ESTIMATING RECRUITMENT FOR FALL-RUN CHINOOK SALMON POPULATIONS IN THE STANISLAUS, TUOLUMNE, AND MERCED RIVERS

CARL MESICK
Energy and Instream Flow Branch
U.S. Fish and Wildlife Service
2800 Cottage Way, Suite W-2605
Sacramento, California 95825

DEAN MARSTON
Central Region
California Department of Fish and Game
1234 E. ShawAve
Fresno, CA 93710

And

TIM HEYNE
Tuolumne River Restoration Center
California Department of Fish and Game
P.O. Box 10
La Grange, CA 95329

26 August 2009

ABSTRACT

We discuss the methods used to estimate recruitment for fall-run Chinook salmon, *Oncorhynchus tshawytscha*, populations for the Stanislaus, Tuolumne, and Merced rivers in the San Joaquin River Basin (SJRB). We identify data sets of accurate escapement and Age 2 abundance estimates for the Stanislaus and Merced Rivers from 1985 to 2007 and for the Tuolumne River from 1981 to 2007. We use coded-wire-tagged (CWT) recovery data for adult hatchery fall-run Chinook salmon in the Central Valley to test a new method to deconvolve the escapement estimates back into cohorts and to estimate age-specific harvest related ocean mortality for the Central Valley. Our new Age Ratio Method computes the abundance of Age 3 and older salmon for years without scale data by multiplying a multi-year average of ratios of the abundance of known age salmon in the same cohort (e.g., ratio of Age 3 abundance to Age 2 abundance) by the abundance of Age 2 salmon and then adjusting the estimates for each age equally so that the sum of the computed abundance of each age of fish equals the escapement estimate. The Age Ratio Method is shown to be fairly robust at estimating the abundances of Age 3 and older salmon aged with scale analyses as long as the escapement and Age 2 estimates are relatively accurate. Age data from either CWT analyses or scale analyses are needed from at least one river within a basin where the percentages of Age 2 salmon in the escapement are similar between the rivers. We also computed age-specific ocean harvest rates for the commercial troll and sport fisheries based on all Central Valley CWT recoveries. Based on these new methods and data, we present empirically based estimates of adult

recruitment and Age-3-spawner equivalents that we use in our SJRB salmon population trend analyses.

EXECUTIVE SUMMARY

In this paper, we discuss the methods used to estimate recruitment for fall-run Chinook salmon, *Oncorhynchus tshawytscha*, populations for the Stanislaus, Tuolumne, and Merced Rivers in the San Joaquin River Basin (SJRB). We identify data sets of accurate escapement and Age 2 abundance estimates for the Stanislaus and Merced Rivers from 1985 to 2007 and for the Tuolumne River from 1981 to 2007. We use coded-wire-tagged (CWT) recovery data for adult hatchery fall-run Chinook salmon in the Central Valley to test a new method to deconvolve the escapement estimates back into cohorts and to estimate age-specific harvest related ocean mortality for the Central Valley. Based on these new methods and data, we present empirically based estimates of adult recruitment and Age-3-spawner equivalents that we use in our SJRB salmon population trend analyses.

We establish criteria to identify accurate escapement estimates based on whether mark-recapture surveys were conducted for the majority of the spawning period, which typically occurred from early November through mid December, and whether at least 10% of the marked fish were recovered. We also provide evidence that accurate estimates of Age 2 abundance required a combination of length-frequency and scale analysis. The 61-cm (24-inch) criterion that the California Department of Fish and Game (CDFG) used to

distinguish Age 2 fish from the older adults until 1989 was not always accurate for SJRB fish.

The deconvolution process segregates adult fish in each escapement back into cohorts (aka: broods) of fish. The CDFG typically collects length-frequency data since the early 1980s that can be used to determine the abundance of Age 2 salmon in the escapement but cannot be used to segregate the Age 3, Age 4, and Age 5 fish. The CDFG has analyzed scale samples to provide age composition data for the Age 3 and older fish for some years in the San Joaquin River Basin. Our new Age Ratio Method computes the abundance of Age 3 and older salmon for years without scale data by multiplying a multi-year average of ratios of the abundance of known age salmon in the same cohort by the abundance of Age 2 salmon. For example, the CDFG estimated number of Age 2 salmon in the Tuolumne River in fall 2005 was 143 fish. The mean ratio of the abundance of Age 3 fish to Age 2 fish (Age 3:2 ratio) is 1.442 for the Merced River CWT fish. Using the Age Ratio Method, the estimated number of Age 3 fish in fall 2006 is 206 fish (143 * 1.442). The Age Ratio Method estimates are adjusted equally for Age 3, Age 4, and Age 5 fish so that the sum of the computed abundances of each age equals the CDFG escapement estimate. We show that the age ratios and the Age Ratio Method abundance estimates for the Merced River Hatchery CWT population are not significantly different from the scale-based age estimates for the Tuolumne River. Therefore, we use the Merced River Hatchery CWT age ratios to estimate the abundance of Age 3 and older fish on the Stanislaus, Tuolumne, and Merced Rivers during years when there is no scale-based age data.

To estimate recruitment, it is necessary to know age-specific ocean harvest rates. Based on CWT recovery rates, the sport fishery primarily takes Age 2 salmon whereas the commercial troll fish primarily takes Age 3 and older salmon. The Central Valley Index of ocean harvest (CVI) does not provide age-specific ocean harvest rates and so using the CVI requires the assumption that the percentage of each age taken in the sport and troll fisheries remains constant each year. Furthermore, there is also concern that ocean mortality rates might be higher for the Merced River Hatchery fish compared to the Sacramento River Basin fish because the percentages of Age 3 and older fish are substantially lower for the Merced River Hatchery CWT fish compared to the CWT salmon produced at the Coleman National Fish Hatchery or the Feather River Hatchery. Our analyses indicated that there were significant differences in ocean harvest rates between the CWT based estimates and the CVI estimates but not between the CWT based estimates. The mean estimates for the Merced River Hatchery fish were lowest at 38.5% and highest for the CVI at 59.3%. However, the Sacramento River Basin CWT estimates for the Feather River Hatchery and Coleman National Fish Hatchery produced salmon were not significantly different than those for the Merced River Hatchery salmon ($P > 0.166$). Therefore, we computed age-specific ocean harvest rates for the commercial troll and sport fisheries based on all Central Valley CWT recoveries for the purpose of estimating SJRB recruitment.

We suggest that empirically based recruitment estimates can be accurately computed by using accurate escapement estimates, accurate age 2 abundance estimates, our new Age Ratio Method to deconvolve fall-run Chinook salmon escapement estimates into cohorts, and age-specific ocean harvest estimates based on Central Valley CWT recovery data. The Age Ratio Method is shown to be fairly robust at estimating the abundances of Age 3 and older salmon as long as the escapement and Age 2 estimates are relatively accurate. Our results show that the age ratios (e.g., ratio of Age 3 abundance to Age 2 abundance) are relatively consistent within a river basin but that they significantly differ between the Sacramento and San Joaquin River basins. Therefore, age data from either CWT analyses or scale analyses are needed from at least one river within a basin where the percentages of Age 2 salmon in the escapement are similar between the rivers. We also believe that CWT inland and ocean recovery data provide accurate age-specific estimates of sport and commercial troll harvest rates. Such ocean harvest estimates are important for estimating recruitment, because the sport harvest primarily takes Age 2 salmon whereas the commercial troll harvest primarily takes Age 3 and older salmon and there can be considerable variation in the age-related harvest rates over time.

INTRODUCTION

In this paper, we discuss the methods used to estimate recruitment for fall-run Chinook salmon, *Oncorhynchus tshawytscha*, populations for the Stanislaus, Tuolumne, and Merced Rivers in the San Joaquin River Basin (SJRB, Fig. 1). Accurate recruitment estimates are needed to evaluate the relative influence of various environmental factors that affect the survival of eggs and juvenile salmon at the population level. Recruitment is defined as the number of adult salmon in the same cohort that survive to Age 2 including those that returned to spawn in the escapement, harvested in the ocean, or died of natural causes before they could return to spawn (Ricker 1975). A cohort is defined as the fish from the same brood of juvenile salmon that returned in the escapement as adults over a four year period: some as Age 2, Age 3, Age 4, and Age 5 fish.

An empirical method for estimating recruitment is to deconvolve or segregate the escapement estimates into cohorts using age composition data and then to adjust the estimate of cohort abundance with estimates of ocean harvest and natural mortality rates in the ocean. However the data needed to estimate recruitment, which include (1) a continuous series of accurate escapement estimates, (2) age composition data necessary to deconvolve the escapement estimates into cohorts, (3) harvest related ocean mortality by age, and (4) natural mortality rates in the ocean by age are limited, and so there has been little confidence in the past recruitment estimates.

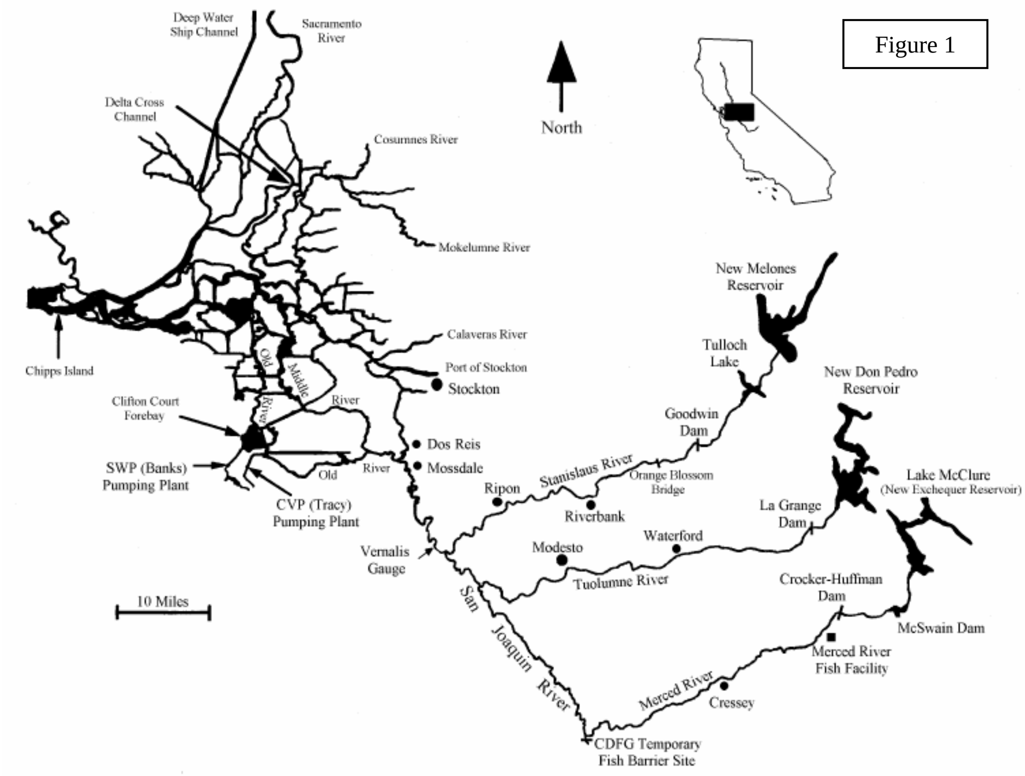

Figure 1

We use recently computed abundance estimates of coded-wire-tagged (CWT) adult hatchery fall-run Chinook salmon in the Central Valley escapement (Mesick et al. 2009) to test a new method to deconvolve the escapement estimates back into cohorts and to estimate harvest related ocean mortality for the Central Valley. Estimates of the CWT hatchery salmon provide estimates of known aged fish as well as abundance estimates of the numbers landed in the commercial and sport ocean fisheries. Based on these new data, we present empirically based estimates of adult recruitment and Age-3-spawner equivalents (a.k.a., stock) that we use in our SJRB salmon population trend analyses. We use an Age-3-spawner equivalent estimate to better reflect the fecundity of the spawner population rather than simply use escapement abundance.

The following reviews the difficulties involved with recruitment estimates, which include (1) accuracy of escapement estimates, (2) cohort segregation and age analyses, (3) harvest related ocean mortality, and (4) natural mortality rates in the ocean.

Escapement Estimates History

The foundation for conducting a population trend analysis is a long-term set of relatively accurate and consecutive estimates of escapement. The California Department of Fish and Game (CDFG) has conducted escapement (aka: carcass) surveys in the Stanislaus, Tuolumne, and Merced Rivers since 1940 (Fry 1961). The following methods have been used by CDFG in the SJRB to estimate escapement:

1. Marking live fish and recovering carcasses in the Stanislaus River during 1947 and 1948 (Fry 1961);
2. Visual counts in the Tuolumne River at the Modesto Dam fish ladder from 1940 to 1944 and in the Stanislaus River in 1940 and 1941 at a "lightly constructed" weir (Fry 1961);
3. Extrapolation of the counts of spawning salmon, carcasses, and redds at the spawning areas based on the expertise of the Department of Fish and Game biologists was done between 1950 and 1972 (Fry 1961). Typically, a single crew worked all three SJB tributaries and so only 3 to 8 surveys were made in each river each year. All fish collected were chopped in half to mark that they had been counted and then the counts were expanded with mark-recapture efficiency data

from other rivers in the Sacramento Basin. Fry (1961) believed that these estimates were conservative and usually underestimated the actual run size.

4. A weir built across the Stanislaus River near the Orange Blossom Bridge for trapping adult salmon between 1965 and 1974; the eggs were reared at the Moccasin Creek Hatchery and the juveniles were released in the Stanislaus, Tuolumne, and/or Merced rivers[i]. The trapped adult fish were included in the visual counts made between 1965 1972 and the carcass surveys in 1973 and 1974.
5. Carcass tag-and-recovery sampling was initiated in 1973 in all three rivers. Typically, all observed carcasses were collected and identified as fresh, decayed, or skeleton. The fresh carcasses have at least one clear eye, the decayed carcasses have cloudy eyes, and the skeletons are in an advanced state of decay. Typically only the fresh and decayed carcasses were tagged; whereas in some cases, only carcasses longer than 61 cm and/or fresh fish were tagged or used to estimate escapement. The skeletons have a relatively low chance of recovery and so they were not tagged but chopped in half to mark that they had been counted. Estimates were usually generated with both the Schaefer (1951) and Jolly-Seber (Seber 1973) models; whereas the Peterson (Ricker 1975) method was used when escapements were low. The estimate judged to be the most accurate based on the number of carcasses tagged and recovered is reported by CDFG in their GrandTab file, which is available at http://www.calfish.org/IndependentDatasets/CDFGFisheriesBranch/tabid/157/Default.aspx

6. An experimental resistance board counting weir was used on the Stanislaus River at Ripon (rkm 50.6) by Cramer Fish Sciences from 2003 through 2007 and continued by Fishbio in fall 2007. The weir employed the Vaki RiverWatcher technology which includes an infrared scanner and digital camera. Studies on other rivers have suggested that the RiverWatcher technology is at least 95% accurate for estimating Pacific salmon escapement (Anderson et al. 2007); whereas the accuracy of the Stanislaus weir estimates also depends on whether adult salmon could go over or under the weir and bypass the live trap with the Riverwatcher scanners. The differences between the weir and the carcass survey estimates were less than 20% from 2002 through 2004 and in 2007; whereas the weir counts were 2.9 and 1.6 times higher than the carcass estimates in 2005 and 2006, respectively (Table 1). One feature of the RiverWatcher technology is that the length of the adult salmon is estimated from an infrared measurement of the maximum body depth. This measurement is multiplied by a mean ratio of the length to body depth for males and females combined. This method tends to overestimate the lengths of females and underestimates the lengths of males.

The carcass tag-and recovery surveys conducted provide the most reliable estimates needed for a time series trend analysis (Table 2). Typically, most salmon were tagged and recaptured during the six week period from early November through mid December (CDFG 2001-2008) and we assume that at least 6 weekly surveys and a tag recovery rate

Table 1. Comparison of fall-run Chinook salmon escapement estimates based on weir counts through 31 December and carcass surveys for the Stanislaus River from 2003 through 2007.

Year	Weir Count	Carcass Estimate
2003	4,834	5,902
2004	4,404	4,068
2005	4,121	1,427
2006	3,023	1,923
2007	408	443

Table 2. The number of weekly surveys and the percentage of tags recovered during the mark-recapture carcass surveys for the Stanislaus, Tuolumne and Merced Rivers from 1973 to 2007. NT indicates that no carcasses were tagged and NR indicates that the data were not reported.

	Stanislaus River		Tuolumne River		Merced River	
Year	#Surveys	%Recovered	#Surveys	%Recovered	#Surveys	%Recovered
1973	4	1.4%	6	13.0%	5	8.3%
1974	3	6.3%	6	8.3%	5	5.2%
1975	4	16.0%	5	6.4%	6	13.4%
1976	3	14.9%	6	18.5%	5	27.6%
1977	1	NT	3	NT	3	NT
1978	3	0.0%	5	5.7%	5	26.1%
1979	6	36.4%	6	26.7%	6	14.0%
1980	4	0.0%	6	63.8%	7	20.5%
1981	2	NT	7	50.3%	NR	30.9%
1982	1	NT	4	42.0%	3	34.9%
1983	1	NT	4	9.3%	5	13.8%
1984	8	9.9%	5	29.0%	7	14.1%
1985	7	27.5%	8	30.5%	6	37.7%
1986	6	11.8%	6	37.7%	6	31.4%
1987	7	40.9%	7	43.9%	6	22.4%
1988	8	45.4%	9	60.3%	8	46.0%
1989	9	61.3%	9	58.6%	11	52.1%
1990	8	57.1%	10	48.3%	10	69.2%
1991	7	29.5%	6	58.3%	11	16.7%
1992	8	37.1%	6	55.3%	8	35.2%
1993	9	13.8%	5	56.5%	12	43.9%
1994	8	35.3%	10	57.1%	9	46.3%
1995	9	20.4%	10	49.0%	10	13.4%
1996	9	0.0%	7	30.2%	6	38.1%
1997	8	14.5%	11	20.4%	10	35.1%
1998	7	14.7%	10	29.9%	10	40.1%
1999	9	46.6%	13	59.0%	10	51.2%
2000	10	12.3%	14	41.7%	12	11.9%
2001	10	15.7%	14	61.2%	12	40.6%
2002	13	63.7%	14	64.4%	15	49.5%
2003	17	32.1%	15	55.0%	14	74.0%
2004	14	52.8%	14	63.6%	14	66.2%
2005	13	41.5%	9	46.0%	13	47.2%
2006	13	33.5%	13	23.1%	13	45.5%
2007	13	15.8%	13	42.9%	13	30.2%

of at least 10% were necessary for an accurate escapement estimate. Confidence intervals have not been computed for the SJB escapement estimates.

Hatchery Fish and Naturally Produced Fish in the Escapement

The escapement estimates for the Stanislaus, Tuolumne, and Merced Rivers contain a mixture of naturally produced salmon and salmon reared in Central Valley hatcheries located in the Merced River, Battle Creek, Feather River, American River, and the Mokelumne River. Only a small portion of the hatchery fish were marked with coded-wire-tags (CWT) and it is not possible to distinguish unmarked hatchery fish from naturally produced fish based on external characteristics alone. Our cohort and recruitment estimates reported here include both natural and hatchery produced salmon.

Cohort Deconvolution

To estimate recruitment, escapement estimates must be deconvolved into cohorts. A cohort is defined as a group of fish that were all produced during the same spawning period. We use the term “cohort” here, because the more commonly used term “brood year” is identified with the year when spawning occurred. Instead, our population trend analysis focuses on the rearing period and so we identify the estimates during the year when the juveniles were present. For example, fish in the brood year 2000 were deposited as eggs in fall 2000 and most of the fish emerged from the gravel in January and February

2001. These fish could be identified as “Brood Year 2000”, whereas we identify these fish as “Recruitment 2001” or “Cohort 2001”.

In our discussion below, we use a single numeral to identify age. Salmon are considered to be Age 0 when deposited as eggs during the fall. An Age 2 fish that returns to spawn has completed its first year of life after emergence from the gravel and it will have lived for 1.5 to 2.0 years between the time it was deposited as an egg to the time of harvest or spawning. Male and female Age 2 fish are also called “jacks” and “jills” respectively or “grilse” collectively. Chinook salmon in the Central Valley between 1947 and 1951 have been reported to live up to Age 6 (Reisenbichler 1986).

Segregation of escapement into cohorts is accomplished with the following equation:

$$\text{Cohort}_{\text{(year 1)}} = \text{Age 2}_{\text{(year 2)}} + \text{Age 3}_{\text{(year 3)}} + \text{Age 4}_{\text{(year 4)}} + \text{Age 5}_{\text{(year 5)}}$$

For example, to estimate cohort abundance for the spring of 1980 (year 1 in the above equation), the abundance of Age 2s in fall 1981, Age 3s in fall 1982, Age 4s in fall 1983, and Age 5s in fall 1984 are summed.

Methods for Aging Fish

There are three generally accepted approaches for aging fish: (1) length-frequency distributions, (2) recapturing fish that were tagged as juveniles and (3) examination of growth rings in hard body structures, such as scales and otoliths (Jearld 1983).

Age 2 Fish

CDFG began estimating the abundance of Age 2 fish in the Tuolumne, Stanislaus, and Merced Rivers in 1951 based on the assumption that all Age 2 fish were smaller than 61.0 cm (24 inches) in length. However, scale and length-frequency analyses indicate that the nadir that separates the Age 2 fish from the older fish is a mean of about 64.0 cm (25.2 inches) for females and a mean of 69.7 cm (27.4 inches) for males in the SJRB from 1981 to 2005. CDFG continued to report the 61-cm criterion estimates as well as collect the length-frequency data for Tuolumne River between 1981 and 1988 and the Stanislaus River between 1984 and 1988. Based on these comparisons, the scale and length-frequency estimates averaged about 12% and 8% higher than the 61-cm criterion estimates for the Stanislaus and Tuolumne Rivers, respectively (Table 3).

Age 3 and Older Fish

The component of escapement that is typically classified as "adults" by CDFG consists of Age 3, 4, and 5 fish. Our analysis of CWT juvenile hatchery fish that were reared in the Central Valley hatcheries and recovered in the Central Valley escapement for brood years 1980 to 2003 (Mesick et al. 2009) suggests that most adults are Age 3, but there are large percentages of Age 4 and 5 fish in the Central Valley rivers during some years (Table 4). The Merced River Hatchery fish also have a substantially different age composition compared to the fish produced at the Coleman National Fish Hatchery and the Feather River Hatchery (Table 4). Previously, the lack of age data to segregate the Age 3 fish from

Table 3. CDFG estimates of the percentage of Age 2 fish in the Stanislaus and Tuolumne Rivers between 1981 and 1988 using the criterion that all Age 2 fish were smaller than 61-cm and the scale and length-frequency (Scale-LF) data provided by CDFG.

	Stanislaus River		Tuolumne River	
Year	61-cm Criterion	Scale-LF	61-cm Criterion	Scale-LF
1981	--	--	32%	79%
1982	--	--	5%	10%
1983	--	--	82%	76%
1984	--	--	52%	62%
1985	9%	16%	4%	8%
1986	17%	22%	7%	9%
1987	36%	68%	93%	93%
1988	4%	9%	5%	10%
Mean	16.5%	28.8%	35.0%	43.4%

Table 4. Age composition data based on the CDFG Inland Recovery Summary Tables of coded-wire-tagged (CWT) adult salmon recovered from all Central Valley rivers for fall-run Chinook salmon produced at the Coleman National Fish Hatchery, Feather River Hatchery, and the Merced River Hatchery for run years 1980 to 2007 (Mesick et al. 2009). A few Age 6 Feather River Hatchery and Merced River Hatchery salmon were collected in fall 1986 and 1991, respectively.

	Coleman National Fish Hatchery				Feather River Hatchery				Merced River Hatchery			
Run Year	Age 2	Age 3	Age 4	Age 5	Age 2	Age 3	Age 4	Age 5	Age 2	Age 3	Age 4	Age 5
1980	--	--	--	--	3.0%	92.1%	4.8%	0.00%	21.5%	78.5%	0.0%	0.00%
1981	--	--	--	--	78.6%	11.3%	10.1%	0.00%	0.0%	93.9%	6.1%	0.00%
1982	70.5%	29.5%	0.0%	0.00%	9.3%	89.9%	0.8%	0.00%	94.6%	0.0%	5.4%	0.00%
1983	53.6%	45.6%	0.8%	0.00%	4.0%	59.9%	36.1%	0.00%	96.8%	3.2%	0.0%	0.00%
1984	0.1%	96.3%	3.6%	0.00%	3.5%	65.9%	30.6%	0.00%	12.5%	85.2%	2.3%	0.00%
1985	36.5%	5.3%	58.2%	0.00%	3.5%	34.5%	61.0%	1.04%	28.7%	48.8%	22.5%	0.00%
1986	4.3%	91.5%	3.4%	0.76%	44.8%	31.9%	22.4%	0.81%	37.9%	54.0%	8.1%	0.00%
1987	53.8%	29.3%	16.9%	0.00%	42.8%	49.7%	7.2%	0.27%	88.3%	11.1%	0.6%	0.00%
1988	3.9%	93.4%	2.2%	0.51%	5.4%	89.4%	4.6%	0.59%	10.6%	89.2%	0.2%	0.00%
1989	7.8%	42.3%	49.7%	0.12%	22.9%	39.1%	37.7%	0.30%	2.1%	66.0%	32.0%	0.00%
1990	4.9%	79.7%	15.0%	0.41%	22.8%	60.9%	15.3%	0.98%	23.8%	9.4%	63.7%	3.07%
1991	0.3%	52.0%	47.7%	0.00%	4.5%	82.1%	13.2%	0.17%	0.0%	39.9%	23.4%	0.00%
1992	51.8%	29.6%	18.3%	0.32%	38.2%	52.0%	9.5%	0.25%	91.0%	1.7%	7.3%	0.00%
1993	13.3%	83.6%	3.1%	0.00%	8.1%	77.3%	14.5%	0.14%	63.4%	36.6%	0.0%	0.00%
1994	43.5%	34.1%	22.4%	0.00%	24.3%	45.0%	30.1%	0.67%	1.6%	89.0%	9.4%	0.00%
1995	2.9%	92.7%	4.3%	0.00%	36.0%	62.5%	1.4%	0.10%	96.7%	2.2%	1.1%	0.00%
1996	18.3%	29.4%	52.3%	0.00%	17.8%	74.3%	7.9%	0.05%	62.0%	38.0%	0.0%	0.00%
1997	89.0%	9.3%	1.7%	0.05%	18.3%	56.9%	24.8%	0.00%	15.6%	75.1%	9.3%	0.00%
1998	11.2%	88.1%	0.7%	0.00%	6.0%	77.5%	15.8%	0.72%	60.3%	16.8%	22.5%	0.36%
1999	18.3%	58.4%	23.3%	0.01%	27.7%	27.3%	44.6%	0.42%	31.5%	67.4%	1.0%	0.13%
2000	2.3%	55.7%	39.9%	2.10%	10.2%	84.6%	4.5%	0.72%	29.4%	62.9%	7.7%	0.00%
2001	16.0%	47.3%	36.7%	0.00%	0.8%	54.3%	44.9%	0.05%	50.4%	46.7%	2.9%	0.00%
2002	5.8%	72.3%	21.1%	0.77%	61.3%	16.5%	22.2%	0.01%	26.5%	66.4%	7.1%	0.00%
2003	8.4%	30.6%	61.0%	0.09%	7.6%	88.5%	3.8%	0.05%	22.1%	63.9%	14.0%	0.00%
2004	0.1%	73.3%	25.4%	1.12%	14.2%	38.7%	46.9%	0.19%	33.2%	51.8%	14.7%	0.30%
2005	1.1%	8.1%	88.6%	2.11%	5.6%	87.0%	6.9%	0.54%	14.2%	73.7%	11.5%	0.57%
2006	1.1%	92.6%	4.5%	1.87%	1.2%	71.9%	27.0%	0.00%	24.3%	60.4%	15.4%	0.00%
2007	0.4%	6.4%	93.3%	0.00%	3.6%	33.8%	62.6%	0.00%	19.3%	60.7%	20.0%	0.00%
Mean	20.0%	52.9%	26.7%	0.39%	18.8%	59.1%	21.8%	0.29%	37.8%	49.7%	11.0%	0.16%

older fish in the adult escapement estimates individual rivers had been approached in three different ways.

Previous Method 1 - Many researchers, including CDFG (1972, 1987), CMC (1994, 1996), Baker and Morhardt (2001), and SJRGA (2003), simply assumed that almost all of the fish in the SJRB adult escapement are Age 3. However, ignoring that an average of 11% of SJRB escapement was Age 4 and older fish (Table 4) may result in an underestimate of recruitment in years when juvenile survival was high, such as those that occurred during spring flooding, and overestimates for the drier years immediately following the floods.

Previous Method 2 - Reisenbichler (1986) used two sets of age composition data to segregate all the SJRB escapement estimates into cohorts. First, he used age composition data from 1,200 adult Chinook salmon collected in the San Joaquin Delta gill net fishery between 1947 and 1951 to estimate the percentages of Age 3 and Age 4 fish in 1945 and earlier. However, these data may not have been appropriate because gill nets can be highly selective for the older fish. This appears to be the case as the gill net catches indicate that Age 2 fish comprised only 4% of escapement whereas CDFG estimated that Age 2 fish averaged about 35% of escapement to the Stanislaus and Tuolumne Rivers during carcass surveys made during the early 1950s. Reisenbichler also used data from 4,500 adults collected at Tehama Colusa Fish Facility spawning channel and the Red Bluff Diversion Dam in 1979 to estimate the percentages by age of fish in 1975 and later. He then assumed that age composition changed at a constant rate between the 1945 and 1975 year classes, and remained constant before 1945 and after 1975. He also assumed that the accuracy of his estimates would be maximized by ignoring the less abundant age classes: Age 2 and Age 5. In particular, he was concerned that carcasses of Age 2 fish were much less likely to be recovered as were carcasses of older fish, and therefore, he thought that estimates of Age 2 fish were relatively inaccurate.

Reisenbichler applied the age composition estimates to the escapement estimates instead of applying the age data directly to the cohorts. By using his method, a priority is placed on the environmental conditions that affect the migration of adult fall-run Chinook salmon. However, there is a substantial body of evidence that adult fall-run recruitment is primarily affected by the conditions that control the production and survival of the juvenile life history stage (Healey 1991, SJRRP 2008). If the juvenile stage is most important, applying a constant age composition to each year's escapement would assign a large number of fish to the wrong cohort whenever a large shift occurs in environmental factors that affect juvenile production and survival. Kope and Botsford (1988) also discuss this error. Table 5 shows an example of how the application of constant age composition data to escapement, instead of applying age composition ratios to cohorts ("Method 4" below and Table 5A), would reduce estimated recruitment during a highly productive flood year (bold font) from 18,026 fish to 10,209 fish and artificially increase recruitment during the low flow unproductive year following the flood (normal font) from 4,762 fish to 9,722 fish.

Previous Method 3 - Another method called "deconvolution" was used by Kope and Botsford (1988, 1990), EA Engineering, Science, and Technology (1991), Speed (1993), and Speed and Ligon (1997) in which mortality factors in their stock-recruitment models were selected so that their recruitment estimates matched the CDFG estimates of escapement and ocean harvest. In order to deconvolve the escapement and harvest time series, the mortality factors included in their spawner-recruit model were estimated as the fraction of recruits that: (1) die naturally, (2) die in the ocean harvest (including shaker mortality), (3) return to spawn, and (4) remain in the ocean. These researchers used the CDFG estimates of Age 2 fish, total escapement, and ocean harvest, although they also recognized the likely errors associated with these estimates. Monte Carlo type simulations were then used to select a model that best predicted the observed escapement and harvest estimates.

Although the above deconvolution methods are theoretically sound, Monte Carlo type simulations are no guarantee that the recruitment estimates are accurate. It is impossible to judge the validity of these estimates because there are no data on the fraction of Central Valley recruits that die naturally, return to spawn, or remain in the ocean.

Our New Method - For this analysis, we tested the assumption that we could deconvolve escapement estimates by applying the mean ratio of abundance of different ages of salmon within the same cohort from one Central Valley river (e.g., Table 5B) to other Central Valley rivers, such as the Tuolumne, Stanislaus, and Merced Rivers if the percentage of

Table 5. Estimated recruitment by applying age composition data to escapement (Section A) and by applying age ratios to cohorts (Section B).

Section A. Age Composition Percentages Applied to Escapement

Age Percentages

	Escapement	Age 2	Age 3	Age 4	Age 5	Recruitment
Age Percentages		22.8%	61.6%	15.8%	0.3%	
Flood Year						**10,209**
1 year after flood	6,000	**1,368**				9,722
2 years after flood	12,000	2,736	**7,392**			
3 years after flood	9,000		5,544	**1,422**		
4 Years after flood	9,079			1,434	**27**	
5 Years after flood	2,695				8	

Section B. Age Composition Ratios Applied to Cohorts

Cohort Ratios

	Escapement	CDFG	Age 3:2	Age 4:3	Age 5:4	Recruitment
Cohort Ratios		# Age 2	3.63	0.28	0.22	
Age Estimates		Age 2	Age 3	Age 4	Age 5	
Flood Year						**18,026**
1 year after flood	6,000	**3,180**				4,762
2 years after flood	12,000	840	**11,543**			
3 years after flood	9,000		3,049	**3,232**		
4 Years after flood	9,079			854	**71**	
5 Years after flood	2,695				19	

Age 2 fish were known for both populations. Our testable hypothesis is that there is a relatively consistent ratio between the abundance of Age 2 fish in year 1, to the abundance of Age 3 fish in year 2, to the abundance of Age 4 fish in year 4, and to the abundance of Age 5 fish in year 5 for all populations of fall-run Chinook salmon in the Central Valley.

Harvest Related Ocean Mortality

The commercial and sport fisheries are elements of ocean mortality that are factored into estimates of recruitment. The Central Valley Index of ocean harvest (CVI) is estimated each year by the Pacific Fishery Management Council (PFMC 2008) by dividing total harvest south of Point Arena by the total hatchery and natural escapement to all Central Valley rivers. It is an index of the percentage of Central Valley Chinook salmon that are harvested each year. The CVI does not include the Central Valley fish that are landed north of point Arena and but it does include fish that originate from northern populations (e.g., the Klamath River) that are harvested south of Point Arena.

Non-landed fishing mortality includes both release mortality, which occurs when a fish dies after it has been hooked and released, and drop-off mortality, which occurs when a fish dies before it is brought to the fishing vessel intact (e.g., predation on the hooked fish). Hooking mortality associated with California style mooching, for which the whole bait is drifted head down and used primarily south of Point Arena, results in deeper ingestion of the hook and substantially higher mortality (42%) than associated with trolling bait or lures (14%; PFMC STT 2000). The overall hooking mortality rates for fish caught and then released are 25% for the commercial fishery and 20% for the sport fishery south of Point Arena (PFMC STT 2000). The drop-off and incidental mortality rates for both commercial and sport fisheries are assumed to be 5% (PFMC STT 2000).

To estimate recruitment, it is necessary to know the age-specific ocean harvest rates. Based on CWT recovery rates, the sport fishery primarily takes Age 2 salmon whereas the commercial troll fish primarily takes Age 3 and older salmon (Mesick et al. 2009). The CVI does not provide age-specific ocean harvest rates and so using the CVI requires the assumption that the percentage of each age taken in the sport and troll fisheries remains constant each year. Furthermore, there is also concern that the SJRB fish are not caught at the same proportion as the fish produced in the Sacramento River Basin. Ocean mortality rates might be higher for the Merced River Hatchery fish compared to the Sacramento River Basin fish because the percentages of Age 3 and older fish are substantially lower for the Merced River Hatchery CWT fish compared to the CWT salmon produced at the Coleman National Fish Hatchery or the Feather River Hatchery (Table 4). We use the CWT recovery data to test whether the ocean harvest rates are substantially different for the Merced River Hatchery fish compared to the fall-run Chinook salmon produced at the Coleman National Fish Hatchery and the Feather River Hatchery. The CWT recovery data should provide the best estimates of ocean harvest since the data are based on the specific landings of Central Valley fish identified by their CWT code at all ports whereas the CVI assumes that the salmon caught south of Port Arena reflect the total number of Central Valley fish landed.

Natural Mortality Rates in the Ocean

Natural mortality rates of adult Chinook salmon in the ocean have not been well documented, but the rates are probably less than 35% per year and probably close to 20% per year (Healey 1991). Healey (1991) also speculated that age-specific mortality declines with age in Chinook salmon so that most ocean mortality occurs during the first year or two of ocean life. EA Engineering, Science, and Technology (1991) used an ocean mortality rate of 0.875 over 63 weeks and 0.20 for juveniles and adults, respectively, for their EACH model. Neeley (1997) assumed that ocean mortality rates were 0.4 for Age 2 fish and 0.3 for Age 3 fish. Recruitment estimates for the Klamath and Feather rivers assume that ocean mortality rates were 0.5 for Age 2 fish and 0.2 for Age 3 and older fish (KRTT 1986).

METHODS

In this section, we describe how we estimate adult recruitment and Age-3 equivalent spawner abundance for the Stanislaus, Tuolumne, and Merced Rivers. These estimates are based on: 1) an unbiased method to select an accurate escapement data set that would be most appropriate for a trend analysis, 2) our new method of age determination and deconvolution of the escapements into cohorts, 3) our CWT based estimates of mortality in the commercial and sport fisheries and 4) general estimates of natural ocean mortality.

Escapement Data Set

We selected the 1981 to 2007 CDFG GrandTab escapement estimates for the Tuolumne River and the 1985 to 2007 CDFG GrandTab escapement estimates for the Merced and Stanislaus Rivers for our population trend analyses based on two criteria. First, we selected the escapement years with accurate estimates of the abundance of Age 2 salmon based on either length-frequency data or a combination of scale and length-frequency data. These data were available for the Tuolumne River since 1981, the Stanislaus River since 1985, and the Merced River since 1987. We also judged the 1985 and 1986 61-cm-criterion Age 2 estimates for the Merced River to be relatively accurate, because there were relatively small differences between the length-frequency and the 61-cm-criterion estimates for the Tuolumne and Stanislaus Rivers in 1985 and 1986 (Table 3).

The second selection criterion was that there had to be a nearly continuous series of escapement estimates for each data set during which at least 6 weekly surveys were conducted and at least 10% of the tags were recovered. Although this criterion was not met for three Tuolumne River estimates in our data set described above, we did not reject these estimates. Although the Tuolumne River estimates for 1982 to 1984 were based on 4 to 5 weekly surveys, we did not reject the 1982 estimate because it was increased by 20% to account for the surveys that were not done in December (Reavis 1986a) and we did not reject the 1983 and 1984 estimates because the salmon runs were nearly completed by the end of November when the surveys were completed (Reavis 1986b, Kano et al. 1996). On the other hand, we rejected the 1996 Stanislaus River estimate for which only 48 carcasses were marked and none were recovered. Instead, we use our estimate for the 1996 Stanislaus River escapement of 3,850 that was computed using a linear regression model between the Stanislaus River escapements and the Merced River escapements from 1997 to 2007 ($R^2 = 0.74$; Mesick et al. 2009).

We made two other revisions in the GrandTab data set. The 2005 escapement estimate for the Stanislaus River in the February 2009 GrandTab file is 3,315, which is the original incorrect carcass survey estimate (Guignard 2006). We use the corrected carcass survey estimate of 1,427 (Guignard 2007) for our analyses. In addition, the 2004 estimates for the Merced River Fish Facility and the Merced River were transposed in the GrandTab file. The correct estimates are 3,270 fish for the in-river escapement estimate and 1,050 for the hatchery escapement in fall 2004.

Aging Fish

Our hypothesis is that there is a relatively consistent ratio between the abundance of Age 2 fish in year 1, to the abundance of Age 3 fish in year 2, to the abundance of Age 4 fish in year 4, and to the abundance of Age 5 fish in year 5 for all populations of fall-run Chinook salmon in the Central Valley. If true, then it is possible to use the age ratios to compute the age composition of the escapement for a population when only the abundance of Age 2 fish is known. For example, if known age composition data indicates that the mean ratio of the abundance of Age 3 fish to Age 2 fish in the same cohort is 1.5 and the abundance of

Age 2 fish is 1,000 in fall 2000, then the abundance of Age 3 fish in 2001 would equal 1,500 (Age 3/2 ratio of 1.5 multiplied by 1,000 Age 2s).

There were three main elements for our tests of our age ratio hypothesis. First, we estimated the percentage and abundance of Age 2 fish in the San Joaquin River Basin escapement data set using a combination of scale and length-frequency analyses obtained from the escapement surveys. Second, we estimated the percentage and abundance of Age 3 and older salmon using scale analyses for 17.4%, 70.4%, and 47.8% of the escapement surveys from 1980 through 2002 for the Stanislaus, Tuolumne, and Merced Rivers respectively. Third, we computed the age ratios of hatchery fish with CWTs from the Coleman National Fish Hatchery on Battle Creek, Feather River Hatchery, and the Merced River Hatchery for brood years 1980 to 2003 that were recovered during escapement surveys in the Central Valley (Mesick et al. 2009). We compared the age ratios for the Tuolumne River with those based on the hatchery CWT returns to test our age ratio hypothesis. We used a natural log transformation to make the age ratio estimates normally distributed and used paired t-tests to compare the four sets of log transformed scale based estimates and CWT based estimates. Shapiro-Wilk Normality tests were used to verify that the log transformations were necessary and effective.

Our results indicate that our age ratio hypothesis was partially true. Although there are statistically significant differences in the Age 3:2 ratios between the Sacramento River Basin hatcheries, which include the Coleman National Fish Hatchery and the Feather River Hatchery, and the SJRB populations, which include the Merced River Hatchery and the

Tuolumne River population, the differences between the Age 3:2 ratios for the Merced River Hatchery and the Tuolumne River population are small and statistically insignificant ($P = 0.082$). Furthermore, we show that the age abundance estimates based on our Age Ratio Method using the Merced River Hatchery CWT data were not significantly different from the scale based age abundance estimates for the Tuolumne River. We describe our Age Ratio Method below.

Scale and Length Frequency Analyses

The analysis of the adult fall-run Chinook salmon scales was completed by the CDFG La Grange Field Office and funded by the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program. The precision and accuracy of the scale analyses were evaluated by using a blind assessment of known age CWT fish, assessment of each sample by two CDFG biologists, and by checking a sample of the CDFG results by a non-CDFG biologist experienced with scale reading. The report has not been finalized, but the final results and draft report were provided to the authors.

Age 2

We separately estimated the percentage of Age 2 male and female fish in the escapement based on length-frequency data recorded for each sex. This was necessary because the male fish are slightly longer than female fish of the same age. The first step in the length-frequency analysis is to determine the fork length nadir between Age 2 and Age 3 fish. We did this using two methods depending on whether scale analyses were available. For both methods, we assumed that ocean growth rates, and therefore the nadirs, should be the same for all three rivers. Due to the small sample sizes we could not conduct robust statistical tests of this assumption; however, there were no obvious differences in the sizes of salmon between the three rivers. For example in fall 2001, the range in potential nadirs based on a simple length-frequency analysis was 70 to 73 cm (n = 830), 68 to 72 cm (n = 372), and 70 to 74 cm (n = 482) on the Tuolumne, Stanislaus, and Merced Rivers, respectively. The combined analysis indicated that the nadir was 71 cm, which was used for all three rivers for fall 2001.

When scale data were available for the Age 2 analyses, we pooled the scale data for all three rivers to provide a combined basin estimate of the fork length nadirs that was used for each of the three rivers. We then used the basin nadir estimates to conduct a frequency distribution analysis in 1-cm steps with the fork length data separately for each river. This was done because the sample size of the length-frequency data was usually greater than the sample size for the scale analysis.

When no or too few scale data existed for Age 2 fish, we first combined the length-frequency data from all three rivers to estimate a basin nadir estimate. We then used the basin nadir estimates to separately evaluate the length-frequency data for each river. The percentage of Age 2 fish in the escapement for each river was the sum of the estimated percentages of Age 2 male and female fish for each river.

Age Ratio Method

We used the Age Ratio Method (ARM) when scale-based age data were not available for the Age 3 and older salmon. Simply defined the ARM computes the abundance of Age 3 and older salmon by multiplying a multi-year average of ratios of the abundance of known age salmon in the same cohort by the abundance of Age 2 salmon. We use three sets of ratios that match the most commonly observed ages in the Central Valley: Age $3_{(year\ i+1)}$:Age $2_{(year\ i)}$, Age $4_{(year\ i+2)}$:Age $3_{(year\ i+1)}$, and Age $5_{(year\ i+3)}$:Age $4_{(year\ i+2)}$. The ARM estimates used for the Stanislaus, Tuolumne, and Merced Rivers were based on the mean age ratios for the Merced River Hatchery CWT recoveries shown in Table 6. We used the Merced River Hatchery CWT estimates instead of the Tuolumne River scale based estimates because the sum of the Tuolumne River scale based estimates were typically higher than the escapement estimates (Table 7) whereas the sum of the CWT based estimates were closer to the escapement estimates (Table 8).

ARM Example - The CDFG estimated number of Age 2 salmon in the Tuolumne River in fall 2005 was 143 fish. The mean ratio of the abundance of Age 3 fish to Age 2 fish (Age 3:2 ratio) is 1.442 for the Merced River CWT fish (Table 6). Using the ARM, the estimated number of Age 3 fish in fall 2006 is 206 fish (143 * 1.442).

Table 6. Age ratios for adult hatchery salmon with coded-wire tags produced by the Coleman National Fish Hatchery, Feather River Hatchery, and Merced River Hatchery, and for scale based estimates of adult salmon in the Tuolumne River collected during fall-run Chinook salmon escapement surveys for brood years 1980 to 2003.

	Coleman National Fish Hatchery			Feather River Hatchery			Merced River Hatchery			Tuolumne River		
Brood Year	Age 3:2	Age 4:3	Age 5:4	Age 3:2	Age 4:3	Age 5:4	Age 3:2	Age 4:3	Age 5:4	Age 3:2	Age 4:3	Age 5:4
1980	1.162	0.189	0.000	2.552	0.305	0.024	0.516	0.708	0.000	3.118	0.000	
1981	4.278	0.642	0.013	7.816	0.645	0.013	0.877	0.134	0.000	0.455	0.661	0.052
1982	59.934	0.622	0.000	7.795	0.652	0.019	1.971	0.185	0.000	3.861	0.096	0.022
1983	2.428	0.159	0.025	16.729	0.387	0.028	2.090	0.020	0.000	1.064	0.063	0.000
1984	5.831	0.061	0.018	3.029	0.123	0.031	0.551	0.011	0.000	1.130	0.000	0.000
1985	1.423	0.172	0.007	2.682	0.202	0.031	0.537	0.052	0.027	0.379	0.157	0.000
1986	3.500	0.313	0.000	6.362	0.345	0.003	0.912	0.275	0.000	0.661	0.029	0.000
1987	8.977	0.262	0.013	3.083	0.088	0.013	1.299	0.965	0.000	1.052	0.192	0.418
1988	4.639	0.666	0.000	1.457	0.079	0.027	0.653	0.684	0.000	2.840	0.201	0.000
1989	180.028	0.265	0.000	7.864	0.514	0.042	--	--	--	2.997	1.249	
1990	4.116	0.255	0.000	3.737	0.358	0.005	0.671	0.206	0.000	4.082		
1991	2.397	0.169	0.000	5.080	0.044	0.144	1.121	0.041	0.000			0.000
1992	2.890	0.278	0.009	3.596	0.522	0.000	4.682	0.000	0.000	2.843	0.353	0.000
1993	3.266	0.545	0.009	8.530	0.341	0.027	1.348	0.319	0.027	4.309	0.338	0.000
1994	4.762	0.192	0.047	3.268	0.259	0.046	1.583	0.208	0.012	1.904	0.321	
1995	2.840	0.691	0.059	3.943	0.996	0.031	0.747	0.125	0.000	3.765		
1996	12.697	0.445	0.000	9.711	0.354	0.005	2.238	0.120	0.000			
1997	1.920	0.623	0.116	5.657	0.374	0.001	2.097	0.059	0.000			
1998	13.864	2.433	0.002	4.290	0.279	0.003	2.049	0.198	0.000			
1999	23.898	0.137	0.010	14.318	0.402	0.038	1.731	0.069	0.010			
2000	0.835	0.468	0.014	2.540	0.162	0.009	0.797	0.106	0.019			
2001	4.288	0.202	0.007	1.959	0.186	0.009	1.079	0.110	0.000			
2002	2.107	0.181	0.000	5.746	0.166	0.000	1.098	0.124	0.000			
2003	6.567	0.406		13.400	0.303		2.521	0.111				
Mean	5.395	0.431	0.017	6.048	0.337	0.024	1.442	0.210	0.004	2.297	0.282	0.045

Table 7. Estimated abundance of Age 3 and older fall-run Chinook salmon using the mean Tuolumne River age ratios in Table 6 to show that the sum of the abundance of these Age Ratio Method estimates is frequently greater than the CDFG escapement estimate.

CDFG Estimates		ARM Estimates				
Escapement	Age 2	Age 3	Age 4	Age 5	Sum	Difference
11,439	7,138					
13,473	2,115	16,396				
6,497	1,403	4,858	4,624			
6,292	4,279	3,223	1,370	208	9,080	2,788
10,212	960	9,829	909	62	11,759	1,547
1,510	79	2,205	2,772	41	5,097	3,587
480	33	181	622	125	961	481

Table 8. Estimated abundance of Age 3 and older fall-run Chinook salmon using the mean Merced River Hatchery CWT age ratios in Table 6 to show that the sum of the abundance of these Age Ratio Method estimates are more similar to the CDFG escapement estimate compared to the Tuolumne River based estimates.

CDFG Estimates		ARM Estimates				
Escapement	Age 2	Age 3	Age 4	Age 5	Sum	Difference
11,439	7,138					
13,473	2,115	10,293				
6,497	1,403	3,050	2,162			
6,292	4,279	2,023	640	9	6,951	659
10,212	960	6,170	425	3	7,558	-2,654
1,510	79	1,384	1,296	2	2,761	1,251
480	33	114	291	5	443	-37

When using the ARM, the sum of the computed abundances for the different ages of salmon do not exactly equal the CDFG escapement estimate. In some instances, the sum is lower than the CDFG escapement estimate and in other instances, the reverse is true (Table 8). This occurs because we use the mean of the age ratios, whereas the true age ratios vary between rivers and over time (Table 6) probably in response to a combination of factors that effect the age at return (e.g., growth rates) and ocean mortality rates.

To ensure that the sum of ARM based individual age abundances equaled the CDFG escapement estimate, we used the “Solver” tool in a Microsoft Excel version 2002 to adjust the mean Age Ratios for Age 3 and older fish by equal percentages. Three sets of input criteria for the Solver tool were used to adjust the mean Age Ratios and compute percentages of Age 3, Age 4, and Age 5 fish. First, the “Target Cell” was identified as the sum of the percentages of all ages of fish for a given year and it was set equal to the value of 1.0 (100%). Second, the range of cells that would contain the percentages of Age 3, 4, and 5 fish was entered into the input parameter called “By Changing Cells”. Third, constraints were added so that the ratios of the Solver-based age ratios to the mean Merced River Hatchery age ratios (Table 6) were equal to each other. Table 9 shows an example of how Solver increased the mean Merced River Hatchery CWT ratios for Age 3:2, Age 4:3, and Age 5:4 equally by factors of 0.3859 and 1.5187 for the Row 1 and Row 2 estimates, respectively, so that the sum of the age abundances equaled the CDFG escapement estimate.

Table 9. Example of Solver Computation of Age Percentages and Age Ratios.

								Mean MRH CWT Age Ratios		
	Solver Computed Age Percentages				Solver Computed Age Ratios			3:2 Ratio	4:3 Ratio	5:4 Ratio
								1.442	0.210	0.004
Row	Age 2%	Age 3%	Age 4%	Age 5%	3:2 Ratio	4:3 Ratio	5:4 Ratio	Solver to Scale Based Ratio		
1	10%	87.75%	2.43%	0.02%	0.5565	0.0810	0.0015	0.3859	0.3859	0.3859
2	76%	10.31%	13.44%	0.01%	2.1900	0.3189	0.0061	1.5187	1.5187	1.5187

Test of Our Age Ratio Method

Our primary hypothesis is that a mean Age Ratio computed from one Central Valley river could be used to accurately estimate the age composition of the escapement in a different Central Valley river when both total escapement and the Age 2 abundance estimates are relatively accurate. An underlying, secondary hypothesis is that adjusting the mean Age Ratio generated abundances of Age 3 and older fish so that the sum of the abundances of each age was equal to the total escapement estimate, produces Age 3 and older abundance estimates that accurately reflect the natural variation in ocean mortality and the age when adults return to spawn. We assumed that if these hypotheses were both true, then there would be no significant differences between the age ratios for different rivers or the age abundance estimates based on our ARM compared to scale-based estimates. Comparisons were made between age ratios and between our ARM estimates based on the Merced River Hatchery CWT data and the scale-based estimates for the Tuolumne River using natural log transformations of the age ratios and age abundance estimates and paired t-tests were used to compare the transformed estimates. Shapiro-Wilk Normality tests were used to verify that the log transformations were effective.

Ocean Harvest

Fishing mortality includes both fish that are successfully harvested and the non-landed mortality. The significant differences in the escapement age composition between SJRB fall-run Chinook salmon and the Sacramento River Basin salmon (Table 4) suggests that ocean harvest rates and other ocean mortality factors may not be the same for these two basins. If true then it would not be appropriate to use the CVI to estimate recruitment for the SJRB salmon populations. To test for difference in ocean harvest rates for the SJRB and the Sacramento River Basin, we compared the ocean harvest rates for the CWT hatchery fish produced at the Coleman National Fish Hatchery on Battle Creek, Feather River Hatchery, and the Merced River Hatchery. Ocean harvest was computed as the total number of salmon harvested divided by the sum of the harvest and inland escapement for each run year. Comparisons were made by using an arcsin transformation for the ocean harvest rates and paired t-tests were used to compare the transformed estimates. Shapiro-Wilk Normality tests were used to verify that the log transformations were effective.

The results indicated that the CWT ocean harvest estimates were significantly lower than the CVI estimates and that there were no significant differences between any of the CWT estimates for the SJRB and the Sacramento River Basin. Therefore, we computed the recruitment estimates using the commercial troll and sport ocean harvest rates for Age 2 and Age 3 and older salmon (Table 10) based on the CWT recoveries for the entire Central Valley (Mesick et al. 2009). It was our judgment that there were two few CWT recoveries for the Merced River Hatchery fish alone to compute an accurate age-specific ocean harvest index for each fishery. To include the effects of non-landed fishing mortality, we multiplied the Merced River Hatchery CWT ocean harvest estimates by the mean 2000 to 2005 non-landed mortality rates for the commercial and sport fisheries. The estimated percentage of non-landed fishing mortality (a.k.a. bycatch mortality) for the landings south

Table 10. Percentages of Age 2 and Age 3 and older Central Valley CWT Chinook salmon that were landed in the commercial troll and the ocean sport fisheries during the fall-run escapement period from 1980 to 2007. The methods used to compute the abundance of CWT salmon in the Central Valley escapement and ocean fisheries are described in Mesick et al. (2009). The estimates reflect the percentage of each age harvested and so the Age-2 and Age-3-and-older estimates are not additive, but the sport and troll estimates for each age are additive.

	Age 2		Age 3 and Older	
Year	Sport	Troll	Sport	Troll
1980	19.65%	27.79%	8.07%	62.07%
1981	21.55%	4.98%	5.57%	49.46%
1982	28.54%	4.86%	8.54%	45.87%
1983	4.99%	0.57%	14.95%	41.13%
1984	25.20%	0.93%	8.05%	29.62%
1985	32.83%	3.01%	9.47%	32.50%
1986	20.90%	2.15%	9.37%	42.56%
1987	25.54%	4.00%	10.91%	48.79%
1988	35.33%	17.97%	7.81%	72.27%
1989	55.45%	6.09%	10.86%	59.66%
1990	47.96%	2.04%	13.96%	60.64%
1991	50.69%	2.97%	12.83%	54.45%
1992	21.03%	0.55%	10.71%	57.09%
1993	26.73%	18.84%	11.91%	45.82%
1994	31.57%	27.77%	11.26%	34.70%

1995	51.22%	11.24%	21.50%	47.54%
1996	13.11%	7.97%	15.42%	42.28%
1997	30.12%	9.62%	16.52%	47.49%
1998	30.84%	1.51%	12.41%	38.63%
1999	7.77%	3.37%	5.93%	27.43%
2000	34.09%	4.03%	13.93%	26.86%
2001	28.14%	4.72%	12.20%	26.23%
2002	21.22%	2.64%	9.56%	17.85%
2003	21.24%	7.97%	9.99%	43.09%
2004	47.62%	22.67%	13.26%	47.15%
2005	55.97%	26.41%	9.53%	31.85%
2006	58.61%	9.81%	16.80%	15.20%
2007	14.53%	5.92%	8.16%	14.99%
Mean	30.80%	8.66%	11.41%	41.54%

of Horse Mountain, Humboldt County, California ranged between 9% to 15% (mean 11.8%) of the commercial catch and between 11% and 16% (mean 12.2%) of the sport catch from 2000 to 2005 (Pacific Fisheries Management Council, undated).

Natural Ocean Mortality

We used the same estimates of natural ocean mortality as used for the Klamath (KRTT 1986) and Feather Rivers (Melodie Palmer-Zwahlen, personal communication, 4 June 2009), which assume that ocean mortality rates are 0.5 for Age 2 fish and 0.2 for Age 3 and older fish.

Recruitment

Recruitment for year *i* was estimated by expanding the escapement estimates for each age of salmon by the total ocean fishing mortality and natural ocean mortality with the following equation:

$$\text{Recruitment}_{(i)} = \text{Age } 2_{(i+1)}/(1-((SH2*1.122)+(TH2*0.118)))*1.5 +$$

$$\text{Age } 3_{(i+2)}/(1-((SHAdult*1.122)+(THAdult*1.118)))*1.2 +$$

$$\text{Age } 4_{(i+3)}/(1-((SHAdult*1.122)+(THAdult*1.118)))*1.2 +$$

$$\text{Age } 5_{(i+4)}/(1-((SHAdult*1.122)+(THAdult*1.118)))*1.2$$

where,

SH = sport harvest fraction of our Central Valley CWT estimate for Age 2 (SH2) and Age 3 and older salmon (SHAdult) in Table 10; and

TH = troll harvest fraction of our Central Valley CWT estimate for Age 2 (TH2) and Age 3 and older salmon (THAdult) In Table 10.

Age 3 Equivalent Spawner Abundance

The number of spawners was computed as the equivalent number of three-year-old salmon that returned to spawn during the year prior to the recruitment estimate using the following formula:

$$\text{Spawners} = 0.38 * \text{Age 2s} + \text{Age 3s} + 1.2 * \text{Age 4s} + 1.4 * \text{Age 5s}$$

The age-specific escapement estimates were multiplied by an adjustment factor to reflect the relative number of eggs deposited by females in the "spawners" estimate. The adjustment factor used for Age 2 fish was 0.38 to reflect that (1) relatively few Age 2 fish are female and (2) two-year-old females produce relatively few eggs. From 1985 to 1995, only about 33% of the two-year-old fish that returned to the Stanislaus River were female (CDFG, unpublished data). To account for this low percentage of females, a correction factor of 0.66 was computed by dividing the expected percentage of two-year-old females (33%) by the expected number of three-year-old females (50%). Then another correction factor was computed to account for the relatively few eggs produced by two-year-old females. Two-year-old females, which averaged about 61 cm in fork length from 1985 to 1995, would be expected to produce about 3,500 eggs, whereas, three-year-old females, which average about 77 cm in fork length, would produce about 6,000 eggs based on fecundity data from fall-run Chinook salmon recovered at the Los Banos Trap in the San Joaquin River (CDFG 1990). To account for the low number of eggs produced by two-year-olds, a correction factor of 0.58 was computed by dividing 3,500 eggs for two-year-olds by 6,000 eggs for three-year-olds. Both of these correction factors were multiplied together (0.66 * 0.58) to compute the overall adjustment factor of 0.38 for two-year-olds.

The adjustment factor used for four-year-olds is 1.20. It was computed as the expected number of eggs produced by four-year-olds, which was about 7,500 eggs for 86 cm females based on the fecundity data presented in CDFG (1990), divided by the number of eggs produced by three-year-olds.

The adjustment factor for five-year-olds is 1.40. It was computed as the expected number of eggs produced by five-year-olds, which was about 8,700 eggs for relatively large females averaging about 88 cm (CDFG 1990), divided by the number of eggs produced by three-year-olds.

RESULTS

The results of the San Joaquin Basin scale analysis conducted by CDFG, a comparison of the age determinations based on CWT age ratios and CDFG scale analyses, estimates of

CWT based ocean harvest, and estimates of recruitment and spawner abundance for the Stanislaus and Merced Rivers from 1984 to 2005 and the Tuolumne River from 1980 to 2005 are presented below.

CDFG Scale Analysis

The scale analyses for the Stanislaus, Tuolumne, and Merced Rivers are presented in Tables 11, 12, and 13 respectively. Length-frequency data were available for most years on the Stanislaus, Tuolumne, and Merced Rivers (Tables 11 to 13). We used the results of the scale analyses for Age 3 and older fish only if there were a total of at least 15 male and female samples of the adult fish for that year. We assumed that 15 samples would be adequate to provide usable estimates of the percentages of Age 3 and Age 4 fish that were within 5% of the true percentage; whereas accurate estimates of Age 5 fish would require at least 80 samples. At least 15 scale samples had been analyzed for 17.4%, 70.4%, and 47.8% of the escapement surveys in our data sets for the Stanislaus, Tuolumne, and Merced Rivers, respectively.

Age Ratios

Paired t-tests suggest that our hypothesis: A mean Age Ratio computed from one Central Valley river could be used to accurately estimate the age composition of the escapement in a different Central Valley river when both total escapement and the Age 2 abundance estimates are relatively accurate is only partly true. We conducted two sets of tests: one

Table 11. Scale and fork length (FL) frequency analysis for the fall-run Chinook salmon escapement in the Stanislaus River from 1985 to 2007. Our new Age Ratio Method (AR) was used to determine the abundance and percentage of Age 3 and older fish whenever scale based estimates were not available.

Year	Total Male FL Samples	Age 2 Male Nadir (cm)	Total Female FL Samples	Age 2 Female Nadir (cm)	# Adult Male Scales Analyzed	# Adult Female Scales Analyzed	Overall Age 2	Overall Age 3	Overall Age 4	Overall Age 5
1985	172	67 cm	343	64 cm	0	5	15.7%			
1986	141	70 cm	224	64 cm	0	0	21.6%			
1987	218	75 cm	178	65 cm	7	10	68.0%	28.0%	4.0%	0.0%
1988	159	72 cm	285	65 cm	49	63	9.4%	87.9%	2.7%	0.0%
1989	269	70 cm	379	63 cm	106	171	5.2%	62.7%	32.1%	0.0%
1990	77	71 cm	84	61 cm	0	1	6.8%			
1991	46	68 cm	52	65 cm	0	0	13.3%			
1992	39	66 cm	38	61 cm	0	0	26.0%			
1993	37	68 cm	50	63 cm	0	2	23.0%			
1994	128	72 cm	147	64 cm	8	9	18.2%	59.7%	16.7%	5.4%
1995	73	72 cm	71	63 cm	1	0	29.2%			
1996	27	69 cm	21	66 cm	0	0	60.4%			
1997	274	70 cm	325	62 cm	0	0	12.4%			
1998	169	71 cm	160	62 cm	0	4	42.9%			
1999	318	69 cm	324	66 cm	0	0	26.3%			
2000	251	68 cm	422	65 cm	0	0	6.1%			
2001	359	70 cm	574	64 cm	0	0	13.0%			

Year	Total Male FL Samples	Age 2 Male Nadir (cm)	Total Female FL Samples	Age 2 Female Nadir (cm)	# Adult Male Scales Analyzed	# Adult Female Scales Analyzed	Overall Age 2	Overall Age 3	Overall Age 4	Overall Age 5
2002	764	65 cm	1144	65 cm	0	0	14.6%			
2003	773	70 cm	1144	64 cm	0	0	13.4%			
2004	439	73 cm	667	65 cm	0	0	30.2%			
2005	145	70 cm	305	64 cm	0	0	7.1%			
2006	74	72 cm	177	66 cm	0	0	13.9%			
2007	13	72 cm	6	66 cm	0	0	23.8%			

Table 12. Preliminary scale and fork length (FL) frequency analysis for the fall-run Chinook salmon escapement in the Tuolumne River from 1981 to 2007.

Year	Total Male FL Samples	Age 2 Male Nadir (cm)	Total Female FL Samples	Age 2 Female Nadir (cm)	# Adult Male Scales Analyzed	# Adult Female Scales Analyzed	Overall Age 2	Overall Age 3	Overall Age 4	Overall Age 5
1981	353	75	265	64	38	70	78.8%	19.9%	1.3%	0.0%
1982	105	70	130	66	23	79	9.8%	83.6%	6.6%	0.0%
1983	135	70	50	60	15	36	76.2%	14.7%	9.1%	0.0%
1984	513	66	285	63	13	15	62.4%	37.6%	0.0%	0.0%
1985	408	67	523	64	21	24	7.8%	81.8%	8.4%	1.9%
1986	260	70	250	64	36	43	9.4%	45.5%	42.7%	2.4%
1987	783	75	349	65	14	17	92.8%	5.3%	1.4%	0.5%
1988	156	72	245	65	22	32	10.2%	89.8%	0.0%	0.0%
1989	174	70	191	63	255	282	4.9%	30.7%	63.9%	0.5%
1990	20	72	11	61	18	18	19.4%	68.6%	12.0%	0.0%
1991	11	68	9	65	17	22	15.0%	68.5%	16.5%	0.0%
1992	30	66	12	61	10	9	61.7%	26.3%	8.0%	4.0%
1993	71	68	97	63	49	82	20.2%	70.6%	9.2%	0.0%
1994	79	72	78	64	0	0	30.6%			
1995	195	71	211	63	10	20	33.5%	53.2%	13.3%	0.0%
1996	788	69	398	64	72	86	69.1%	27.4%	3.6%	0.0%
1997	451	71	605	64	16	27	14.1%	80.3%	5.6%	0.0%
1998	1065	65	1285	63	30	61	36.8%	42.6%	20.7%	0.0%
1999	793	70	1104	66	3	3	22.8%			
2000	793	68	1337	65	44	69	6.1%	82.2%	11.0%	0.8%

Year	Total Male FL Samples	Age 2 Male Nadir (cm)	Total Female FL Samples	Age 2 Female Nadir (cm)	# Adult Male Scales Analyzed	# Adult Female Scales Analyzed	Overall Age 2	Overall Age 3	Overall Age 4	Overall Age 5
2001	829	71	974	65	0	0	20.2%			
2002	817	65	978	65	16	23	14.9%	36.2%	48.9%	0.0%
2003	231	70	348	66	0	0	10.0%			
2004	216	71	311	65	0	0	37.6%			
2005	56	71	115	65	0	0	19.9%			
2006	49	72	42	66	0	0	39.6%			
2007	23	72	14	66	0	0	13.5%			

Table 13. Preliminary scale and fork length (FL) frequency analysis for the fall-run Chinook salmon escapement in the Merced River from 1985 to 2007.

Year	Total Male FL Samples	Age 2 Male Nadir (cm)	Total Female FL Samples	Age 2 Female Nadir (cm)	# Adult Male Scales Analyzed	# Adult Female Scales Analyzed	Overall Age 2	Overall Age 3	Overall Age 4	Overall Age 5
1982	45	70 cm	79	66 cm	0	0	16.1%			
1983	186	70 cm	97	60 cm	0	0	95.0%			
1984	3	66 cm	1	63 cm	0	0	25.0%			
1985	5	67 cm	3	64 cm	0	0	25.0%			
1986		70 cm		64 cm	0	0				
1987	69	75 cm	69	65 cm	0	0	91.4%			
1988	42	72 cm	56	65 cm	0	0	18.4%			
1989	22	70 cm	33	63 cm	13	28	3.6%	60.1%	36.2%	0.0%
1990	10	72 cm	6	61 cm	4	5	31.3%			
1991	2	68 cm	10	65 cm	4	12	16.7%	73.6%	9.7%	0.0%
1992	75	66 cm	92	61 cm	37	51	29.9%	52.8%	16.5%	0.8%
1993	321	68 cm	216	63 cm	11	27	32.6%	65.2%	2.3%	0.0%
1994	444	72 cm	579	64 cm	66	137	20.3%	72.3%	7.4%	0.0%
1995	135	73 cm	174	63 cm	13	51	26.2%	65.2%	6.7%	1.9%
1996	599	69 cm	661	66 cm	52	127	41.0%	52.0%	7.1%	0.0%
1997	325	71 cm	449	64 cm	35	82	9.8%	84.6%	5.6%	0.0%
1998	477	66 cm	555	63 cm	43	84	24.1%	36.7%	39.1%	0.0%
1999	391	71 cm	406	66 cm	31	38	44.7%	51.2%	4.1%	0.0%
2000	301	68 cm	453	65 cm	135	260	8.8%	85.3%	5.9%	0.0%
2001	482	71 cm	610	65 cm	0	0	16.6%			

2002	477	65 cm	500	65 cm	0	0	16.6%
2003	212	70 cm	337	66 cm	0	0	14.4%
2004	349	74 cm	435	65 cm	0	0	33.4%
2005	98	71 cm	268	66 cm	0	0	7.7%
2006	97	71 cm	160	66 cm	0	0	15.2%
2007	22	72 cm	69	66 cm	0	0	1.1%

comparing the age ratios between the different populations and the other comparing the abundance estimates based on the ARM with Tuolumne River scale-based estimates. The comparisons of the age ratio estimates presented in Table 6 based on paired t-tests of the natural log transformations of the Age 3:2 ratios indicate that there were significant differences between the SJRB estimates and the Sacramento River Basin estimates ($P < 0.01$, $df > 14$, t-values > 3.15) whereas the differences between the Merced River CWT-based Age 3:2 estimates and the Tuolumne River scale-based estimates were not significantly different ($P = 0.082$, $df = 13$, t-value $= 1.88$). Although there were too few samples to use paired t-tests for the Age 4:3 and Age 5:4 ratios, the percentage of Age 4 is generally computed as the remainder of the escapement not consisting of Age 2 and Age 3 salmon along with a very small percentage of Age 5 salmon. Therefore, an accurate Age 3:2 ratio is much more important than the Age 4:3 and Age 5:4 ratios.

The paired *t*-test comparisons of the Age 3 and Age 4 abundance estimates based on the ARM and the Tuolumne River scale-based estimates presented in Table 14 indicate that there were no significant differences between the two sets of age abundances (Table 15). The Age 5 abundance estimates could not be transformed into a normal distribution due to the prevalence of 0 and 1 abundance estimates and so statistical tests for Age 5 estimates were not conducted. The Age 3 and Age 4 results provide further evidence that accurate estimates of age composition data can be generated using the ARM if known age ratio data exist for the basin.

It may be possible to determine whether age ratio data from one river or hatchery can be

Table 14. Abundance estimates for ages 3, 4, and 5 the Tuolumne River from 1981 to 2002 based on the Age Ratio Method and Merced River Hatchery CWT age ratio data (ARM3, ARM4, and ARM5) and scale based estimates (Scale3, Scale4, and Scale5).

Year	Escapement	Age 2	ARM3	ARM4	ARM5	Scale3	Scale4	Scale5
1981	14,253	11,237	2,138	872	6	2,831	185	0
1982	7,126	698	6,253	173	1	5,959	469	0
1983	14,836	11,311	1,530	1,994	1	2,178	1,347	0
1984	13,689	8,545	5,144	0	0	5,144	0	0
1985	40,322	3,163	34,164	2,995	0	32,994	3,398	767
1986	7,404	697	2,604	4,096	7	3,366	3,163	177
1987	14,751	13,682	685	372	11	788	213	68
1988	5,779	592	5,187	0	0	5,187	0	0
1989	1,275	63	533	680	0	391	814	7
1990	96	19	34	42	1	66	12	0
1991	77	12	51	14	0	53	13	0
1992	132	81	31	20	0	35	11	5
1993	471	95	356	19	0	332	43	0
1995	827	277	452	97	1	440	110	0
1996	4,362	3,013	1,089	259	1	1,194	155	0
1997	7,146	1,007	5,831	307	1	5,736	403	0
1998	8,910	3,278	3,054	2,576	3	3,791	1,841	0
2000	17,873	1,087	11,701	5,071	13	14,685	1,965	136
2002	7,173	1,066	4,964	1,110	33	2,599	3,508	0

Table 15. Results of paired *t*-tests comparing the natural log transformations of the Age 3 and Age 4 abundance estimates for the Tuolumne River presented in Table 14 that are based on our Age Ratio Method (ARM) and scale-based estimates.

	Age 3	Age 4
P	0.304	0.371
df	18	16
t-value	-1.06	0.92

used for another river or hatchery is by comparing the mean percentages of Age 2 salmon between the populations. The percentages of Age 2 salmon were relatively low for the Feather River Hatchery and Coleman National Fish Hatchery compared to the percentage for the Merced River Hatchery, whereas the percentages were intermediate for the Tuolumne River (Table 4). The mean Age 3:2 ratios showed the opposite trends, with the highest ratios for the Feather and Coleman hatcheries and the lowest ratio for the Merced River Hatchery (Table 6). Applying the low Merced River Hatchery ratios to the Stanislaus, Tuolumne, and Merced Rivers resulted in intermediate ratios for all three rivers (Tables 16 to 18) that were most similar to the Tuolumne River scale-based estimates (Table 6). This suggests that the mean age ratio estimates used in the ARM need to be close but not necessarily exactly match both rivers, because the adjustment of the ARM estimates to match the sum of the age abundance estimates with the original escapement estimate corrects for any differences. Therefore, the ARM is a fairly robust technique as long as the percentages of Age 2 salmon are similar between the two populations.

Ocean Harvest

The results indicated that there were significant differences in ocean harvest rates between the CWT based estimates and the CVI estimates (PFMC 2008) but not between the CWT based estimates. The mean estimates for the Merced River Hatchery fish were lowest at 38.5% and highest for the CVI at 59.3% (Table 19). Paired t-tests of the arcsin transformed estimates in Table 16 indicated that the CVI estimates were significantly higher ($P \leq 0.0015$) than any of the CWT based estimates. However, the Sacramento

Table 16. Stanislaus River estimates of escapement (CDFG), percentages of Age 2, 3, 4, and 5 fish, recruitment, three-year-old equivalent spawners, and age ratios used to segregate escapement estimates into cohorts.

Year	Escapement	Age 2	Age 3	Age 4	Age 5	Recruitment	Age 3 Spawners	Age3:2	Age 4:3	Age 5:4
1984	11,439	62.4%	36.8%	0.7%	0.0%	14,695	6,819	0.4492	0.0654	0.0012
1985	13,473	15.7%	77.6%	6.7%	0.0%	12,336	7,029	1.4646	0.2133	0.0041
1986	6,497	21.6%	45.5%	32.8%	0.1%	115,479	12,341	1.3980	0.2036	0.0039
1987	6,292	68.0%	28.0%	4.0%	0.0%	11,043	6,052	1.2522	0.0858	0.0000
1988	10,212	9.4%	87.9%	2.7%	0.0%	2,246	3,691	2.0985	0.1546	0.0000
1989	1,510	5.2%	62.7%	32.1%	0.0%	1,398	9,669	0.9814	0.0540	0.0000
1990	480	6.8%	33.8%	58.8%	0.6%	1,310	1,558	2.0490	0.2984	0.0057
1991	394	13.3%	49.8%	35.7%	1.2%	1,953	517	5.9682	0.8692	0.0166
1992	255	26.0%	47.7%	26.0%	0.4%	2,756	392	2.3221	0.3382	0.0064
1993	677	23.0%	60.6%	16.2%	0.2%	3,399	228	6.2012	0.9031	0.0172
1994	1,031	18.2%	59.7%	16.7%	5.4%	6,543	603	3.9593	0.4202	0.5049
1995	619	29.2%	47.8%	22.9%	0.1%	26,224	972	1.5806	0.2302	0.0044
1996	3,850	60.4%	31.9%	7.6%	0.1%	4,951	536	6.7963	0.9897	0.0189
1997	5,588	12.4%	81.3%	6.2%	0.0%	13,513	2,467	1.9534	0.2845	0.0054
1998	3,087	42.9%	29.2%	27.9%	0.0%	22,843	5,230	1.3018	0.1896	0.0036
1999	4,349	26.3%	67.0%	6.6%	0.1%	9,346	2,439	2.2000	0.3204	0.0061
2000	8,498	6.1%	68.4%	25.4%	0.0%	16,325	3,700	5.0880	0.7410	0.0141
2001	7,033	13.0%	32.9%	53.6%	0.4%	15,432	8,609	4.4546	0.6487	0.0124
2002	7,787	14.6%	61.9%	22.8%	0.7%	8,827	7,229	5.2557	0.7654	0.0146
2003	5,902	13.4%	53.4%	33.0%	0.2%	12,646	7,459	2.7711	0.4036	0.0077

2004	4,015	30.2%	44.0%	25.5%	0.3%	3,089	5,806	2.2300	0.3248	0.0062
2005	1,427	7.1%	76.5%	16.2%	0.2%	3,940	3,472	0.8995	0.1310	0.0025
2006	1,923	26.2%	28.6%	45.1%	0.2%		1,412	5.4495	0.7936	0.0151
2007	443	11.9%	75.7%	12.0%	0.4%		1,786	0.6666	0.0971	0.0018
Average	4,449	23.5%	53.7%	22.4%	0.4%	14,163	3,917	2.8663	0.3969	0.0280

Table 17. Tuolumne River estimates of escapement (CDFG), percentages of Age 2, 3, 4, and 5 fish, recruitment, three-year-old equivalent spawners, and age ratios used to segregate escapement estimates into cohorts.

Year	Escapement	Age 2	Age 3	Age 4	Age 5	Recruitment	Age 3 Spawners	Age3:2	Age 4:3	Age 5:4
1981	14,253	78.8%	19.9%	1.3%	0.0%	10,429	513	24.7298	0.5771	0.0000
1982	7,126	9.8%	83.6%	6.6%	0.0%	36,961	7,323	0.5303	0.1655	0.0000
1983	14,836	76.2%	14.7%	9.1%	0.0%	102,076	6,787	3.1179	0.2261	0.0000
1984	13,689	62.4%	37.6%	0.0%	0.0%	18,343	8,093	0.4548	0.0000	0.0000
1985	40,322	7.8%	81.8%	8.4%	1.9%	4,295	8,391	3.8612	0.6605	
1986	7,404	9.4%	45.5%	42.7%	2.4%	94,908	39,347	1.0641	0.0959	0.0522
1987	14,751	92.8%	5.3%	1.4%	0.5%	4,514	7,675	1.1295	0.0632	0.0215
1988	5,779	10.2%	89.8%	0.0%	0.0%	869	6,338	0.3791	0.0000	0.0000
1989	1,275	4.9%	30.7%	63.9%	0.5%	372	5,412	0.6609	0.1570	
1990	96	19.4%	68.6%	12.0%	0.0%	363	1,402	1.0520	0.0295	0.0000
1991	77	15.0%	68.5%	16.5%	0.0%	1,580	87	2.8396	0.1924	0.0000
1992	132	61.7%	26.3%	8.0%	4.0%	1,448	72	2.9973	0.2009	0.4180
1993	471	20.2%	70.6%	9.2%	0.0%	3,541	86	4.0816	1.2490	0.0000
1994	506	30.6%	46.0%	23.4%	0.1%	7,136	421	2.4420	0.3556	0.0068
1995	827	33.5%	53.2%	13.3%	0.0%	35,352	434	2.8426	0.4727	0.0000
1996	4,362	69.1%	27.4%	3.6%	0.0%	15,383	677	4.3091	0.3526	0.0000
1997	7,146	14.1%	80.3%	5.6%	0.0%	22,481	2,525	1.9037	0.3376	0.0000
1998	8,910	36.8%	42.6%	20.7%	0.0%	45,415	6,602	3.7653	0.3209	0.0000
1999	8,232	22.8%	66.0%	11.1%	0.1%	13,928	7,246	1.6571	0.2413	0.0046
2000	17,873	6.1%	82.2%	11.0%	0.8%	10,217	7,255	7.8247	0.3618	0.1486

2001	8,782	20.2%	26.9%	52.8%	0.1%	8,644	17,646	2.1701	0.3160	0.0060
2002	7,173	14.9%	36.2%	48.9%	0.0%	2,911	8,617	1.4683	1.4869	0.0000
2003	2,163	10.0%	66.0%	23.4%	0.6%	6,321	7,214	1.3389	0.1950	0.0037
2004	1,984	37.6%	31.7%	30.5%	0.2%	2,495	2,136	2.9128	0.4242	0.0081
2005	500	19.9%	71.2%	8.8%	0.2%	748	1,645	0.4775	0.0695	0.0013
2006	500	18.7%	53.4%	27.8%	0.1%		447	2.6828	0.3907	0.0074
2007	115	13.7%	60.7%	25.3%	0.3%		470	0.7470	0.1088	0.0021
Average	7,011	30.2%	51.4%	18.0%	0.4%	18,029	5,736	3.0904	0.3352	0.0272

Table 18. Merced River estimates of escapement (CDFG), percentages of Age 2, 3, 4, and 5 fish, recruitment, three-year-old equivalent spawners, and age ratios used to segregate escapement estimates into cohorts.

Year	Escapement	Age 2	Age 3	Age 4	Age 5	Recruitment	Age 3 Spawners	Age3:2	Age 4:3	Age 5:4
1984	27,640	62.4%	36.6%	1.0%	0.0%	4,765	8,933	0.8018	0.1168	0.0022
1985	14,841	3.0%	89.4%	7.6%	0.0%	2,035	17,000	0.7688	0.1120	0.0021
1986	6,789	6.9%	17.4%	75.6%	0.1%	45,605	14,791	2.6557	0.3868	0.0074
1987	3,168	91.4%	6.2%	2.3%	0.2%	4,132	7,528	0.4185	0.0609	0.0012
1988	4,135	18.4%	80.8%	0.8%	0.0%	173	1,391	1.1551	0.1682	0.0032
1989	345	3.6%	60.1%	36.2%	0.0%	825	3,671	0.2732	0.0374	0.0000
1990	36	31.3%	20.0%	48.2%	0.6%	1,767	362	0.5742	0.0836	0.0016
1991	78	16.7%	73.6%	9.7%	0.0%	3,885	33	5.1037	1.0517	0.0000
1992	618	29.9%	52.8%	16.5%	0.8%	6,807	71	25.0957	1.7793	0.6202
1993	1,269	32.6%	65.2%	2.3%	0.0%	11,185	526	4.4715	0.0880	0.0000
1994	2,646	20.3%	72.3%	7.4%	0.0%	9,477	1,018	4.6232	0.2368	0.0000
1995	2,320	26.2%	65.2%	6.7%	1.9%	15,967	2,351	2.8110	0.0808	0.2256
1996	3,291	41.0%	52.0%	7.1%	0.0%	4,350	1,992	2.8139	0.1535	0.0000
1997	2,714	9.8%	84.6%	5.6%	0.0%	6,413	2,502	1.7040	0.0881	0.0000
1998	3,292	24.1%	36.7%	39.1%	0.0%	32,847	2,579	4.5374	0.5608	0.0000
1999	3,129	44.7%	51.2%	4.1%	0.0%	12,080	3,057	2.0183	0.1055	0.0000
2000	11,130	8.8%	85.3%	5.9%	0.0%	15,895	2,288	6.7907	0.4126	0.0000
2001	9,181	17.0%	34.3%	48.7%	0.1%	10,133	10,658	3.2309	0.4705	0.0090
2002	8,866	16.6%	64.1%	18.8%	0.5%	6,573	9,109	3.6406	0.5302	0.0101
2003	2,530	13.7%	55.1%	31.0%	0.2%	12,647	8,306	0.9484	0.1381	0.0026

2004	3,270	32.8%	42.2%	24.7%	0.3%	4,552	2,474	3.9821	0.5799	0.0110
2005	2,111	8.0%	77.3%	14.5%	0.2%	1,822	2,770	1.5223	0.2217	0.0042
2006	1,470	11.9%	36.5%	51.4%	0.2%		2,069	3.1781	0.4628	0.0088
2007	495	1.8%	67.3%	30.1%	0.8%		1,514	1.9054	0.2775	0.0053
Average	4,807	23.9%	55.3%	20.6%	0.2%	9,724	4,458	3.5427	0.3418	0.0381

Table 19. Ocean harvest estimates based on the CWT inland and ocean recoveries for salmon produced at the Coleman National Fish Hatchery, Feather River Hatchery, and the Merced River Hatchery as well as the Central Valley Index of Ocean Harvest (PFMC 2008) from 1979 to 2007.

Year	CNFH	FRH	MRH	CVI
1979	77.3%	56.7%	30.2%	65.2%
1980	88.4%	65.9%	71.3%	67.1%
1981	73.4%	34.2%	38.1%	62.4%
1982	58.6%	53.0%	20.7%	71.0%
1983	41.8%	57.2%	9.1%	61.6%
1984	36.6%	45.4%	25.0%	57.4%
1985	27.2%	46.8%	47.4%	50.1%
1986	48.0%	36.3%	48.5%	67.0%
1987	25.6%	38.7%	44.5%	72.8%
1988	48.3%	51.6%	78.9%	78.0%
1989	53.9%	54.8%	85.9%	74.1%
1990	56.5%	58.8%	ND	78.9%
1991	41.5%	44.5%	78.6%	70.2%
1992	29.4%	49.5%	11.3%	72.3%
1993	41.4%	44.1%	6.6%	71.1%
1994	59.8%	45.9%	40.4%	72.2%
1995	66.3%	70.3%	16.6%	76.3%
1996	72.3%	48.4%	27.1%	59.9%
1997	43.1%	54.6%	42.1%	62.5%
1998	45.6%	48.6%	16.1%	52.0%

1999	27.7%	28.2%	22.3%	43.9%
2000	32.3%	39.9%	28.0%	54.6%
2001	31.8%	29.5%	26.0%	26.4%
2002	23.5%	44.7%	34.9%	34.6%
2003	41.4%	63.9%	47.6%	34.4%
2004	52.8%	62.4%	63.0%	61.9%
2005	50.0%	40.2%	49.9%	46.1%
2006	49.5%	31.5%	30.7%	28.7%
2007	19.4%	22.8%	38.6%	48.1%
Mean	47.0%	47.2%	38.5%	59.3%

River Basin CWT estimates of Feather River Hatchery and Coleman National Fish Hatchery produced salmon were not significantly different than those for the Merced River Hatchery salmon ($P > 0.166$). Therefore, we computed age-specific ocean harvest rates for the commercial troll and sport fisheries based on all Central Valley CWT recoveries (Table 10) for the purpose of estimating SJRB recruitment.

Recruitment and Spawner Abundance Estimates

The estimates of CDFG GrandTab escapement, age percentages, our CWT age-specific estimates of sport harvest and troll harvest, recruitment, Age-3-equivalent spawners, and the Age Ratios from 1980 to 2007 for the Tuolumne River and from 1984 to 2007 for the Stanislaus and Merced Rivers are presented in Tables 17 to 19, respectively.

CONCLUSIONS

We suggest that empirically based recruitment estimates for the SJRB can be accurately computed by using 1) accurate escapement estimates that exist from the early to mid 1980s; 2) accurate Age 2 abundance estimates based on a combination of length frequency and scale analyses; 3) our new Age Ratio Method to deconvolve fall-run Chinook salmon escapement estimates into cohorts; and 4) age-specific ocean harvest estimates based on Central Valley CWT recovery data. The Age Ratio Method is shown to be fairly robust at estimating the abundances of Age 3 and older salmon as long as the escapement and Age 2 estimates are relatively accurate. Our results show that the age ratios (e.g., ratio of Age 3 abundance to Age 2 abundance) are relatively consistent within a river basin but that they significantly differ between the Sacramento and San Joaquin River basins. Therefore, age data from either CWT analyses or scale analyses are needed from at least one river within a basin where the percentages of Age 2 salmon in the escapement are similar between the rivers. We also believe that CWT inland and ocean recovery data provide accurate age-specific estimates of sport and commercial troll harvest rates. Such ocean harvest estimates are important for estimating recruitment, because the sport harvest primarily takes Age 2 salmon whereas the commercial troll harvest primarily takes Age 3 and older salmon and there can be considerable variation in the age-related harvest rates over time.

ACKNOWLEDGEMENTS

The authors wish to express their heart felt appreciation to all who have assisted us in the completion of this paper. Too many are the names who have provided in one way or another over the years to specifically mention here, so we simply say thank you to all.

LITERATURE CITED

Baker, P.F. and J.E. Morhardt. 2001. Survival of Chinook salmon smolts in the Sacramento-San Joaquin Delta and Pacific Ocean. In: Brown, R.L., editor. Fish Bulletin 179: Contributions to the biology of Central Valley salmonids. Volume 2. Sacramento (CA): California Department of Fish and Game. Pages 163-182.

Fry DH, Jr. 1961. King salmon spawning stocks of the California Central Valley, 1940–1959. California Fish and Game 47 (1):55–71

Healey, M. C. 1991. Life history of Chinook salmon. Pages 311–393 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver.

Jearld, A., Jr. 1983. Chapter 16 Age Determination. In L.A Nielsen and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Maryland. Pages 301-324.

Kope, R.G. and L.W. Botsford. 1988. Detection of environmental influence on recruitment using abundance data. Can. J. Fish. Aquat. Sci. 45:1448-1458.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fisheries Research Board of Canada, 191. Ottawa.

Schaefer, M. B. 1951. Estimation of the size of animal populations by marking experiments. *U.S. Fish and Wildlife Service Bull.*, **52**:189-203.

Seber, G. A. F., 1973, Estimation of animal abundance and related parameters, Griffin, London, 506pp

Speed, T. 1993. Chapter 13 Modelling and managing a salmon population, pages 267-293 *In* Barnett, V. and K.F. Turkman [ed.] Statistics for the Environment. John Wiley & Sons Ltd.

NOTES

Anderson, J.T., C.B. Watry, and A. Gray. 2007. Upstream fish passage at a resistance board weir using infrared and digital technology in the Lower Stanislaus River, California. 2006-2007 Annual Data Report produced for the U.S. Fish and Wildlife Service Anadromous Fish Restoration Program by Cramer Fish Sciences, Gresham, Oregon.

[CDFG] California Department of Fish and Game. 1990. Annual Report, Fiscal Year 1988–1989, San Joaquin River Chinook Salmon Enhancement Project. Sport Fish Restoration Act, Project F–51–R–1, Sub Project Number IX, Study Number 5, Jobs 1 through 7. Region 4, Fresno.

[CDFG] California Department of Fish and Game. 1991 to 1998. Annual Reports, Fiscal Years 1987–1997, San Joaquin River Chinook Salmon Enhancement Project. Sport Fish Restoration Act, Project F–51–R–4, Sub Project Number IX, Study Number 5, Jobs 1 through 7. Region 4, Fresno.

[CMC] Carl Mesick Consultants. 1994. The effects of streamflow requirements, water quality, Delta exports, ocean harvest, and El Nino conditions on fall-run Chinook salmon escapement in the San Joaquin River drainage. Draft report prepared for Stanislaus River Council. 28 November 1994. San Carlos, CA.

[CMC] Carl Mesick Consultants. 1996. The effects of minimum instream flow requirements, release temperatures, Delta exports, and stock on fall-run chinook salmon production in the Stanislaus and Tuolumne rivers. Draft report prepared for

Thomas R. Payne & Associates, Neumiller & Beardslee, and the Stockton East Water District. 10 May 1996. El Dorado, CA.

EA Engineering, Science, and Technology. 1991. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project. Appendix 1. San Joaquin River system Chinook salmon Population Model documentaiton and validation. Prepared for Turlock Irrication District and Modesto Irrigation District.

Guignard, J. 2006. Stanislaus River fall Chinook salmon escapement survey 2005. Report prepared for the U.S. Bureau of Reclamation, Contract # R0540004. California Department of Fish and Game, April 2006.

Guignard, J. 2007. Stanislaus River fall Chinook salmon escapement survey 2005. Report prepared for the U.S. Bureau of Reclamation, Contract # R0540004. California Department of Fish and Game, Revised March 2007.

Kano, R.M, R. Reavis, and F. Fisher. 1996. Chinook salmon spawning stocks in California's Central Valley, 1984. California Department of Fish and Game, Inland Fisheries Division, Administrative Report 96-3, Sacramento, California.

KRTT (Klamath River Technical Team). 1986. Recommended spawning escapement policy for Klamath River fall-run Chinook. Technical Report to Klamath Fishery Management Council. Available from Yreka Fish and Wildlife Office, U.S. Fish and Wildlife Service, 1829 S. Oregon Street, Yreka, California 96097. 73 pp.

Mesick, C.F., D. Marston, and T. Heyne. 2009. Estimating the total number of coded-wire-tagged adult fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley rivers. El Dorado, CA. 18 July 2009.

Neeley, D. 1997. Sensitivity of analyses of Stanislaus ocean recruits as a function of instream and ocean variables to different age-distribution and fecundity assumptions. Report prepared for Oakdale and South San Joaquin Irrigation Districts under subcontract to S.P. Cramer & Associates. Gresham, Oregon.

[PFMC STT] Pacific Fisheries Management Council Salmon Technical Team. 2000. STT Recommendations for hooking mortality rates in 2000 ocean recreational Chinook and coho fisheries. Salmon Technical Team Report B.2. Final. March 2000. Portland, OR.

[PFMC] Pacific Fisheries Management Council. 2008. Preseason Report I: stock abundance analysis for 2007 ocean salmon fisheries. February 2008. Portland, OR.

[PFMC] Pacific Fisheries Management Council. Undated. Review of the Ocean Salmon Fisheries reports for 2000 to 2005. Pacific Fisheries Management Council, 7700 NE Ambassador Place, Suite 200, Portland Oregon.

Reavis, R.L. 1986a. Chinook salmon spawning stocks in California's Central Valley, 1982. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report 84-10, Sacramento, California.

Reavis, R.L. 1986b. Chinook salmon spawning stocks in California's Central Valley, 1983. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report 86-01, Sacramento, California.

Reisenbichler R.R. 1986. Use of spawner-recruit relations to evaluate the effect of degraded environment and increasing fishing on the abundance of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in several California streams [Ph.D. dissertation]. Seattle (WA): University of Washington. 175 p.

[SJRGA] San Joaquin River Group Authority. 2003. 2002 annual technical report.on implementation and monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan. Prepared for the California State Water Resources Control Board in compliance with D-1641. January 2003.

[SJRRP] San Joaquin River Restoration Program. 2008. Conceptual models of stressors and limiting factors for San Joaquin River Chinook salmon. Distributed by the U.S. Bureau of Reclamation, Sacramento, CA in January 2008.

Speed, T.P. and F.K. Ligon. 1997. An environment-dependent stock recruitment model for Chinook salmon in the San Joaquin River system. Draft manuscript, 23 pp. + figures and tables. March 1997.

Figure 1. Map of the Stanislaus, Tuolumne, Merced and San Joaquin rivers and the Sacramento-San Joaquin Delta.

List of Footnotes

[i] Reported in the annual California Department of Fish and Game Anadromous Fisheries Branch Administrative Reports for the carcass surveys through fall 1983 and in the Inland Fisheries Branch Division Administrative Reports for the carcass surveys since fall 1984.