[a]The maximum length of natural-origin age two males was estimated using length-frequency analysis.
[b] Non-fresh carcass.

Gender Ratio

As in previous surveys, substantially more female than male carcasses were recovered in 2006 (Table 4). Among natural-origin fish observed in 2006, females outnumbered males 2.58 to 1 and among hatchery-origin fish, females outnumbered males by 3.15 to 1.

Table 4. Gender ratio of Sacramento River winter Chinook salmon carcasses by origin, return years 2001 – 2006.

Return Year	Natural-origin			Hatchery-origin		
	Females (F)	Males (M)	F:M	Females (F)	Males (M)	F:M
2001	1,178	637	1.85	62	51	1.22
2002	927	335	2.77	82	22	3.73
2003	1,894	345	5.49	94	23	4.09
2004	969	351	2.76	73	47	1.55
2005	2,409	777	3.10	596	185	3.22
2006	1,905	738	2.58	321	102	3.15

Pre-spawning Mortality

The percentage of female carcasses recovered that were categorized as “not fully spawned” was low for natural-origin carcasses in 2006, but was the highest recorded for hatchery-origin carcasses (Table 5).

Table 5. Pre-spawning mortality of female Sacramento River winter Chinook salmon by origin, return years 2001 – 2006.

	Natural-origin			Hatchery-origin		
Return year	Total carcasses	Number not fully pawned[1]	Percent not fully spawned[1]	Total carcasses	Number not fully pawned[1]	Percent not fully pawned[1]
2001	1,178	10	0.85	62	0	0.00
2002	927	19	2.05	82	4	4.88
2003	1,894	11	0.58	94	0	0.00
2004	969	6	0.62	73	3	4.11
2005	2,409	34	1.41	596	22	3.69
2006	1905	25	1.31	321	23	7.17

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

Discussion

Return year 2006 was the largest return of winter Chinook salmon since 1981 (Killam 2006). Almost 7,700 carcasses were handled in 2006, accounting for about 45% of the total run. Hatchery origin fish represented approximately 14% of the total run.

The percentage of age two males returning was very low in 2006, 4% and 0.5%, for natural-origin and hatchery-origin winter Chinook, respectively. The average percentage of age two males returning for run years 2001 – 2005 was 24% for natural-origin males and 42% for hatchery-origin males. The number of fish returning at age two can provide an indication of the survival experienced by any given brood year. As such, the number of fish returning at age three, the predominant age group in any return of winter Chinook, may be substantially lower in 2007 than in recent years.

The percentage of hatchery-origin age four fish was much higher in 2006 than in previous years (USFWS 2001, 2002, 2003, 2004, 2005). This finding was reflected in the length-frequency histograms of hatchery-origin carcasses, which showed greater numbers of larger sized fish compared to previous years. The better representation of larger fish in the length-frequency histograms of hatchery-origin fish resulted in length-frequency distributions that were more similar to those of natural-origin fish than has been observed in the past (USFWS 2001, 2002, 2003, 2004, 2005). Assuming similar length-at-age of hatchery-origin and natural-origin fish, this suggests that the age composition of hatchery-origin returns in 2006 was more similar to that of natural-origin fish than in recent years, however, this hypothesis requires validation by aging of natural-origin adults. Return year 2006 completed the returns from brood year 2002, which had the highest survival rate of any of the hatchery-origin winter Chinook brood years to date.

Temporal and spatial distributions, and gender ratios, between natural-origin and hatchery-origin fish were similar, as in the past. Prespawning mortality was low for natural-origin fish, but higher than usual for hatchery-origin fish. There were no apparent differences in the temporal or spatial distributions of prespawning mortalities for natural-origin and hatchery-origin carcasses and the reason for the higher than usual prespawning mortality of hatchery-origin winter Chinook 2006 is not known.

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.

Hatchery Scientific Review Group, Washington Department of Fish and Wildlife, and the Northwest Indian Fisheries Commission. Technical Discussion Paper #1: Integrated hatchery programs. Puget Sound and Coastal Washington Hatchery Reform Project. Available: http://www.lltk.org/HRP.html (June 21, 2004).

Killam, D. S. 2006. Sacramento river winter-run Chinook salmon carcass survey summary report for years 1996-2006. SRSSAP Tech. Report No. 06-4, 2006.

National Marine Fisheries Service. 1997. Proposed recovery plan for the Sacramento River winter-run Chinook salmon. National Marine Fisheries Service – Southwest Region Office, Long Beach, California.

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.

University of California – Davis Bodega Marine Laboratory. 2001. Genetic maintenance of hatchery- and natural-origin winter-run Chinook salmon – Final Report. Cooperative agreement of University of California – Davis and U.S. Fish & Wildlife Service numbers 1448-11330-97-J194, 1448-11330-97-J045, and 1448-11330-97-J094. University of California – Davis, Bodega Marine Laboratory, Bodega Bay, California.

USFWS. 2001. Winter Chinook salmon carcass survey annual report. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California.

USFWS. 2002. Upper Sacramento River Winter Chinook salmon carcass survey 2002 annual report. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California.

USFWS. 2003. Upper Sacramento River Winter Chinook salmon carcass survey 2003 annual report. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California.

USFWS. 2004. Upper Sacramento River Winter Chinook salmon carcass survey 2004 annual report. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California.

USFWS. 2005. Upper Sacramento River Winter Chinook salmon carcass survey 2005 annual report. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Acknowledgements

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Appendix 1. Estimated escapement of hatchery-origin winter Chinook salmon in the upper Sacramento River, 2006.

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, and 4. to include hatchery-origin fish that did not have a clipped adipose fin. Descriptions of these expansions follow:

1. Expansion of non-fresh carcasses for decreased coded-wire tag recovery and fin clip recognition.

Non-fresh hatchery-origin carcass recoveries were expanded 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.

2. Expansion 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 naturally reproducing 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 ($N_{J\text{-}S}$):

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

where,
$H_{Unk\text{-}Obs}$ = 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).

3. 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}):

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

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

- Lastly, CWT_{Final} was summed to obtain the estimate of total hatchery-origin winter Chinook salmon (H_{Total}).

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

Data

427	=	$H_{F\text{-}Obs}$	=	Fresh hatchery carcass recoveries
4,607	=	$T_{NF\text{-}Obs}$	=	Non-fresh hatchery and natural carcass recoveries
3,084	=	$T_{F\text{-}Obs}$	=	Fresh hatchery and natural carcass recoveries
17,112	=	$N_{J\text{-}S}$	=	Naturally reproducing salmon escapement
5	=	H_{Unk}	=	Hatchery fish with unknown carcass condition
2	=	$LSNFH_H$	=	Hatchery fish retained for Livingston Stone NFH broodstoc
7,696	=	T_{Obs}	=	Total carcasses observed during the carcass survey

Appendix Table 1. Coded-wire tag codes recovered during the 2006 run year, by recovery location, with juvenile tag retention data. (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			
CWTCode	Survey	LSNFH	T/C	NT/C	T/NC	NT/NC
051276	2	0	194	6	0	0
051279	1	0	187	13	0	0
051280	1	0	192	8	0	0
051282	1	0	182	17	1	0
051285	1	0	181	19	0	0
051287	1	0	170	30	0	0
051291	1	0	195	5	0	0
051293	2	0	189	10	1	0
051294	2	0	191	9	0	0
051296	1	0	190	10	0	0
051297	2	0	187	13	0	0
051298	7	0	193	2	5	0
051364	1	0	181	19	0	0
051366	2	0	194	6	0	0
051370	1	0	196	1	3	0
051371	5	0	188	10	2	0
051372	1	1	195	4	1	0
051679	17	0	200	0	0	0
051696	1	0	591	108	2	0
051964	11	0	199	1	0	0
051965	19	0	196	4	0	0
051966	22	0	198	2	0	0
051967	19	0	199	1	0	0
051968	24	0	199	1	0	0
051969	17	0	196	3	1	0
051970	17	0	199	1	0	0
051971	19	0	199	1	0	0
051972	33	0	199	1	0	0
051973	20	0	200	0	0	0
051974	21	0	199	1	0	0
051975	23	0	200	0	0	0
051976	20	0	200	0	0	0
051977	15	0	199	1	0	0
051978	16	0	199	1	0	0
051979	15	0	200	0	0	0
051980	10	0	199	1	0	0
051981	11	1	198	2	0	0
051982	15	0	198	2	0	0
051983	16	0	197	3	0	0
051984	23	0	200	0	0	0
051985	7	0	200	0	0	0
051986	6	0	198	0	2	0
051987	18	0	198	2	0	0
051988	18	0	199	1	0	0
051989	12	0	199	1	0	0
051990	9	0	199	1	0	0
051991	21	0	198	2	0	0
051992	9	0	199	1	0	0
051993	40	0	199	1	0	0
051994	38	0	195	5	0	0
051995	52	0	198	2	0	0
051996	47	0	199	1	0	0
051997	49	0	195	5	0	0
	762	2				

Calculations

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

$$\left(\underset{427}{H_{F\text{-}Obs}} \times \underset{4{,}607}{T_{NF\text{-}Obs}}\right) / \underset{3{,}084}{T_{F\text{-}Obs}} = \underset{\mathbf{638}}{H_{NF\text{-}Exp}}$$

2. Expansion to include carcasses not observed

$$\left(\underset{637.8693}{H_{NF\text{-}Exp}} + \underset{427}{H_{F\text{-}Obs}} + \underset{5}{H_{Unk}}\right) / \underset{7{,}696}{T_{Obs}} \times \underset{17{,}112}{N_{J\text{-}S}} = \underset{\mathbf{2379}}{H_{Sac}}$$

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

$$\underset{2{,}379}{H_{Sac}} + \underset{2}{LSNFH_{H}} = \underset{\mathbf{2381}}{H_{Clip}}$$

Appendix Table 2. Estimated number of hatchery-origin winter Chinook salmon returning in 2006 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}
051276	:	2,380.8467	×	(	2	/	764	)	=	**6.2**
051279	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051280	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051282	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051285	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051287	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051291	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051293	:	2,380.8467	×	(	2	/	764	)	=	**6.2**
051294	:	2,380.8467	×	(	2	/	764	)	=	**6.2**
051296	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051297	:	2,380.8467	×	(	2	/	764	)	=	**6.2**
051298	:	2,380.8467	×	(	7	/	764	)	=	**21.8**
051364	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051366	:	2,380.8467	×	(	2	/	764	)	=	**6.2**
051370	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051371	:	2,380.8467	×	(	5	/	764	)	=	**15.6**
051372	:	2,380.8467	×	(	2	/	764	)	=	**6.2**
051679	:	2,380.8467	×	(	17	/	764	)	=	**53.0**
051696	:	2,380.8467	×	(	1	/	764	)	=	**3.1**
051964	:	2,380.8467	×	(	11	/	764	)	=	**34.3**
051965	:	2,380.8467	×	(	19	/	764	)	=	**59.2**
051966	:	2,380.8467	×	(	22	/	764	)	=	**68.6**
051967	:	2,380.8467	×	(	19	/	764	)	=	**59.2**
051968	:	2,380.8467	×	(	24	/	764	)	=	**74.8**
051969	:	2,380.8467	×	(	17	/	764	)	=	**53.0**
051970	:	2,380.8467	×	(	17	/	764	)	=	**53.0**
051971	:	2,380.8467	×	(	19	/	764	)	=	**59.2**
051972	:	2,380.8467	×	(	33	/	764	)	=	**102.8**
051973	:	2,380.8467	×	(	20	/	764	)	=	**62.3**
051974	:	2,380.8467	×	(	21	/	764	)	=	**65.4**
051975	:	2,380.8467	×	(	23	/	764	)	=	**71.7**
051976	:	2,380.8467	×	(	20	/	764	)	=	**62.3**
051977	:	2,380.8467	×	(	15	/	764	)	=	**46.7**
051978	:	2,380.8467	×	(	16	/	764	)	=	**49.9**
051979	:	2,380.8467	×	(	15	/	764	)	=	**46.7**
051980	:	2,380.8467	×	(	10	/	764	)	=	**31.2**
051981	:	2,380.8467	×	(	12	/	764	)	=	**37.4**
051982	:	2,380.8467	×	(	15	/	764	)	=	**46.7**
051983	:	2,380.8467	×	(	16	/	764	)	=	**49.9**
051984	:	2,380.8467	×	(	23	/	764	)	=	**71.7**
051985	:	2,380.8467	×	(	7	/	764	)	=	**21.8**
051986	:	2,380.8467	×	(	6	/	764	)	=	**18.7**
051987	:	2,380.8467	×	(	18	/	764	)	=	**56.1**
051988	:	2,380.8467	×	(	18	/	764	)	=	**56.1**
051989	:	2,380.8467	×	(	12	/	764	)	=	**37.4**
051990	:	2,380.8467	×	(	9	/	764	)	=	**28.0**
051991	:	2,380.8467	×	(	21	/	764	)	=	**65.4**
051992	:	2,380.8467	×	(	9	/	764	)	=	**28.0**
051993	:	2,380.8467	×	(	40	/	764	)	=	**124.7**
051994	:	2,380.8467	×	(	38	/	764	)	=	**118.4**
051995	:	2,380.8467	×	(	52	/	764	)	=	**162.0**
051996	:	2,380.8467	×	(	47	/	764	)	=	**146.5**
051997	:	2,380.8467	×	(	49	/	764	)	=	**152.7**
										2,381

Appendix Table 3. Estimated number of hatchery-origin winter Chinook salmon returning in 2006 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}
051276	:	6.2326	/ (	200	/	200	)	=	**6.2**
051279	:	3.1163	/ (	200	/	200	)	=	**3.1**
051280	:	3.1163	/ (	200	/	200	)	=	**3.1**
051282	:	3.1163	/ (	199	/	200	)	=	**3.1**
051285	:	3.1163	/ (	200	/	200	)	=	**3.1**
051287	:	3.1163	/ (	200	/	200	)	=	**3.1**
051291	:	3.1163	/ (	200	/	200	)	=	**3.1**
051293	:	6.2326	/ (	199	/	200	)	=	**6.3**
051294	:	6.2326	/ (	200	/	200	)	=	**6.2**
051296	:	3.1163	/ (	200	/	200	)	=	**3.1**
051297	:	6.2326	/ (	200	/	200	)	=	**6.2**
051298	:	21.8140	/ (	195	/	200	)	=	**22.4**
051364	:	3.1163	/ (	200	/	200	)	=	**3.1**
051366	:	6.2326	/ (	200	/	200	)	=	**6.2**
051370	:	3.1163	/ (	197	/	200	)	=	**3.2**
051371	:	15.5815	/ (	198	/	200	)	=	**15.7**
051372	:	6.2326	/ (	199	/	200	)	=	**6.3**
051679	:	52.9770	/ (	200	/	200	)	=	**53.0**
051696	:	3.1163	/ (	699	/	701	)	=	**3.1**
051964	:	34.2792	/ (	200	/	200	)	=	**34.3**
051965	:	59.2095	/ (	200	/	200	)	=	**59.2**
051966	:	68.5584	/ (	200	/	200	)	=	**68.6**
051967	:	59.2095	/ (	200	/	200	)	=	**59.2**
051968	:	74.7910	/ (	200	/	200	)	=	**74.8**
051969	:	52.9770	/ (	199	/	200	)	=	**53.2**
051970	:	52.9770	/ (	200	/	200	)	=	**53.0**
051971	:	59.2095	/ (	200	/	200	)	=	**59.2**
051972	:	102.8376	/ (	200	/	200	)	=	**102.8**
051973	:	62.3258	/ (	200	/	200	)	=	**62.3**
051974	:	65.4421	/ (	200	/	200	)	=	**65.4**
051975	:	71.6747	/ (	200	/	200	)	=	**71.7**
051976	:	62.3258	/ (	200	/	200	)	=	**62.3**
051977	:	46.7444	/ (	200	/	200	)	=	**46.7**
051978	:	49.8607	/ (	200	/	200	)	=	**49.9**
051979	:	46.7444	/ (	200	/	200	)	=	**46.7**
051980	:	31.1629	/ (	200	/	200	)	=	**31.2**
051981	:	37.3955	/ (	200	/	200	)	=	**37.4**
051982	:	46.7444	/ (	200	/	200	)	=	**46.7**
051983	:	49.8607	/ (	200	/	200	)	=	**49.9**
051984	:	71.6747	/ (	200	/	200	)	=	**71.7**
051985	:	21.8140	/ (	200	/	200	)	=	**21.8**
051986	:	18.6977	/ (	198	/	200	)	=	**18.9**
051987	:	56.0932	/ (	200	/	200	)	=	**56.1**
051988	:	56.0932	/ (	200	/	200	)	=	**56.1**
051989	:	37.3955	/ (	200	/	200	)	=	**37.4**
051990	:	28.0466	/ (	200	/	200	)	=	**28.0**
051991	:	65.4421	/ (	200	/	200	)	=	**65.4**
051992	:	28.0466	/ (	200	/	200	)	=	**28.0**
051993	:	124.6517	/ (	200	/	200	)	=	**124.7**
051994	:	118.4191	/ (	200	/	200	)	=	**118.4**
051995	:	162.0472	/ (	200	/	200	)	=	**162.0**
051996	:	146.4657	/ (	200	/	200	)	=	**146.5**
051997	:	152.6983	/ (	200	/	200	)	=	**152.7**
						H_{Final}		=	**2,382**