ESTIMATING THE TOTAL NUMBER OF CODED-WIRE-TAGGED ADULT FALL-RUN CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*) IN CALIFORNIA'S CENTRAL VALLEY RIVERS

CARL MESICK, Ph.D.
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

August 26, 2009

ABSTRACT

The Central Valley fall-run Chinook salmon CWT recovery database that we assembled provides data from 1979 to 2000 that were previously unavailable on the Regional Mark Information System, the most accurate estimates of the number of carcasses examined for ad-clips, and a new method for estimating the total number of CWT recoveries for rivers when the recovery data were either incomplete or nonexistent. Our analyses suggest that for the Central Valley rivers with hatcheries, the percentages of CWT recoveries in the river are the same as those at the hatcheries. This result provides the means to verify in-river CWT recovery rates and if necessary use the hatchery data to accurately estimate CWT recovery rates for the hatchery rivers. We also show that the CWT recoveries for the mainstem Sacramento River in 2003 and 2004 are related to those at the Tehama Colusa Fish Facility, the Coleman National Fish Hatchery, and the Feather River Hatchery. We use those relationships to estimate the CWT recovery rates for the Sacramento River when the CWT recovery data are absent or incomplete. Finally, we show that stray rates are relatively consistent between the Feather and Yuba rivers and between the Stanislaus, Tuolumne, and Merced rivers to a lesser degree. We use the mean stray rates to estimate CWT recovery rates for the Yuba, Stanislaus, and Tuolumne rivers during years when no accurate recovery data exists.

We recommend that for all future carcass surveys and CWT recovery efforts, accurate records must be kept of the number of carcasses examined for ad-clips, which are necessary to compute the total number of CWT returns in the salmon population. An

effective protocol for collecting CWT recovery data is particularly important for rivers that do not have salmon hatchery data that can be used to verify the in-river recovery data.

EXECUTIVE SUMMARY

Since 1973, juvenile fall-run Chinook salmon (*Oncorhynchus tshawytscha*) reared in California's Central Valley hatcheries have been marked with coded-wire tags (CWT) for estimating stock abundance, harvest rates, hatchery release locations, and assessing habitat management on juvenile survival rates (e.g., instream flow releases and diversion rates). However, only some of the CWT recovery data are reported in the Regional Mark Information System (RMIS), which is an online database managed by the Regional Mark Processing Center in Portland, Oregon.

Estimating the total number of CWT salmon in the Central Valley escapement is difficult for three reasons. First, the methods used for examining carcasses for ad-clips differed between Central Valley rivers and over time and the sampling protocols and counts of the number of carcasses examined were not always documented in the California Department of Fish and Game (CDFG) escapement reports. Second, some of the ad-clips on fresh and slightly decayed carcasses were missed because the survey crews were probably overwhelmed by their primary responsibility of tagging, recovering, and measuring thousands of carcasses for the purpose of estimating escapement. It is also possible that regenerated ad-clips are more difficult to detect on a decaying fish than on a freshly sacrificed fish in the hatchery and the percentage of regenerated ad-clips varies between rivers and over time depending on how completely the adipose fins are removed. Third, the accuracy and precision of the expanded estimates depend on examining either a large percentage (e.g., > 40%) of carcasses for ad-clips in the small tributary escapements or large numbers (e.g., > 1,000) of carcasses in the large tributary escapements because recovering CWTs can be analogous to looking for a needle in a haystack. Relatively few fish were examined when turbid flows or dangerous boating conditions made it difficult to collect more than a few carcasses in some years on the large Central Valley tributaries, which include the Feather, Yuba, American, Stanislaus, Tuolumne, and Merced Rivers as well as Mill and Deer Creeks. In addition, there are no CWT recovery data for some of the escapement surveys because either weirs were used to count live fish or conditions were too hazardous to complete the river surveys. This is a particular problem for the Sacramento and Mokelumne Rivers, which used counting weirs for most of the escapement estimates.

The Central Valley CWT fall-run Chinook salmon recovery database that we assembled provides data prior to 2000 that were previously unavailable on RMIS, the most accurate available estimates of the number of carcasses examined for ad-clips, and a new method for estimating the total number of CWT recoveries for rivers when the recovery data were either incomplete or nonexistent. Our analyses suggest that for the Central Valley rivers with hatcheries, the percentages of CWT recoveries in the river are the same as those at the hatcheries, which is consistent with a 2003 Battle Creek study. This result provides the means to verify in-river CWT recovery rates and if necessary use the hatchery data to accurately estimate CWT recovery rates for the hatchery rivers. Our analyses also suggest that the CWT recoveries for the mainstem Sacramento River in 2003 and 2004 are related to those at the Tehama Colusa Fish Facility, the Coleman National Fish Hatchery, and the

Feather River Hatchery. We use those relationships to estimate the CWT recovery rates for the Sacramento River when the CWT recovery data are absent or incomplete. Finally, we show that stray rates are relatively consistent between the Feather and Yuba rivers and between the Stanislaus, Tuolumne, and Merced rivers to a lesser degree. We use the mean stray rates to estimate CWT recovery rates for the Yuba, Stanislaus, and Tuolumne rivers during years when no accurate recovery data exists.

The percentage of Chinook salmon that were released as tagged (CWT) and associated untagged juveniles was as high as 42% in the San Joaquin Basin fall-run Chinook salmon escapements and 65% in the Sacramento River Basin fall-run Chinook salmon escapements during fall 2002, primarily as a result of increased tagging efforts. A mean of 37.2% of the fall-run Chinook salmon produced in Central Valley hatcheries were released in tagged and associated untagged groups for brood years 1977 to 2004, which corresponds to the mean percentages of the tagged and associated untagged recoveries in the fall-run escapement of 16.8% and 14.6% for the San Joaquin Basin and the Sacramento River Basin fall-run Chinook salmon escapements from 1980 to 2007. These results suggest that the mean percentage of hatchery fish in the Central Valley fall-run Chinook salmon escapement is about 42% from 1980 to 2007.

Our analyses do not conclusively prove that for the Central Valley rivers with hatcheries, the percentages of CWT recoveries in the river are the same as those at the hatcheries. Conclusive verification studies require that independent crews specifically examine salmon carcasses for ad-clips and regenerated ad-clips or CWTs with wands during the in-river carcass surveys and that the number of carcasses examined for ad-clips or CWTs is carefully recorded. These studies are necessary to improve the level of confidence in the CWT recovery estimates from 1979 to 2007. In particular, we suggest that verification studies should be on the mainstem Sacramento, Yuba, Mokelumne, and Stanislaus Rivers and Cottonwood and Clear Creeks.

We also recommend that for all future carcass surveys and CWT recovery efforts, accurate records must be kept of the number of carcasses examined for ad-clips, which are necessary to compute the total number of CWT returns in the salmon population. This may require additional crew members that have the sole responsibility of examining carcasses for ad-clips, taking the heads from those with ad-clips, and recording the number of fish examined. One possible solution would be to carefully examine a set number of fresh carcasses for ad-clips during the first part of the day, and then stop taking ad-clip data and heads for the remainder of the day. This should not increase the work load of the carcass survey crews but would provide highly accurate data. Another improvement would be to have a protocol for detecting regenerated ad-clips. A functional and effective protocol for collecting CWT recovery data is particularly important for rivers that do not have salmon hatchery data that can be used to verify the in-river recovery data.

INTRODUCTION

Since 1973, juvenile fall-run Chinook salmon (*Oncorhynchus tshawytscha*) reared in California's Central Valley hatcheries have been marked with coded-wire tags (CWT) for estimating stock abundance, harvest rates, hatchery release locations, and assessing habitat management on juvenile survival rates (e.g., instream flow releases and diversion rates). The CWT is a small piece of magnetized stainless steel wire with a binary code etched on the surface. A standard size CWT is 1.07 mm long x 0.25 mm diameter and is inserted into the snout of juvenile salmon larger than 2 grams in weight. During tagging, the juvenile fish have their adipose fin removed to signify the presence of the CWT throughout their lives. Marking with CWTs began at the Feather River Hatchery (FRH) in 1973, Tehama Colusa Fish Facility (TCFF) in 1975, Coleman National Fish Hatchery (CNFH) in 1976, Mokelumne River Fish Installation (MRFI) in 1977, Merced River Hatchery (MRH) in 1978, and the Nimbus Fish Hatchery (NFH) in 1983. The locations of the Central Valley salmon hatcheries are shown in Fig. 1. The TCFF was a 3.2-mile artificial spawning channel between Coyote Creek and the Tehama-Colusa Canal that operated between 1971 and spring 1986. The number of fall-run juvenile salmon marked with CWTs in all the Central Valley salmon hatcheries gradually increased from 169,886 for Brood Year 1973 to a high of about 19,247,806 for Brood Year 2001. In spring 2007, the Central Valley Constant Fractional Marking program began to consistently tag and ad-clip 25% of all juvenile salmon produced in the five Central Valley hatcheries (Pacific States Marine Fisheries Commission 2008).

Some of the data on the number of adult salmon marked with a CWT that were recovered during the escapement surveys or sampled from sport and commercial harvest are reported in the Regional Mark Information System (RMIS), which is an online database managed by the Regional Mark Processing Center in Portland, Oregon. RMIS provides the recovery data for adult salmon collected in the sport and ocean harvest, CNFH, and the TCFF for all years, and all the Central Valley inland recoveries for run years 2000 to 2007. Using a combination of the RMIS data and recovery data provided by California Department of Fish and Game (CDFG) and US Fish and Wildlife Service (USFWS) biologists, we developed a CWT recovery database for the fall-run Chinook salmon escapement surveys for run years 1979 to 2007.

The CWT database includes both 1) the recovery data and 2) the expanded estimates of the total number of CWT hatchery salmon in the fall-run escapement and harvest. The expansions are necessary because not all adult salmon in the escapement are examined for a clipped adipose fin (ad-clip) that signifies the presence of a CWT. The expanded estimates are made by multiplying the number of CWT recoveries by the escapement estimate and then dividing by the number of fish examined for ad-clips (i.e., CWTs). The number of fish examined for ad-clips is relatively easy to obtain for the hatcheries and the ocean harvest. All of the fish recovered at the hatcheries were visually examined for ad-clips based the information provided by the CDFG and the USFWS to RMIS. For the ocean harvest estimates, RMIS provides both the expansion factors and the estimated expanded estimates that are specific for each harvest type and location. For run years 1985 to 2005, a mean of 27.4% (range of 23% to 41%) of the total catch in the sport harvest and a mean of 25.0% (range of 15 to 39%) of the commercial troll catch were examined for ad-clips by the CDFG.

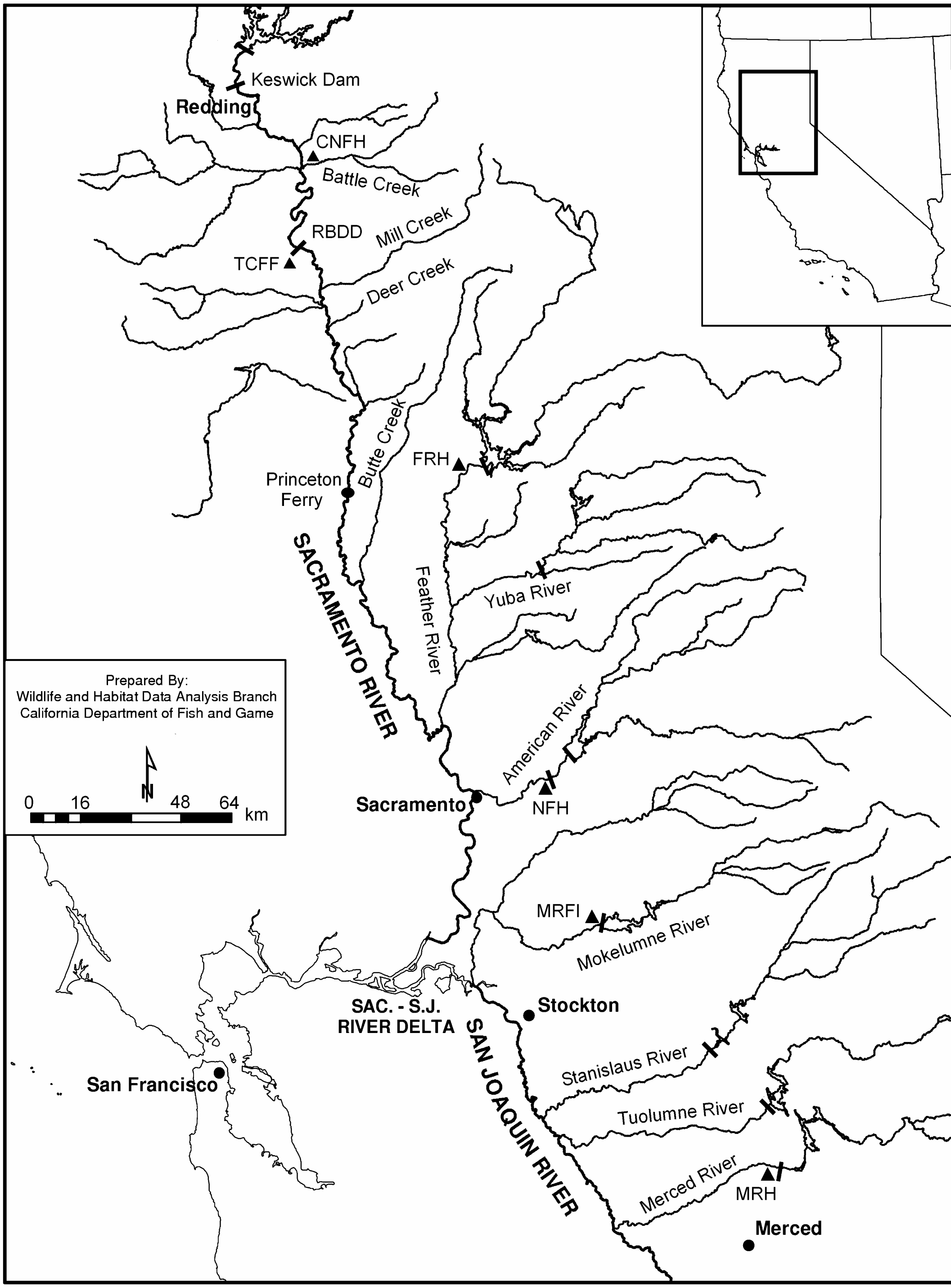
Estimating the total number of CWT salmon in the Central Valley escapement is difficult for three reasons. First, the methods used for examining carcasses for ad-clips differed between Central Valley rivers (Fig. 1) and differed over time and the sampling protocols were not always documented in the CDFG escapement reports. For example on the Mokelumne River, all carcasses were examined with a CWT wand since 2003 to verify whether a CWT was present (Workman, personal communication, see "Notes"). For the Stanislaus, Tuolumne, and Merced rivers, a wand is not used and the sampling protocol is that fresh carcasses (those with at least one clear eye and reddish colored gills) and the slightly decayed carcasses (those with two cloudy eyes) that were tagged for the escapement estimate and then measured and sexed were visually examined for ad-clips; whereas the highly decayed fish (called skeletons) that are covered with fungus are not examined for ad-clips because they are too decayed to determine whether a missing adipose fin was due to a clip during tagging or due to natural decay. On the Yuba (Massa, personal communication, see "Notes") and American rivers (Healey, personal communication, see "Notes") only fresh fish were examined for ad-clips in recent years. Unfortunately for many of the older escapement surveys, there is little or no information on the number of fish examined for ad-clips in the CDFG escapement reports. In these cases, we assume that the number of fish examined for ad-clips is equal to the number of fresh carcasses and the slightly decayed carcasses that were tagged for the escapement estimates and then measured and sexed. This protocol was mentioned in the early Feather and Yuba River escapement reports and was typically used for most Central Valley surveys at least through the early 2000s. However in some cases, the number of fresh and slightly decayed fish was not provided in the CDFG escapement reports and so it is not possible to directly estimate the total number of CWT recoveries for these surveys.

A second problem for estimating the total number of CWT salmon in the Central Valley escapement is that some of the ad-clips on fresh and slightly decayed carcasses were missed because the survey crews were probably overwhelmed by their primary responsibility of tagging, recovering, and measuring thousands of carcasses for the purpose of estimating escapement. The USFWS conducted a study in Battle Creek from 2000 to 2002 when they showed that their crew, which looked specifically for ad-clips, observed a 3.0 to 3.4 times higher percentage of ad-clips than the escapement survey crew (Null et al. 2003).

A third problem for estimating the total number of CWT salmon in the Central Valley escapement is that the accuracy (i.e., veracity) and precision (i.e., reproducibility) of the expanded estimates depend on examining either a large percentage (e.g., > 40%) of carcasses for ad-clips in the small tributary escapements or large numbers (e.g., > 1,000) of carcasses in the large tributary escapements because recovering CWTs can be analogous to looking for a needle in a haystack. For example, the mean survival rate of juvenile CWT salmon to adulthood (i.e., recovered in the escapement) that were released into the Merced River at the hatchery from years 2000 to 2004 was 0.074%. When 25,000 tagged juveniles were released in the Merced River (as was common), then only 18 would be expected to return as adults. In 1987, only 4.5% of the adult carcasses in the Merced River escapement were examined for ad-clips and so only 0.83 carcasses with a CWT would have been expected to have been recovered for this imaginary CWT lot. Therefore, examining relatively few carcasses in the escapement survey creates a high likelihood that no adults carcasses would be recovered for some CWT lots whereas unusually high recoveries (1 or 2 fish) could occur for other CWT lots simply due to chance, thereby creating the likelihood for inaccurate estimates.

The problem of examining too few salmon carcasses for ad-clips occurred in several of the Central Valley rivers. In particular, the escapement surveys for the mainstem Sacramento River, which typically has the greatest percentage of fall-run Chinook salmon in the Central Valley escapement, are mostly based on ladder counts at the Red Bluff Diversion Dam (RBDD) or aerial redd surveys during which few if any fish were examined for ad-clips. The same was true for the Mokelumne River, which usually relied on ladder counts at the Woodbridge District Irrigation Dam. The Battle Creek surveys switched from tagging carcasses to video monitoring in fall 2006 and 2007 and so few carcasses were examined for ad-clips in 2006 and 2007.

Figure 1



In addition, turbid flows and dangerous boating conditions made it difficult to collect and examine more than a few carcasses in some years on the large Central Valley tributaries, which include the Feather, Yuba, American, Stanislaus, Tuolumne, and Merced Rivers as well as Mill and Deer Creeks. Fortunately, relatively large numbers of fish were examined for ad-clips on Battle Creek during most surveys through fall 2005 and for the other major Central Valley tributaries during recent years. The small Central Valley tributaries that are not sampled or sampled infrequently typically contribute no more than 2% of the total fall-run escapement for the Central Valley. Therefore the absence of CWT data from these smaller tributaries should not substantially affect CWT analyses.

In this paper, we identify our sources of data used to create a Central Valley database of CWT recoveries for the fall-run Chinook salmon surveys from 1979 to 2007. A particular concern was to identify when the number of adult carcasses examined for CWTs was reported and when it was necessary to estimate this number based on other counts. We also describe the relationships between the river and hatchery CWT recovery percentages that we use to compute expanded CWT abundance estimates for rivers with inaccurate or no CWT recovery data. We have identified five critical hypotheses that affect the methods used for expanding in-river CWT recoveries:

1. The counts of the number of adult fish examined for CWTs were highly accurate at all of the Central Valley salmon hatcheries, including the TCFF. The hatcheries have relatively large crews with member(s) that focus on identifying ad-clips, sex, and whether the fish are adults or grilse. In comparison, the carcass survey crews are relatively small and their members usually have a greater number of duties that

make it more likely that some ad-clips are missed. We do not test this hypothesis here.

2. Adult salmon randomly enter the hatchery or spawn in the river regardless of whether they were naturally produced or hatchery produced such that the percentage of adult salmon with CWTs in the hatchery is the same as the percentage of adult salmon with CWTs that spawn naturally in the same river. Null et al. (2003) showed that the percentage of ad-clips in Battle Creek (mean 6.4%) was similar to the percentage of ad-clips at the CNFH (mean 6.6%) from 2000 to 2003 when the in-river crews had the specific task of looking for ad-clipped carcasses. We test this hypothesis by comparing the ratio of in-river to hatchery recoveries for in-basin hatchery fish to the ratios for out-of-basin hatchery fish. We assume that out-of-basin hatchery fish would not home to the hatchery whereas the in-basin hatchery fish might home to their hatchery of origin, thereby resulting in different ratios between the in-basin and out-of-basin if this hypothesis is false.
3. The counts of the number of salmon carcasses examined for CWTs were accurate for the major Central Valley rivers in recent years, when new sampling protocols to recover CWTs were initiated. The most accurate data were provided by the Fish and Wildlife Service Red Bluff Office (Null et al. 2003) that conducted separate surveys to specifically count ad-clipped carcasses in Battle Creek during fall 2000 to 2002. The need to improve CWT recovery data on other Central Valley rivers was discussed in 2001 by the Interagency Ecological Program Salmonid Escapement Project Work Team. New sampling protocols were established and the

recovery data were well documented on the Feather River beginning in fall 2000, American River in fall 2003, Mokelumne River in fall 2003, and the San Joaquin tributaries in fall 1998. We test this hypothesis by comparing the ratio of in-river recoveries to hatchery recoveries between the recent years with the new sampling protocols and the previous years when the protocols and results were not well documented.

4. The percentage of ad-clips of CNFH, FRH, NFH, MRFI and MRH produced salmon that were recovered at the TCFF was the same as those that returned to the mainstem Sacramento River. The TCFF was an artificial spawning channel connected to Coyote Creek, which was about mid way within the Chinook salmon spawning reach in the mainstem Sacramento River (Fig. 1). The flows in the TCFF originated from the Sacramento River via the Tehama Diversion Canal and so upstream migrating salmon would not be expected to differentiate between the TCFF and the Sacramento River based on the water's scent. We present data on the CWT recoveries in the TCFF and the CWT recoveries during Sacramento River carcass surveys to test this hypothesis.
5. The rate that adult salmon stray to the non hatchery rivers is relatively constant over time for a given hatchery and planting location. The homing behavior of adult Chinook salmon is thought to be primarily affected by location where the juvenile fish were planted (Quinn 1993, 2005), the release of an attraction flow from the natal river (i.e., olfactory cues) during the upstream migration (Mesick 2001), and genetics (Bams 1976, McIsaac and Quinn 1988). Pheromones released from other

salmon may affect the selection of specific spawning sites or entry into a hatchery (Quinn 2005). Since most of the large Central Valley rivers, with the exception of the San Joaquin River tributaries during drought years, have adequate attraction flows (Mesick 2001), the rate that the adult salmon stray should remain relatively constant over time for a given hatchery and a planting location. For example if this hypothesis is true, then the mean of 20.5% of the CWT recoveries of FRH smolts planted in the Delta and Bay that returned to the Yuba River compared to the number that returned to the Feather River in 1991 and 2005 would not be substantially different from the rate that the FRH Delta and Bay plants strayed to the Yuba River during other time periods. We cannot fully test this hypothesis because without a hatchery or other data to evaluate the accuracy of the CWT recovery data for the non hatchery rivers, it is impossible to determine whether a lack of a consistent stray rate is due to inaccurate recovery estimates or a false hypothesis.

METHODS

The following describes how we assembled our database of escapement estimates, estimates of the number of fish examined for ad-clips, CWT recoveries, and expanded estimates of the total number of CWT salmon in the fall-run Chinook salmon escapement surveys from 1979 to 2007 in Central Valley rivers.

Central Valley Escapement Estimates

We used the March 2009 CDFG GrandTab document for the escapement estimates needed to expand the CWT recoveries. The GrandTab document is a compliation of the final Chinook salmon escapement estimates through 2006 and the preliminary estimates for 2007 and 2008. It can be downloaded from the CalFish.org web site:

http://www.calfish.org/IndependentDatasets/CDFGFisheriesBranch/tabid/157/Default.aspx

Missing Escapement Estimates

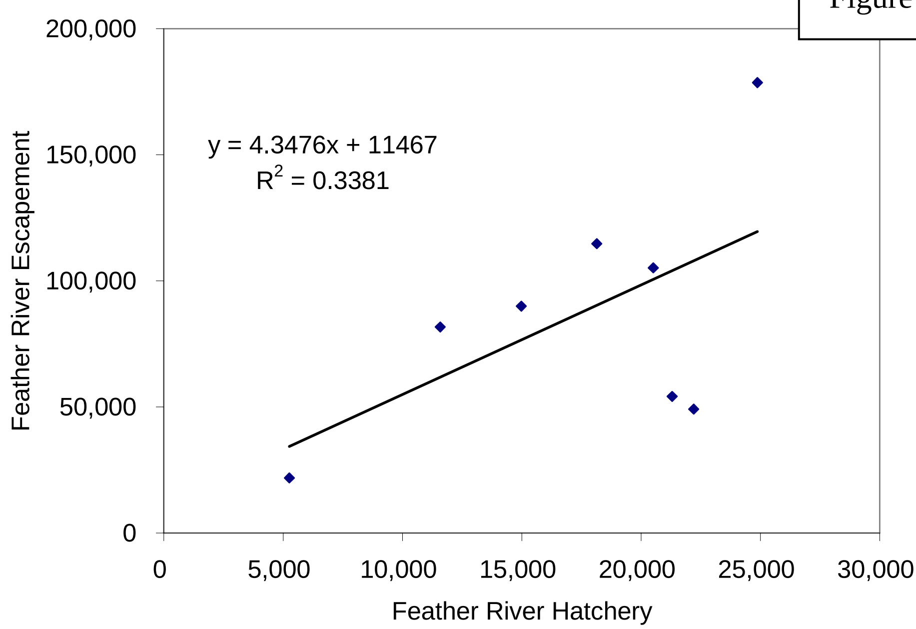
There are no escapement estimates for some of the major tributaries in some years and these missing estimates substantially affect the ability to conduct some CWT analyses. In particular, using CWT analyses to evaluate the survival of juvenile salmon requires an estimate of the total number of adult salmon in the same cohort (a.k.a. brood year). Each escapement contains salmon that belong to up to four cohorts (ages 2, 3, 4, and 5) and so one missing escapement estimate precludes the accurate computation of abundance for up to four cohorts. In addition, a missing estimate on one Central Valley river affects the ability to assess straying rates, and to a lesser degree, survival rates and harvest rates, for all hatchery releases for that year.

CDFG has used hatchery returns to help estimate the in-river escapement for the Mokelumne River when flows were too high to conduct the carcass surveys and we use the same principle to generate escapement estimates for other Central Valley rivers that have no CDFG GrandTab estimate. In fall 1982 and 1983, flows on the Mokelumne River were too high to conduct escapement surveys and so CDFG estimated escapement based on the strong relationship (r = 0.88) between past hatchery returns and in-river escapement for the period between 1972 to 1981 (Reavis 1986a, 1986b). In addition to the Mokelumne River, there are no GrandTab estimates for the Feather River in 1990, 1998, and 1999; the Yuba River in 1990; and the Stanislaus River in 1982. In addition, there are two GrandTab estimates for the Stanislaus River in fall 1983 and 1996 that obviously underestimate the true escapement. In 1983 and 1996, few carcasses were tagged, none were recovered, and the Stanislaus River estimates were unusually low compared to the escapements in the Tuolumne and Merced Rivers where the carcass surveys tagged and recovered sufficient numbers of carcasses to generate the escapement estimates.

We generate the following estimates for the above missing or inaccurate GrandTab estimates for the Feather, Yuba, and Stanislaus Rivers using linear regression analyses between the escapements for these rivers and other rivers or hatcheries in the same basin during periods when the escapement estimates are believed to be the most accurate. The following linear regression models have relatively low to moderate R^2 values and so the estimates may not be very accurate. We suggest that they should only be used for general analyses such as estimating ocean harvest rates, straying rates, and general trends in the hatchery populations.   More specific analyses, such as investigating the effects of specific management actions on juvenile survival rates, should use these escapement estimates with caution.

Feather River - We first computed a linear regression model between Feather River escapement and Feather River Hatchery returns from 2000 to 2007 (Fig. 2), which are probably the most accurate Feather River escapement estimates (Anonymous 2001). We then input the GrandTab estimates for the FRH escapements into the model to compute Feather River escapement estimates of 38,109, 93,589, and 67,668 for fall 1990, 1998, and 1999, respectively.

Figure 2

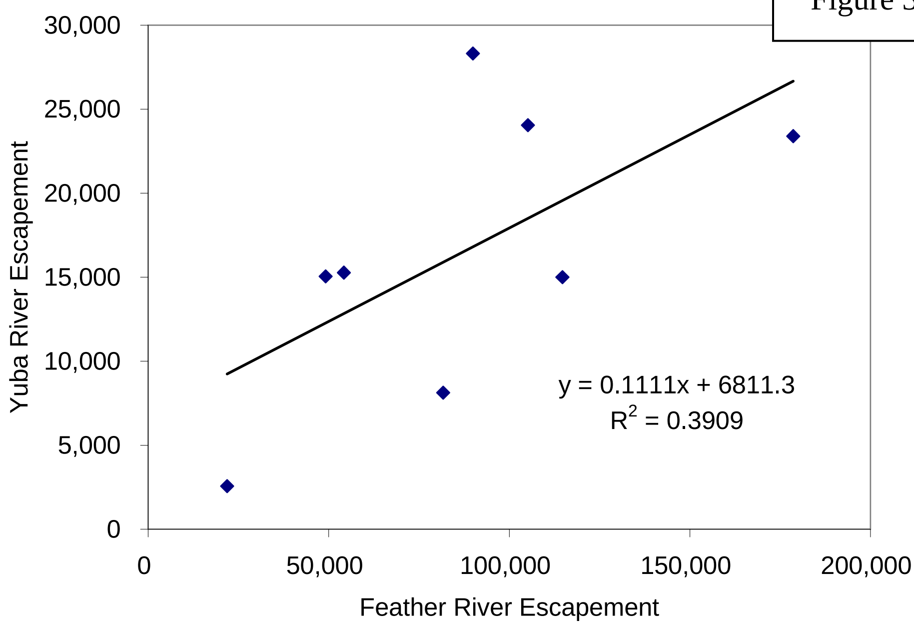


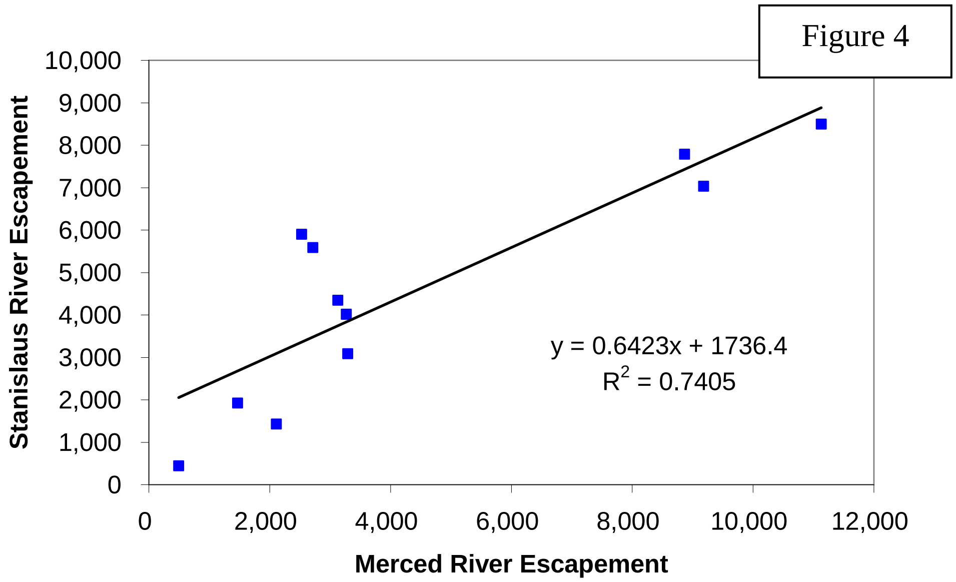
Yuba River - We first computed a linear regression model between Yuba River escapement and Feather River Hatchery returns from 2000 to 2007 (Fig. 3). We then input the above

1990 Feather River escapement estimate of 38,109 into the model to compute a 1990 Yuba River escapement estimate of 11,045.

Stanislaus River - We first computed a linear regression model between the Stanislaus River and Merced River escapements from 1997 to 2007 (Fig. 4), when carcass survey efforts were increased on the Stanislaus River (Mesick et al. 2009). We then input the 1982, 1983, and 1996 GrandTab estimates for the Merced River into the model to compute of Stanislaus River escapement estimates of 3,711, 12,304, and 3,850 for fall 1982, 1983, and 1996, respectively.

Figure 3





CWT Recovery Data Set

We obtained CWT recovery data from five different sources.

1. The escapement survey database provided by the CDFG's Tuolumne River Restoration Center (TRRC) for the Stanislaus, Tuolumne, and Merced rivers that included CWT recovery data. The TRRC processes the heads from the ad-clipped carcasses and reads the CWTs and so their database was judged to be the most accurate for San Joaquin Basin fish.
2. Microsoft Excel files of the inland CWT recoveries for the Central Valley escapement surveys for 1975 to 2004 that were provided to RMIS by the CDFG Ocean Salmon Project (Neillands, personal communication, see "Notes"). These files included all data collected on every fish collected that had an ad-clip for most Central Valley rivers and hatcheries, except for the CNFH in 1991 and from 1995 to 2004. There are a few instances where the tag code in the database did not

match any release data at RMIS and so we assume that these codes were misread.

3. We obtained the CWT recovery data for Battle Creek from 1987 to 2005 from the CDFG Red Bluff office (Harvey Arrison, personal communication, see “Notes”). We assumed that this database would be more accurate than those provided by the Ocean Salmon Project, although we did not check for descrepancies.
4. We obtained the CWT recovery data for the CNFH for fall 2007 from the USFWS Red Bluff office (Niemela, personal communication, see “Notes”).
5. We obtained CWT recovery data from RMIS by running queries on all fish recovered for the entire list of Central Valley rivers and hatcheries during the Chinook salmon escapement surveys (species code 1, fishery codes 50 and 54, sampled run code 3 for fall-run) from 1979 through 2007. The queries were not restricted to only fall-run since some spring-run and late fall-run Chinook salmon are recovered during the fall-run surveys and they are included in the fall-run escapement estimates. This database was used for all recoveries at the CNFH from 1979 to 2006 and most Central Valley rivers, except the San Joaquin Basin and Battle Creek, from 2000 to 2007. We also obtained CWT release data from RMIS for all tag codes released in the Central Valley. For each tag code released in the Central Valley, we ran separate RMIS queries to obtain the estimated number of CWT recoveries in the ocean and sport harvest. We computed a combined commercial ocean harvest estimate called “Troll” that summed all the RMIS fishery codes from 10 to 39, 80 to 99, and 803 and a combined sport harvest estimate called “Sport” that summed all the RMIS fishery codes from 40 to 49.

All of these databases provide information on each individual fish recovered. We used the Pivot Table function in Microsoft Excel to count the number of recoveries for each tag code by river. In those cases where the code that signified that the CWT was recovered during the fall-run carcass survey was not provided, we sorted the data by recovery date and assumed that all recoveries between October 1 and December 31 were made during the fall-run survey. This was particularly important for the CNFH and FRH where multiple salmon runs are taken. We also excluded CWT recoveries made using alternative methods, such as counting weirs and creel surveys, since these fish are not of the CDFG escapement estimate.

It is important to note that all CWT fish collected during the fall-run surveys are not fall-run Chinook salmon and all fall-run Chinook salmon are not collected during the fall-run surveys. The fall-run surveys frequently include some spring-run and late-fall run fish that returned between early October and late December. Conversely, fall-run fish that return in September would be included in the spring-run escapement estimates and those that return in January would be included in the late fall-run escapement estimates.

Our analyses of CWT recoveries includes not only the recovered tags, but also the number of heads collected that either did not contain a CWT (CDFG code 100,000 or 200,000) or had an unreadable CWT (CDFG code 400,000) as well as the number of ad-clips observed but no heads were taken (CDFG code 300,000). RMIS includes other codes such as unresolved and pseudotags. It is particularly important to include the number of ad-clips observed but no heads taken because these numbers are highly variable and can be quite large. The carcass surveys on Battle, Mill, Deer, and Cottonwood Creeks are done by foot and the crew can only take as many heads from ad-clipped fish as can be carried in back packs. As a result, many heads with CWTs are not taken from the ad-clipped fish when escapements are high. Some of the CWT databases did not provide a code or description for heads without CWTs.

Number of Carcasses Examined for Ad-Clips

We obtained estimates of the number of carcasses examined for ad-clips during the escapement surveys from individual tributary reports, databases, or communication with the carcass survey leader where possible, and otherwise from the DFG annual Central Valley reports and RMIS. These sources contained six different sets of estimates:

1. Direct counts of the number of carcasses examined for ad-clips;
2. Counts of the number of fresh and slightly decayed carcasses that were tagged, measured, and sexed that were presumably examined for ad-clips;
3. Counts of the number of fresh carcasses tagged to estimate escapement that were presumably somewhat lower than the number examined for ad-clips because some decayed carcasses were examined for ad-clips but not tagged or otherwise counted;

4. Counts of all carcasses observed, which presumably included some carcasses that were too decayed to detect an ad-clip (e.g., skeletons);
5. The Battle Creek verification studies (Null et al. 2003) provided accurate counts of the number of ad-clips and the number of carcasses examined for ad-clips in Battle Creek in fall 2000 to 2002 and these data were used to correct the DFG counts of the number of carcasses examined during the corresponding Battle Creek escapement surveys; and
6. No data on the number of carcasses observed were reported.

The individual tributary reports, databases and carcass survey leader communications gave the best description of the condition of the carcasses examined for ad-clips (Hartwigsen, Harvey Arrison, Healey, Killam, Khirihara, Massa, Null, Theis, Tsao, Workman, personal communications, see “Notes”). The counts for the Sacramento River Basin and San Joaquin River Basin are presented in Tables 1 and 2, respectively.

Based on the few highly detailed reports that are available, it is not possible to assess whether the number of total carcasses observed during the carcass surveys contain highly decayed carcasses or only the relatively fresh fish that were all examined for ad-clips. For example during fall 2004, only 405 of the 1,261 total carcasses observed in Mill Creek were examined for ad-clips, measured, and sexed (Kano 2006, Null, personal communication, see “Notes”); whereas all 1,636 carcasses observed in Butte Creek were examined for ad-clips (McReynolds et al. 2005).

Inaccurate Estimates of Number of Carcasses Examined for Ad-Clips

Hatchery Rivers - The Battle Creek study (Null et al. 2003) indicated that the percentage of ad-clips in the river was similar to the percentage of ad-clips in the CNFH. The mean percentage of ad-clips in Battle Creek and the hatchery were 6.36% (4.33% to 8.14%) and 6.55% (5.80% to 7.72%), respectively. This result suggests that our second hypothesis is true that the tagged and untagged salmon were randomly entering the hatchery and that the percentages of tagged fish should be the same in the river and the hatchery for all Central Valley hatchery rivers. We test this hypothesis for the other hatchery rivers by comparing the ratio of in-river to hatchery recoveries of in-basin hatchery fish to out-of-basin hatchery fish. We assume that out-of-basin hatchery fish would not home to the hatchery whereas the in-basin hatchery fish is likely to home to their hatchery of origin, thereby resulting different ratios between the in-basin and out-of-basin fish if this hypothesis is false.

Testing the second hypothesis was complicated because the tests required that our third hypothesis, that the counts of the number of salmon carcasses examined for CWTs were accurate for the major Central Valley rivers in recent years, was true. The Battle Creek study (Null et al. 2003) indicates that the reported number of carcasses examined for ad-clips was about three times greater than the actual number of carcasses examined for surveys conducted in 2000 to 2002. The Null et al. study crew observed that 6.62%, 4.33%, and 8.14% of the examined carcasses had ad-clips in 2000, 2001, and 2002 respectively. In contrast, the DFG escapement crew reported that 1.94%, 1.45%, and

2.39% of the examined carcasses had ad-clips in 2000, 2001, and 2002, respectively. We corrected the count of the number of carcasses examined for ad-clips for the DFG surveys from 2000 to 2002 by multiplying the DFG counts by the ratio of the DFG percentage of ad-clips to the Null et al. verification study's percentage of ad-clips. For example in fall 2000, DFG reported that 22,656 carcasses were examined for ad-clips. We multiplied this estimate by 0.293 (1.94/6.62) for a corrected count of 6,639 carcasses examined (Table 1). The Null et al. study crew did not collect heads from the ad-clipped carcasses, and so no further comparisons were possible.

We believe that most of the recent counts of the number of carcasses were accurate for the other hatchery rivers, particularly when escapements were not so high that the crews were overwhelmed by their task of tagging the carcasses to estimate escapement, because new sampling protocols to recover CWTs had been initiated in response to the need to assess the contribution rates of hatchery fish to Central Valley salmon populations (Pacific States Marine Fisheries Commission 2008). As mentioned previously, we had accurate data for Battle Creek from 2000 to 2002 based on the Null et al. study (2003). The new sampling protocols were established and the recovery data were well documented on the Feather River beginning in fall 2000, American River in fall 2003, Mokelumne River in fall 2003, and the San Joaquin tributaries in fall 1998. We test our third hypothesis by comparing the ratio of in-river recoveries to hatchery recoveries between the recent years with the new sampling protocols and the previous years when the protocols and results

Table 1. The number of Chinook salmon carcasses examined for ad-clips during the Sacramento River Basin fall-run Chinook salmon surveys from 1979 to 2007. The number examined counts are followed by a dash and two codes. The first numeric code indicates the certainty of the count: 1 = number of ad-clips examined reported; 2 = number of carcasses sexed and measured and presumably examined for ad-clips; 3 = number of carcasses tagged for the purpose of estimating escapement that presumably does not include all decayed carcasses examined for ad-clips; 4 = total number of carcasses observed that presumably includes highly decayed carcasses that were not examined for ad-clips; and 5) the corrected number of carcasses observed in Battle Creek in fall 2000 to 2002 based on Null et al. (2003) computed by multiplying the reported number by 0.293, 0.333, and 0.294 for 2000, 2001, and 2002 respectively. The second code is a letter corresponding to the source of information: A = tributary report or communication with carcass survey leader; and B = California Department of Fish and Game Reports “Chinook Salmon Spawning Stocks in California’s Central Valley, 1979-2004. The code “NS” indicates that no carcass survey was conducted.

Run Year	Clear Cr	Battle	Cottonwood	Sacramento Above RBDD	Sacramento Below RBDD	Mill	Butte	Deer	Feather	Yuba	American
1979	NS	Unknown	NS	0	1,093-3B	162-3B		156-3B	2,107-1B	890-1B	667-2B
1980	NS	Unknown	NS	Unknown	Unknown	32-3B		21-3B	3,003-1B	2,095-1B	1,968-1B
1981	647-4B	Unknown	410-4B	Unknown	Unknown	102-4B	0	82-4B	2,518-1B	1,083-1B	659-1B
1982	491-4B	Unknown	Unknown	0	Unknown	129-4B		48-4B	3,212-2B	703-1B	Unknown
1983	NS	Unknown	Unknown	0	Unknown	20-4B	49-4B	37-4B	1,670-1B	413-2B	Unknown
1984	100-4B	2,272-2B	Unknown	0	Unknown	580-4B		68-4B	3,268-2B	557-2B	586-2B
1985	NS	5,924-2B	NS	0	Unknown	384-4B	14-4B	90-4B	5,590-2B	1,266-3B	Unknown
1986	429-4B	4,233-2B	290-4B	0	0	287-4B		92-4B	2,292-2B	1,336-2B	1,005-2B
1987	322-2B	2,604-2B	NS	0	0	127-4B		29-4B	3,566-2B	1,328-2B	649-2B
1988	1,142-4B	14,850-2B	NS	0	0	394-2B	143-4B	13-4B	Unknown	2,482-3B	Unknown

Run Year	Clear Cr	Battle	Cottonwood	Sacramento Above RBDD	Sacramento Below RBDD	Mill	Butte	Deer	Feather	Yuba	American
1989	750-2B	6,609-2B	34-4B	0	0	334-2B		105-2B	3,719-2B	464-3B	Unknown
1990	370-2B	3,816-2B	NS	0	0	NS		NS	Unknown	NS	Unknown
1991	1,020-2B	3,500-2B	205-2B	0	0	37-4B		NS	1,420-2B	1,252-3B	Unknown
1992	34-4B	3,777-2B	851-4B	0	0	290-4B		10-4B	1,710-2B	464-3B	Unknown
1993	160-3B	3,716-2B	NS	0	0	67-4B		NS	3,158-2B	375-3B	Unknown
1994	663-4B	11,370-2B	NS	0	0	Unknown		NS	4,115-2B	1,056-3B	Unknown
1995	3,828-2B	25,501-2B	NS	0	0	NS		NS	4,389-2B	854-1A	Unknown
1996	2,807-2B	18,550-2B	NS	0	0	NS		NS	5,224-2B	1,214-1A	Unknown
1997	2,479-2B	14,068-2B	NS	0	0	109-2B		307-2B	2,127-2B	1,750-1A	Unknown
1998	1,875-2B	Unknown	NS	0	0	112-4B		89-4B	Unknown	2,078-1A	Unknown
1999	2,302-2B	21,656-2B	NS	0	0	NS		NS	Unknown	1,588-1A	Unknown
2000	3,281-2B	6,639-5B	NS	0	0	NS	714-4B	NS	6,224-1A	1,585-1A	Unknown
2001	3,868-2B	8,189-5B	NS	1,277-2B	0	NS	1,701-2B	NS	5,246-1A	1,163-1A	Unknown
2002	6,117-2B	5,360-5B	NS	1,414-3B	0	1,671-2B	1,631-1A	34-4B	3,234-1A	1,742-1A	4,125-1A
2003	4,609-2B	30,005-2B	210-1B	1,148-1A	0	1,295-2B	1,875-1A	22-4B	6,047-1A	1,854-1A	6,468-1A
2004	3,225-1A	2,151-1A	NS	1,565-1A	0	405-1A	1,636-1A	130-1A	4,040-1A	1,280-1A	4,695-1A
2005	5,619-1A	10,258-1A	NS	3,419-1A	0	1,114-1A	2,345-1A	485-1A	3,107-1A	1,729-1A	2,835-1A
2006	4,923-1A	NS	NS	6,084-1A	0	748-1A	1,116-1A	1,275-1A	3,913-1A	1,269-1A	1,451-1A
2007	2,613-1A	NS	NS	874-1A	358-1A	396-1A	5,020-1A	391-1A	1,664-1A	3,46-1A	714-1A

Table 2. The number of Chinook salmon carcasses examined for ad-clips during the San Joaquin River Basin fall-run Chinook salmon surveys from 1979 to 2007. The number examined counts are followed by a dash and two codes. The first numeric code indicates the certainty of the count: 1 = number of ad-clips reported; 2 = number of carcasses sexed and measured and presumably examined for ad-clips; 3 = number of carcasses tagged for the purpose of estimating escapement that presumably does not include all decayed carcasses examined for ad-clips; and 4 = total number of carcasses observed that presumably includes highly decayed carcasses that were not examined for ad-clips. The second code is a letter corresponding to the source of information: A = tributary report or communication with carcass survey leader; B = California Department of Fish and Game Reports "Chinook Salmon Spawning Stocks in California's Central Valley, 1979-2004; and C = Regional Mark Information System. The code "NS" indicates that no carcass survey was conducted.

Run Year	Cosumnes	Mokelumne	Stanislaus	Tuolumne	Merced
1979	Unknown	Unknown	44-2A	358-2A	95-2A
1980	14-3B	91-3B	15-4B	198-2A	339-2A
1981	Unknown	136-1B	26-2A	703-2A	Unknown
1982	NS	0	Unknown	239-2A	126-2A
1983	NS	0	Unknown	347-1A	1,124-2A
1984	162-4B	302-2B	386-2B	944-1A	448-2B
1985	86-4B	118-2B	515-2A	1,052-1A	535-2B
1986	NS	146-2B	388-2A	806-1A	291-2B
1987	NS	Unknown	405-2A	1,446-1A	138-2A
1988	NS	6-3B	395-2A	719-1A	173-2A
1989	NS	Unknown	651-2A	625-1A	57-2A
1990	NS	NS	165-2A	33-2A	16-2A
1991	NS	NS	105-2A	20-1A	11-2A
1992	NS	NS	71-2A	47-1A	129-2A
1993	NS	NS	89-2A	169-1A	538-2A
1994	NS	NS	278-2A	81-1A	1,023-2A
1995	NS	NS	144-2A	415-1A	313-2A
1996	NS	NS	48-2A	1,186-1A	1,260-2A

1997	NS	NS	603-2A	1,056-1A	777-2A
1998	40-2B	NS	269-2A	2,170-1A	1,033-2A
1999	NS	NS	646-2A	2,375-1A	798-2A
2000	NS	NS	673-2A	2,162-1A	758-2A
2001	NS	NS	950-2A	1,808-1A	1,101-2A
2002	NS	NS	1,912-2A	1,795-1A	978-2A
2003	NS	429-1A	1,929-2A	585-1A	549-2A
2004	NS	580-1A	1,107-2A	529-2A	784-2A
2005	NS	5,924-1A	450-2A	176-2A	366-2A
2006	Unknown-1C	459-1A	233-2A	91-2A	257-2A
2007	Unknown-1C	135-1A	19-2A	37-2A	86-2A

were not well documented. The comparisons were made for both in-basin hatchery fish and out-of-basin hatchery fish.

Non Hatchery Rivers – To evaluate the accuracy of the recovery data for non-hatchery rivers, which include the Sacramento, Yuba, Stanislaus, and Tuolumne rivers, we utilized a two-phase approach. We first needed to know how trucking juvenile hatchery salmon to downstream areas (e.g., San Pablo Bay) affected their ability to home back to their natal stream. The CWT recovery data show that juvenile salmon that are trucked downstream home at a lower rate than those that are released in their natal rivers. For example, means of 16.0% (0.7% to 24.7%) and 42.2% (30% to 52.6%) of FRH produced salmon strayed to other Central Valley rivers depending on whether the FRH juveniles were planted in the Feather River or the Delta and Bay, respectively, from 2000 to 2007 based on our database estimates. Therefore, we began by investigating the relationships between the number of ad-clip recoveries sorted by 1) in-river juvenile releases, 2) mainstem juvenile releases downstream to Rio Vista on the Sacramento River, Bean Ranch Road on the Mokelumne River, and Dos Reis on the San Joaquin River, 3) Delta and Bay juvenile releases upstream to Collinsville on the Sacramento River, New Hope Landing on the Mokelumne River, and Jersey Point on the San Joaquin River, and 4) other hatchery strays between the non hatchery river and a nearby hatchery river with relatively accurate recovery data. We made two separate comparisons with the recoveries for the Sacramento River: one with the final estimates for Battle Creek and CNFH as a combined population and the other with the Feather River and FRH as a combined population. We compared the recoveries in the

Yuba River with the final estimates for the Feather River and the FRH as a combined population. We compared the recovery estimates for the Stanislaus and Tuolumne Rivers with the final estimates for the Merced River and the MRH as a combined population.

Then for each of these data sets, we evaluated the ratio of the recovery estimates for the two populations (e.g., Yuba River/Feather River) over time assuming that unusually low ratios for the river with the uncertain estimates would indicate inaccurate recovery data. For example, if 1 CWT returned to the Yuba River for every 10 CWTs that returned to the total Feather River population (ratio of 0.1) during most years, whereas there were some years when 1 Yuba River CWT returned for every 100 Feather River CWT returns (ratio of 0.01), then the estimates for those years with the ratio of 0.01 or lower were judged to be inaccurate. We also believed that when a new CWT sampling protocol had been instituted (e.g., 2005 for the Yuba River, 2003 for the Sacramento River, and 1998 for the Stanislaus River), those estimates should be relatively accurate.

Too Few Carcasses Examined for Ad-clips

As discussed in the introduction, when few carcasses are examined, there is a high likelihood that some CWT codes will be oversampled whereas others would be undersampled. So even when the number of carcasses examined for ad-clips was directly reported, we judged the in-river recovery data to be relatively inaccurate compared to the hatchery data whenever the number of in-river carcasses examined was less than 1,000 and the number of in-river carcasses examined was less than 50% of the number of hatchery carcasses examined. In these cases, we relied on the hatchery data instead of the in-river data.

CWT Recovery Expansions

For the accurate recovery data and the preliminary analyses used to test Hypotheses 2 and 3, we estimated the total number of CWTs in a fall-run Chinook salmon population as the number recovered multiplied by the escapement estimate, divided by the estimated number of carcasses examined for ad-clips shown in Tables 1 and 2, and divided by a no-tag correction factor for the number of observed ad-clips for which there were no CWTs. The no-tag correction factor equaled 1 minus the number of no-tag ad-clips divided by the total number of ad-clips observed. For example, if 1000 carcasses were examined in an escapement population of 10,000 salmon, 50 ad-clipped carcasses were observed, and 10 of the ad-clips had no tags, the 40 CWTs would be multiplied by 10,000, divided by 1,000 (escapement by number examined), and then divided by 0.8 (1 minus 10 no-tags divided by 50 ad-clips) for a result of 340 total CWTs.

Hatchery Rivers

Our results indicate that both Hypotheses 2 and 3 are true for all the Central Valley hatchery rivers and so the percentage of CWT recovered in the river should be the same as the percentage of CWTs in the hatchery for most of the hatchery rivers. Since the hatcheries usually sampled a substantially greater number of carcasses for ad-clips (Tables

1 and 2) and the counts of the number of carcasses examined for ad-clips was accurate at the hatcheries, we used the percentage of CWTs recovered in the hatchery to estimate the percentage of CWTs recovered in the hatchery rivers, except for Battle Creek from 2000 to 2002 and the Mokelumne River in 1981 and 1984 when there no fish taken at the MRFI. These in-river estimates were made by multiplying the number of CWTs recovered in the hatchery by the river escapement divided by the hatchery escapement. In 2006 and 2007, when more carcasses were examined in the Merced River than at the MRH and the ratio of in-river recoveries to hatchery recoveries was near 1, we used the Merced River recovery data as described above for accurate data.

Non Hatchery Rivers

In some years there were no recovery data or the data were judged to be inaccurate for the Sacramento, Yuba, Stanislaus, and Tuolumne Rivers, which had no hatcheries that could provide an alternate source of recovery data. To compute expanded estimates for these rivers, we computed a ratio of the ad-clips for the non-hatchery rivers to the hatchery river estimates during years when the non hatchery river CWT recovery data were judged to be accurate. We used the final hatchery river estimates that were the sum of the in-river and the hatchery CWT recoveries. The estimate for the non-hatchery river was computed by multiplying the CWT recoveries for the entire hatchery river population by the mean ratio of the accurate recoveries for the non-hatchery river to the hatchery river. For example, if the mean recovery ratios for the relatively accurate data indicate that for every CWT recovery in the total Feather River population, there were 0.1 CWT recoveries in the Yuba River of salmon that had been released in the Delta and Bay and 0.01 CWT recoveries in the Yuba River that had been released as juveniles in the Feather River, then we multiplied the total Feather River recoveries for each CWT code by 0.1 and 0.01 for the Delta-Bay releases and the in-river releases, respectively, to compute the recoveries for the Yuba River during years when the data were missing or judged to be inaccurate. As for the hatchery rivers, the in-river estimates for the non-hatchery river were judged to be inaccurate if the ratios of in-river to hatchery recoveries were outside of the range observed for the accurate data.

Unique CWT codes

If a unique CWT code was recovered in the river with the inaccurate data but none were recovered in the hatchery, those recoveries were kept in our alternate method estimate to help maintain the accuracy of survival estimates that compared different CWT releases (e.g., upstream and downstream releases for the Vernalis Adaptive Management Plan). This unique code was not multiplied by an expansion factor because we assumed that there was only one of the unique CWT codes recovered in the river since none were recovered at the hatchery where the most fish were processed.

Associated Releases of Untagged Hatchery Salmon

For our final CWT expansion estimates, we included the number of untagged hatchery salmon that were released at the same location and date in association with a group of tagged salmon based on the assumption that both groups would return at the same rate. RMIS refers to these untagged fish as the non CWT counts that are provided as release information for the tagged releases for each CWT code. The number of untagged returns was computed with the following equation:

$$\frac{\text{Number of unmarked juveniles released * Number of CWTs recovered * Escapement estimate}}{\text{Number of marked juveniles released * Number of carcasses examined for ad-clips}}$$

The total number of recoveries was the sum of the estimated CWT recoveries and the estimated unmarked recoveries.

Statistical Analyses

The relationships between the number of tags recovered, a meristic variable (McDonald 2008), in different rivers was described using linear regression analyses computed using Statistix software, version 8. Statistical analyses appropriate for ratios, percentages, and counts of nominal variables (McDonald 2008), such as the proportion of carcasses with ad-clips in the escapement, may be conducted for a future draft of this paper.

RESULTS

The results of our analyses suggest that all of our hypotheses, restated below, are true to the extent that CWT recovery data from the Central Valley hatcheries can be used to verify, and if necessary, compute relatively accurate in-river CWT recovery rates. We present our results in four sections.

1. Evaluation of the counts of the number of carcasses examined for ad-clips in hatchery rivers as tests of Hypotheses 2 and 3:
    a. Hypothesis 2 - Adult salmon randomly enter the hatchery or spawn in the river regardless of whether they were naturally produced or hatchery produced such that the percentage of adult salmon with CWTs in the hatchery is the same as the percentage of adult salmon with CWTs that spawn naturally in the same river.
    b. Hypothesis 3 - The counts of the number of salmon carcasses examined for CWTs were accurate for the major Central Valley rivers in recent years, when new sampling protocols to recover CWTs were initiated.
2. Comparison of CWT recoveries between the TCFF and the Sacramento River as a test of Hypothesis 4: The percentage of ad-clips of CNFH, FRH, NFH, MRFI and MRH produced salmon that were recovered at the TCFF was the same as those that returned to the mainstem Sacramento River.
3. Evaluation of the counts of the number of carcasses examined and recovered in non hatchery rivers as a test of Hypothesis 5: The rate that adult salmon stray to the

non hatchery rivers is relatively constant over time for a given hatchery and planting location.

4. The estimated total percentage of CWT and associated untagged hatchery salmon in the Central Valley escapement from 1979 to 2007.

There are no data to directly evaluate Hypothesis 1, which is that the counts of the number of adult fish examined for CWTs were highly accurate at all of the Central Valley salmon hatcheries, including the TCFF. However, the procedures used in Central Valley hatcheries to visually count the salmon with ad-clips are robust, the fish are freshly sacrificed with relatively little decay or wounds to the adipose fin area, and so we assume that the CWT recovery data are accurate.

Evaluation of Counts of Number of Carcasses Examined for Ad-Clips in Hatchery Rivers: Tests of Hypotheses 2 and 3

Our results suggest that Hypothesis 2, that adult salmon randomly enter the hatchery regardless of whether they were naturally produced or hatchery produced, is true for all the hatchery rivers, and therefore, the percentage of in-river recoveries is about the same as the percentage of hatchery recoveries. The ratios of the percentages of in-river CWT recoveries to the percentage of hatchery CWT recoveries for Battle Creek (Table 3), Feather River (Table 4), American River (Table 5), and the Merced River (Table 6), all indicate that the percentage of in-basin produced hatchery fish and out-of-basin hatchery fish both show no preference for spawning in the river or returning to the hatchery (ratios ~ 1.0).

For the Mokelumne River, the in-river recovery data from 2003 to 2007 was highly unusual because the results suggested that the mean percentage of Mokelumne River hatchery fish that homed to their natal hatchery was 2.6 times greater than the percentage that spawned in the river (Table 7) whereas the other Central Valley hatchery salmon showed no preference for either the hatchery or the river. The Mokelumne River data for 2003 to 2007 should have been accurate, because a wand was used to detect CWTs in all carcasses with an ad-clip and there were moderate numbers of carcasses examined. However, it seems likely that many of the ad-clips and/or CWTs were not detected during the carcass surveys, because there was conflicting evidence from a microchemistry analysis of Mokelumne River fish for fall 2004. The microchemistry analyses corrected identified 100% of CWTs as hatchery fish in a blind study and also showed that 90% of the in-river spawners (100 samples) and 97% of the fish that entered the hatchery (100 samples) were hatchery fish, which includes both CWT and untagged fish (Weber et al. 2009). This computes to a ratio of hatchery fish in the river to the number in the hatchery of 0.93, which is similar to all the other hatchery rivers, whereas the overall ratio of in-river recoveries to hatchery recoveries for the 2004 carcass survey was 0.69. Therefore, we assumed that the recovery data from 2003 to 2007 were not accurate because all the ratios were ≤ 0.69. One possible explanation is that there was an unusually high rate of regenerated adipose fins for MRFI fish that may have been difficult to detect during the carcass surveys (Workman, personal communication, see “Notes”) and if the ad-clips were not detected, the wand was not used to check for the CWT. Therefore, the Mokelumne River CWT recovery data do not falsify Hypothesis 3.

We believe that Hypothesis 3 is true that most of the counts of the number of salmon carcasses examined for CWTs were accurate for the major Central Valley rivers in recent years, when new sampling protocols to recover CWTs were initiated. For Battle Creek, the Null et al (2003) study ensured that the estimates were accurate for 2000 to 2002 and the estimates for 2004 and 2005 also appeared to be accurate based on ratios near 1.0. For the Feather, American, and Merced Rivers, the in-basin ratios and the out-of-basin ratios were near 1.0 for many of the years after the new sampling protocols were initiated (Tables 3 to 6). However, there were some years after the new protocol had been initiated when the ratio was substantially less than 1 and other years when it was substantially greater than 1.0. For example, the ratios were 0.38 and 0.48 for the Feather River in 2000 and 2001 (Table 4) when the new sampling program was started and the number of carcasses handled was high. We assume that not all of the fresh carcasses were examined for ad-clips as reported for 2000 and 2001 perhaps due to the heavy work load required to estimate escapement. Another example is that the ratios were 2.59 and 1.86 for the Feather River in 2006 and 2007 (Table 4), which may have been caused by counting ad-clips from decayed carcasses or by not accurately counting all the fresh carcasses that were examined by the multiple Feather River crews. For the Mokelumne River, we assumed that all the estimates for fall 2003 to 2007 are inaccurate on the basis of the otolith microchemistry study described above (Weber et al. 2004).

Comparison of CWT Recoveries between the TCFF and the Sacramento River: A Test of Hypothesis 4

The returns to the TCFF from 1979 to 1985 and to the mainstem Sacramento River above the Red Bluff Diversion Dam from 2003 to 2007 primarily consisted of salmon produced at the FRH and the CNFH with a few returns from the NFH, MRFI, and MRH (hereafter referred to as the other hatcheries; Table 8). We excluded the TCFF produced juveniles from this analysis because the TCFF was not operated after spring 1986. The Delta and Bay releases comprised the majority of the recoveries: 56% of all CWT recoveries at the TCFF from 1979 to 1985 and 65% of all CWT recoveries in the mainstem Sacramento River above the Red Bluff Diversion Dam in 2003 and 2004 (Tables 8 and 9).

The ratio of CWT recoveries for the TCFF are similar to those for the Sacramento River in 2003 and 2004 when a new CWT recovery protocol was initiated, which suggests that Hypothesis 4 is true; however the ratios were relatively low for the Sacramento River from 2005 to 2007. We based our assessment on the ratio of CWTs recovered at the TCFF and in the Sacramento River relative to the number of CWT recoveries in the Feather River population (FRH and in-river recoveries combined) for juvenile salmon produced at all Central Valley hatcheries that were released in the Delta and Bay. From 1979 to 1985, the mean ratio of the percentage of these fish recovered at the TCFF to the percentage of these fish recovered in the Feather River population is 1.30 (range 0.29 to 4.29, ALL ratio, Table 9). This mean is similar to the mean ratio of 0.89 (range 0.86 to 0.93) for 2003 and 2004 for the Sacramento River carcass surveys, but is substantially greater than the mean ratio of 0.08 (range 0.04 to 0.13) for 2005 to 2007 Sacramento River carcass surveys. We assume that the recovery ratios declined in 2005 and 2006 because the number of fish examined for ad-clips increased from 1,148 and 1,565 in 2003 and 2004, respectively, to 3,419 and 6,084 in 2005 and 2006, respectively, and the crews could no longer effectively process all the carcasses. However, we have no explanation for the low recovery ratio (0.042) in 2007 when only 874 carcasses were examined for ad-clips. Nevertheless, the similar mean ratios (1.30 vs. 0.89) and overlap in ranges (0.29 to 4.29) for the TCFF ratios from 1979 to 1985 and the Sacramento River ratios in 2003 and 2004 (Table 9) suggest that Hypothesis 4 is true.

Table 3. The percentage of ad-clips of CNFH produced salmon (in-basin) and out-of-basin Central Valley hatchery fish that were recovered at the CNFH and in Battle Creek, the number of carcasses examined for ad-clips at the CNFH and Battle Creek, and the ratio of the percentages of the in-river to hatchery recoveries. The estimates that were judged to be accurate (probably and yes) or inaccurate (no) are also presented.

	CNFH			Battle Creek			In-River: Hatchery Recoveries			
Year	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Hatchery Ratio	Out-Of-Basin Hatchery Ratio	Overall Ratio	Accurate
1984	3.780%	0.030%	21,648	1.364%	0.000%	2,272	0.3609	0.0000	0.3580	No
1985	4.916%	0.042%	16,320	0.506%	0.000%	5,924	0.1030	0.0000	0.1022	No
1986	4.829%	0.223%	12,709	0.819%	0.055%	4,233	0.1697	0.2454	0.1730	No
1987	2.465%	0.543%	16,256	1.114%	0.000%	2,604	0.4518	0.0000	0.3702	No
1988	1.999%	0.182%	13,615	0.598%	0.076%	14,850	0.2990	0.4146	0.3087	No
1989	1.335%	0.058%	11,986	0.840%	0.204%	6,609	0.6293	3.5090	0.7493	No
1990	1.797%	0.033%	14,635	1.066%	0.069%	3,816	0.5933	2.0958	0.6203	No
1991	1.107%	0.035%	10,683	0.529%	0.099%	3,500	0.4783	2.8100	0.5504	No
1992	1.384%	0.087%	7,275	0.898%	0.187%	3,777	0.6490	2.1633	0.7381	No
1993	3.083%	0.014%	7,587	0.942%	0.000%	3,716	0.3055	0.0000	0.3041	No
1994	2.466%	0.095%	18,991	1.412%	0.171%	11,370	0.5727	1.7970	0.6182	No
1995	3.007%	0.018%	26,677	1.262%	0.044%	25,501	0.4198	2.4873	0.4318	No
1996	1.517%	0.051%	21,178	0.248%	0.005%	18,550	0.1635	0.1066	0.1616	No
1997	2.433%	0.014%	50,670	0.135%	0.000%	14,068	0.0555	0.0000	0.0552	No
1999	6.001%	0.013%	26,970	1.076%	0.000%	21,656	0.1793	0.0000	0.1789	No
2000	5.738%	0.061%	21,659	6.462%	0.030%	6,639	1.1260	0.4952	1.1194	Yes
2001	5.825%	0.219%	25,082	3.866%	0.518%	8,189	0.6637	2.3645	0.7254	Yes
2002	7.684%	0.170%	66,147	8.880%	0.261%	5,360	1.1557	1.5360	1.1639	Yes
2003	5.058%	0.102%	88,281	0.312%	0.038%	30,005	0.0617	0.3711	0.0678	No
2004	7.521%	0.059%	68,232	6.697%	0.788%	2,151	0.8905	13.3271	0.9874	Probably
2005	0.976%	0.013%	144,739	0.826%	0.012%	10,258	0.8465	0.9153		Probably
Mean Inaccurate Data							0.3433	1.0000	0.3617	
Mean Accurate Data							0.9818	1.4652	1.0029	

Table 4. The percentage of ad-clips of FRH produced salmon (in-basin) and out-of-basin Central Valley hatchery fish that were recovered at the FRH and in the Feather River, the number of carcasses examined for ad-clips at the FRH and Feather River, and the ratio of the percentages of the in-river to hatchery recoveries. The estimates that were judged to be the most accurate (Best) or inaccurate (no) are also presented.

	FRH			Feather River			In-River: Hatchery Recoveries			
Year	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Hatchery Ratio	Out-Of-Basin Hatchery Ratio	Overall Ratio	Accurate
1979	9.824%	0.445%	4,090	2.326%	0.000%	2,107	0.2367	0.0000	0.2265	No
1980	6.244%	0.938%	3,690	1.985%	0.113%	3,003	0.3178	0.1209	0.2921	No
1981	3.191%	0.154%	8,282	0.635%	0.000%	2,518	0.1992	0.0000	0.1900	No
1982	11.191%	0.392%	7,563	3.487%	0.000%	3,212	0.3116	0.0000	0.3010	No
1983	6.962%	0.156%	7,699	3.413%	0.120%	1,670	0.4903	0.7684	0.4964	No
1984	7.528%	0.967%	9,288	1.059%	0.196%	3,268	0.1406	0.2027	0.1477	No
1985	6.784%	1.751%	5,811	1.253%	0.518%	5,590	0.1846	0.2960	0.2075	No
1986	6.547%	0.674%	8,628	2.345%	0.229%	2,292	0.3582	0.3397	0.3565	No
1987	9.664%	1.159%	10,108	1.795%	0.224%	3,566	0.1857	0.1936	0.1866	No
1989	10.556%	0.555%	7,578	5.009%	0.423%	3,719	0.4745	0.7621	0.4888	No
1991	4.116%	0.176%	10,717	1.761%	0.000%	1,420	0.4278	0.0000	0.4102	No
1992	3.022%	0.250%	16,440	1.920%	0.069%	1,710	0.6352	0.2742	0.6076	No
1993	4.675%	0.278%	11,991	2.350%	0.184%	3,158	0.5026	0.6594	0.5114	No
1994	4.289%	0.322%	15,202	1.858%	0.062%	4,115	0.4332	0.1923	0.4163	No
1995	4.046%	0.169%	12,149	1.466%	0.107%	4,389	0.3622	0.6323	0.3730	No
1996	13.294%	0.485%	8,107	2.988%	0.113%	5,224	0.2248	0.2335	0.2251	No
1997	12.278%	0.980%	15,128	0.000%	0.000%	2,127	0.0000	0.0000	0.0000	No
2000	8.083%	0.811%	18,146	3.270%	0.071%	6,224	0.4046	0.0881	0.3757	No
2001	10.686%	0.485%	24,870	5.199%	0.176%	5,246	0.4866	0.3637	0.4812	No
2002	9.118%	1.029%	20,507	13.164%	0.998%	3,234	1.4437	0.9693	1.3956	Best
2003	7.577%	1.051%	14,976	5.996%	0.851%	6,047	0.7913	0.8099	0.7936	Best
2004	10.280%	0.417%	21,297	5.920%	0.416%	4,040	0.5759	0.9997	0.5924	No
2005	18.268%	0.178%	22,384	25.897%	0.141%	3,107	1.4176	0.7902	1.4116	Best
2006	7.626%	0.113%	14,034	19.947%	0.114%	3,913	2.6158	1.0122	2.5925	No
2007	7.110%	0.248%	5,341	13.642%	0.060%	1,664	1.9186	0.2423	1.8621	No
Mean Inaccurate Data							0.5221	0.3355	0.5155	
Mean Best Data							1.2176	0.8564	1.2002	

Table 5. The percentage of ad-clips of NFH produced salmon (in-basin) and out-of-basin Central Valley hatchery fish that were recovered at the NFH and in the American River, the number of carcasses examined for ad-clips at the NFH and American River, and the ratio of the percentages of the in-river to hatchery recoveries. The estimates that were judged to be the most accurate (Best or Probably) or inaccurate (no) are also presented.

	NFH			American River			In-River: Hatchery Recoveries			
Year	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Hatchery Ratio	Out-Of-Basin Hatchery Ratio	Overall Ratio	Accurate
1979	0.000%	0.328%	10,351	0.000%	0.000%	667	ND	0.0000	0.0000	No
1980	0.000%	0.624%	15,543	0.000%	0.711%	1,968	ND	1.1399	1.1399	Probably
1981	0.000%	0.136%	20,593	0.000%	3.490%	659	ND	25.6687	25.6687	No
1984	0.000%	1.584%	12,249	0.000%	0.000%	586	ND	0.0000	0.0000	No
1986	1.139%	0.740%	5,695	3.444%	1.531%	1,005	3.0248	2.0682	2.6480	Probably
1987	1.107%	0.715%	6,258	2.107%	4.981%	649	1.9038	6.9676	3.8908	No
2002	2.426%	3.747%	9,817	0.263%	1.628%	4,125	0.1083	0.4345	0.3063	No
2003	6.059%	2.626%	14,887	4.602%	2.741%	6,468	0.7596	1.0439	0.8455	Best
2004	2.411%	1.823%	26,400	3.065%	1.557%	4,695	1.2711	0.8538	1.0914	Best
2005	0.441%	0.838%	22,349	0.605%	0.806%	2,835	1.3698	0.9618	1.1026	Best
2006	0.014%	0.490%	8,728	0.000%	0.207%	1,451	0.0000	0.4215	0.4101	No
2007	0.000%	0.674%	4,597	ND	ND	714				Unknown
Mean All Data							0.6707	5.5821	5.0460	
Mean Best Data							1.1335	0.9532	1.0132	

Table 6. The percentage of ad-clips of MRH produced salmon (in-basin) and out-of-basin Central Valley hatchery fish that were recovered at the MRH and in the Merced River, the number of carcasses examined for ad-clips at the MRH and Merced River, and the ratio of the percentages of the in-river to hatchery recoveries. The estimates that were judged to be the most accurate (Best or Probably) or inaccurate (no) are also presented.

	MRH			Merced River			In-River:Hatchery Recoveries			
Year	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Hatchery Ratio	Out-Of-Basin Hatchery Ratio	Overall Ratio	Accurate
1979	4.295%	1.432%	227	0.000%	0.000%	95	0.0000	0.0000	0.0000	No
1980	6.369%	0.000%	157	7.375%	0.000%	339	1.1578	ND	1.1578	Probably
1982	6.984%	4.656%	189	0.794%	0.794%	126	0.1136	0.1705	0.1364	No
1983	16.156%	0.167%	1,795	0.445%	0.089%	1,124	0.0275	0.5323	0.0327	No
1984	9.862%	0.000%	2,109	0.000%	0.000%	448	0.0000	ND	0.0000	No
1985	9.992%	0.000%	1,211	2.991%	0.000%	535	0.2993	ND	0.2993	No
1986	20.832%	0.861%	650	7.560%	0.000%	291	0.3629	0.0000	0.3485	No
1987	4.748%	0.158%	958	0.000%	0.000%	138	0.0000	0.0000	0.0000	No
1988	5.848%	0.278%	457	0.000%	0.000%	173	0.0000	0.0000	0.0000	No
1989	30.329%	1.379%	82	ND	ND	57	ND	ND		No
1990	8.696%	0.000%	46	0.000%	0.000%	16	0.0000	ND	0.0000	No
1991	2.439%	0.000%	41	9.091%	0.000%	11	3.7273	ND	3.7273	No
1992	14.031%	7.165%	368	0.000%	0.000%	129	0.0000	0.0000	0.0000	No
1993	17.002%	10.870%	409	4.215%	7.867%	538	0.2479	0.7237	0.4335	No
1994	4.101%	5.549%	943	2.873%	4.165%	1,023	0.7004	0.7507	0.7293	No
1995	26.819%	12.716%	602	6.346%	5.156%	313	0.2366	0.4055	0.2909	No
1996	31.256%	3.450%	1,141	26.323%	6.772%	1,260	0.8422	1.9627	0.9536	No
1997	24.678%	1.010%	946	19.820%	1.802%	777	0.8032	1.7848	0.8417	No
1998	33.642%	3.279%	799	21.128%	7.043%	1,033	0.6280	2.1480	0.7630	No
1999	29.853%	0.874%	1,637	25.398%	1.294%	798	0.8508	1.4806	0.8687	Best
2000	24.974%	1.850%	1,946	16.731%	0.552%	758	0.6699	0.2982	0.6443	No

	MRH			Merced River			In-River:Hatchery Recoveries			
Year	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Hatchery Ratio	Out-Of-Basin Hatchery Ratio	Overall Ratio	Accurate
2001	39.416%	5.323%	1,663	24.092%	4.427%	1,101	0.6112	0.8318	0.6375	No
2002	48.805%	7.934%	1,840	31.228%	8.854%	978	0.6398	1.1160	0.7064	No
2003	34.593%	10.945%	549	31.116%	9.685%	549	0.8995	0.8849	0.8960	Best
2004	11.549%	5.880%	1,050	14.793%	8.677%	784	1.2809	1.4757	1.3466	Best
2005	10.087%	1.552%	421	11.966%	0.876%	366	1.1863	0.5642	1.1033	Best
2006	15.172%	0.722%	151	9.948%	0.947%	257	0.6557	1.3113	0.6855	No
2007	8.861%	0.000%	79	6.512%	1.628%	86	0.7349	ND	0.9186	Best
Mean All Data							0.5031	0.7080	0.5348	
Mean Best Data							0.9905	1.1014	1.0266	

Table 7. The percentage of ad-clips of MRFI produced salmon (in-basin) and out-of-basin Central Valley hatchery fish that were recovered at the MRFI and in the Mokelumne River, the number of carcasses examined for ad-clips at the MRFI and Mokelumne River, and the ratio of the percentages of the in-river to hatchery recoveries. None of the estimates were judged to be accurate based on an otolith microchemistry study that showed that the true ratio of hatchery fish in the river to the hatchery was 0.93 in fall 2004 (Weber et al. 2009).

	MRFI			Mokelumne River			In-River: Hatchery Recoveries			
Year	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Recoveries	Out-Of-Basin Recoveries	# Examined	In-Basin Hatchery Ratio	Out-Of-Basin Hatchery Ratio	Overall Ratio	Accurate
1980	6.2146%	3.0185%	639	0.0000%	0.0000%	91	0	0	0.0000	No
1985	0.0000%	0.8969%	223	0.0000%	0.0000%	118	ND	0	0.0000	No
1986	0.1807%	2.5898%	1913	0.0000%	0.0000%	146	0	0	0.0000	No
2003	12.1705%	2.5148%	8117	1.3598%	0.2720%	429	0.1117	0.1081	0.1111	No
2004	7.1926%	0.5227%	10356	4.6322%	0.7126%	1588	0.6440	1.3633	0.6928	No
2005	4.3324%	0.2464%	5722	0.8018%	0.0422%	5924	0.1851	0.1713	0.1843	No
2006	1.9815%	0.2171%	4139	0.3268%	0.3268%	459	0.1649	1.5050	0.2973	No
2007	0.9342%	0.2076%	1051	0.7407%	0.0000%	135	0.7929	0.0000	0.6488	No
Mean All Data							0.0000	0.0000	0.0000	
Mean 2003 to 2007							0.3797	0.6295	0.3868	

Table 8. The percentage of CWT recoveries at the TCFF from 1979 to 1985 and for the mainstem Sacramento River upstream from the Red Bluff Diversion Dam from 2003 to 2007 for releases of juvenile salmon from the CNFH, FRH, NFH, MRH, and MRFI. The estimate of all CWT recoveries includes fish produced by non Central Valley hatcheries.

			TCFF			
Year	CNFH	FRH	NFH	MRH	MRFI	All
1979	0.000%	2.450%	0.000%	0.000%	0.993%	5.032%
1980	0.000%	6.982%	0.000%	0.000%	1.232%	9.564%
1981	0.000%	7.286%	0.000%	0.000%	1.223%	9.839%
1982	2.023%	3.958%	0.000%	0.000%	0.352%	6.333%
1983	3.048%	1.478%	0.000%	0.000%	0.185%	4.710%
1984	6.605%	1.676%	0.000%	0.000%	0.000%	8.281%
1985	3.234%	0.777%	0.000%	0.062%	0.000%	4.073%
Mean	2.130%	3.515%	0.000%	0.009%	0.569%	6.833%
			Mainstem Sacramento River			
2003	2.028%	3.830%	0.000%	0.338%	0.225%	6.760%
2004	2.363%	2.870%	0.000%	0.253%	0.253%	5.908%
2005	0.423%	0.115%	0.000%	0.154%	0.059%	0.769%
2006	0.019%	0.152%	0.000%	0.019%	0.000%	0.171%
2007	0.229%	0.686%	0.000%	0.000%	0.000%	6.292%
Mean	1.012%	1.531%	0.000%	0.153%	0.107%	2.803%
Mean						
03-04	2.196%	3.350%	0.000%	0.296%	0.239%	6.334%

Table 9. The percentage of CWT recoveries in Battle Creek (in-river and CNFH), Feather River (in-river and FRH), TCFF from 1979 to 1985, and the mainstem Sacramento River upstream from the Red Bluff Diversion Dam from 2003 to 2007 for releases of juvenile salmon in the Delta and Bay. The juvenile releases are sorted by hatcheries: CNFH, FRH, other Central Valley hatcheries combined (NFH, MRH, and MRFI collectively identified as OTHERS), and all hatchery releases combined (ALL). The ratios of CWT recovery percentages for the TCFF or Sacramento River relative to: (1) the percentages of the recoveries in Battle Creek (in-river and CNFH) for CNFH reared juvenile salmon (CNFH Ratio); (2) percentages of the recoveries in the Feather River population (in-river and FRH) for FRH releases (FRH Ratio); (3) percentages of the recoveries in the Feather River population for NFH, MRH, and MRFI releases (OTHERS Ratio), and the percentages of the recoveries in the Feather River for all hatcheries releases combined are also presented. ND indicates that no recoveries were made because no or too few smolts were released. The mean (EM) and sample size (n) of the ratios used for expanding recovery estimates are presented for the CNFH and FRH recoveries.

						Juvenile Releases in the Delta and Bay								
	Number Smolts Released			Battle		TCFF			Feather			Ratios		
Year	CNFH	FRH	OTHERS	CNFH	CNFH	FRH	OTHERS	CNFH	FRH	OTHERS	CNFH	FRH	OTHERS	ALL
1979	0	604,363	159,542	ND	ND	2.2510%	2.2510%	ND	5.1206%	0.3896%	ND	0.4396	5.7776	0.8170
1980	0	881,424	91,514	ND	ND	6.9236%	1.4082%	ND	2.5502%	0.6156%	ND	2.7150	2.2877	2.6319
1981	182,282	1,205,698	130,196	0.2768%	0.0000%	7.0205%	1.3296%	0.0000%	1.9032%	0.0420%	0.0000	3.6888	31.6713	4.2927
1982	295,210	1,111,505	94,456	0.3726%	0.5277%	3.5181%	0.0000%	0.1205%	9.2330%	0.1506%	1.4164	0.3810	0.0000	0.4257
1983	467,687	1,364,888	61,503	0.1573%	0.0924%	1.3854%	0.1847%	0.0296%	5.6761%	0.0130%	0.5871	0.2441	14.2217	0.2907
1984	249,796	774,724	150,442	0.1208%	0.1972%	0.7886%	0.0000%	0.0829%	3.2874%	0.0000%	1.6323	0.2399	ND	0.2925
1985	300,096	1,160,989	515,819	0.0250%	0.3731%	0.4042%	0.0311%	0.2904%	2.0272%	0.1330%	14.954	0.1994	0.2338	0.3299
Mean				0.1905%	0.2381%	3.1845%	0.7435%	0.1047%	4.2568%	0.1920%	3.7180	1.1297	9.0320	1.2972
						Sacramento River								
2003	0	2,360,438	3,664,570	ND	ND	3.7178%	1.0139%	ND	4.4250%	0.6445%	ND	0.8402	1.5733	0.9334
2004	0	2,699,086	3,133,057	ND	ND	2.7851%	0.7596%	ND	3.8576%	0.2837%	ND	0.7220	2.6771	0.8559
2005	0	2,501,859	2,345,590	ND	ND	0.0769%	0.2307%	ND	2.2688%	0.1085%	ND	0.0339	2.1254	0.1294

2006		0	1,643,085	714,222	ND	ND	0.1142%	0.0190%	ND	2.5350%	0.0724%	ND	0.0450	0.2629	0.0511
2007		0	2,133,867	219,084	ND	ND	0.2288%	0.0000%	ND	5.3739%	0.0620%	ND	0.0426	0.0000	0.0421
Mean	03-04						3.2515%	0.8868%		4.1413%	0.4641%		0.7811	2.1252	0.8947
Mean	05-07						0.1400%	0.0832%		3.3926%	0.0810%		0.0405	0.7961	0.0742
EM												3.7180	0.9470	1.4947	1.0870
n												5	9	3	9

The number of CWT recoveries at the TCFF from 1979 to 1985 and the Sacramento River above the Red Bluff Diversion Dam from 2003 to 2004 were affected by the hatchery that produced the juvenile salmon and the location where the juveniles were released. For the FRH and other hatchery plants in the Delta and Bay, the percentages of CWT recoveries at the TCFF and Sacramento River are similar to the percentage of CWT recoveries in the Feather River (Table 9). The mean ratios of the percentages are 0.947 and 1.495 for the FRH plants and the combined other hatchery plants, respectively, for run years when a total of at least 500,000 juveniles had been planted during the previous four brood year releases (Table 9). The ratio for the other hatchery plants is based on relatively small CWT recovery percentages, which would tend to create a greater degree of error in the ratios compared to those for the FRH plants. Therefore, the mean ratio of 1.495 for the other hatcheries may not be statistically different from a ratio of 1.0. For the CNFH juvenile salmon planted in the Delta and Bay, the percentages of CWT recoveries at the TCFF and Sacramento River are much higher than in Battle Creek (Table 9). The mean ratio of the percentages is 3.718 for the CNFH plants from 1981 to 1985 when a total of at least 182,282 juveniles had been planted during the previous four years (Table 5). These mean ratios are used to compute the expanded CWT recovery estimates for the Bay and Delta juvenile releases as described below.

For juvenile releases in the mainstem Sacramento and San Joaquin Rivers, the majority recovered at the TCFF from 1979 to 1985 and in the mainstem Sacramento River in 2003 and 2004 are CNFH plants (Table 10). The percentages of CWT recoveries at the TCFF and the Sacramento River of these mainstem plants are about 30% higher than the percentage of CWT recoveries in Battle Creek for CNFH plants, about 30% lower than the percentage of CWT recoveries in the Feather River for the other hatchery plants, and the percentages are very low compared to the CWT recoveries in the Feather River for FRH plants. The mean ratios of the percentages are 1.308, 0.047, and 0.664 for the CNFH plants, FRH plants, and other hatchery plants, respectively for run years when a total of at least 500,000 juveniles had been planted during the previous four brood year releases (Table 10). These mean ratios are used to compute the expanded CWT recovery estimates for the juvenile releases in the mainstem rivers as described below.

For the juvenile releases within the tributaries, the percentages of CWT recoveries at the TCFF and the Sacramento River are about 40% of those observed for CNFH and FRH releases in Battle Creek and the Feather River, respectively, but about five times higher than those for the other hatchery fish recovered in the Feather River. The mean ratios of the percentages are 0.408, 0.381, and 4.845 for the CNFH plants, FRH plants, and the other hatchery plants, respectively for run years when a total of at least 297,000 juveniles had been planted during the previous four brood year releases (Table 11). These mean ratios are used to compute the expanded CWT recovery estimates for the juvenile releases in the tributaries with hatcheries as described below.

Table 10. The percentage of CWT recoveries in Battle Creek (in-river and CNFH), Feather River (in-river and FRH), TCFF from 1979 to 1985, and the mainstem Sacramento River upstream from the Red Bluff Diversion Dam from 2003 to 2004 for releases of juvenile salmon in the mainstem Sacramento and San Joaquin rivers. The juvenile releases are sorted by hatcheries: CNFH, FRH, other Central Valley hatcheries combined (NFH, MRH, and MRFI collectively identified as OTHERS), and all hatchery releases combined (ALL). The ratios of CWT recovery percentages for the TCFF or Sacramento River relative to: (1) the percentages of the recoveries in Battle Creek (in-river and CNFH) for CNFH reared juvenile salmon (CNFH Ratio); (2) percentages of the recoveries in the Feather River population (in-river and FRH) for FRH releases (FRH Ratio); (3) percentages of the recoveries in the Feather River population for NFH, MRH, and MRFI releases (OTHERS Ratio), and the percentages of the recoveries in the Feather River for all hatcheries releases combined are also presented. ND indicates that no recoveries were made because no or too few smolts were released. The mean (EM) and sample size (n) of the ratios used for expanding recovery estimates are presented for the CNFH and FRH recoveries.

Juvenile Releases in the Mainstem River

	Number Juveniles Released			Battle	TCFF			Feather			Ratios			
Year	CNFH	FRH	OTHERS	CNFH	CNFH	FRH	OTHERS	CNFH	FRH	OTHERS	CNFH	FRH	OTHERS	ALL
1979	1,252,409	0	82,934	3.5000%	0.0000%	ND	0.2648%	0.0000%	ND	0.0278%	0.0000	ND	9.5161	9.5161
1980	597,033	0	80,894	0.0213%	0.0000%	ND	1.1735%	0.0000%	ND	0.2345%	0.0000	ND	5.0043	5.0043
1981	0	0	120,031	ND	ND	ND	1.0637%	ND	ND	0.0840%	ND	ND	12.6685	12.669
1982	390,380	8,864	129,380	0.3420%	1.4072%	0.0000%	0.3518%	0.0301%	0.0904%	0.0753%	4.1143	0.0000	4.6715	8.9836
1983	736,962	35,155	264,199	1.6732%	2.7708%	0.0924%	0.0000%	0.0520%	0.2078%	0.0130%	1.6560	0.4444	0.0000	10.497
1984	795,968	361,731	231,994	3.0990%	4.9291%	0.2957%	0.0000%	0.0276%	0.5387%	0.0138%	1.5905	0.5490	0.0000	9.0062

1985	1,059,718	796,484	431,647	2.5784%	2.1455%	0.1555%	0.0000%	0.0905%	1.5963%	0.0000%	0.8321	0.0974	ND	1.3642
Mean				1.8690%	1.8754%	0.1359%	0.4077%	0.0334%	0.6083%	0.0641%	1.3655	0.2727	5.3101	8.1485
Sacramento River														
2003	545,413	1,048,561	1,015,829	0.1412%	0.3380%	0.0000%	0.3380%	0.0308%	0.4822%	0.2546%	2.3938	0.0000	1.3277	0.8806
2004	632,159	958,167	953,388	0.1885%	0.5064%	0.0844%	0.0000%	0.0866%	1.8842%	0.0325%	2.6858	0.0448	0.0000	0.2949
Mean				0.1649%	0.4222%	0.0422%	0.1690%	0.0587%	1.1832%	0.1435%	2.5398	0.0224	0.6639	0.5878
EM											1.3083	0.0474	0.6639	6.4684
n											7	3	2	9

Table 11. The percentage of CWT recoveries in Battle Creek (in-river and CNFH), Feather River (in-river and FRH), TCFF from 1979 to 1985, and the mainstem Sacramento River upstream from the Red Bluff Diversion Dam from 2003 to 2004 for releases of juvenile salmon in the tributaries with hatcheries. The juvenile releases are sorted by hatcheries: CNFH, FRH, other Central Valley hatcheries combined (NFH, MRH, and MRFI collectively identified as OTHERS), and all hatchery releases combined (ALL). The ratios of CWT recovery percentages for the TCFF or Sacramento River relative to: (1) the percentages of the recoveries in Battle Creek (in-river and CNFH) for CNFH reared juvenile salmon (CNFH Ratio); (2) percentages of the recoveries in the Feather River population (in-river and FRH) for FRH releases (FRH Ratio); (3) percentages of the recoveries in the Feather River population for NFH, MRH, and MRFI releases (OTHERS Ratio), and the percentages of the recoveries in the Feather River for all hatcheries releases combined are also presented. ND indicates that no recoveries were made because no or too few smolts were released. The mean (EM) and sample size (n) of the ratios used for expanding recovery estimates are presented for the CNFH and FRH recoveries.

						Juvenile Releases in the Tributaries								
	Number Juveniles Released			Battle		TCFF			Feather			Ratios		
Year	CNFH	FRH	OTHERS	CNFH	CNFH	FRH	OTHERS	CNFH	FRH	OTHERS	CNFH	FRH	OTHERS	ALL
1979	0	162,253	93,785	ND	ND	0.0000%	0.0662%	ND	0.0000%	0.028%	ND	ND	2.3790	2.3790
1980	0	322,404	148,583	ND	ND	0.0587%	0.0000%	ND	0.0293%	0.088%	ND	2.0017	0.0000	0.5004
1981	86,213	343,380	191,087	0.0095%	0.0000%	0.2659%	0.1064%	0.0000%	0.7557%	0.028%	0.0000	0.3519	3.8006	0.4751
1982	180,015	483,630	222,596	0.3909%	0.0880%	0.4398%	0.0000%	0.0000%	1.8677%	0.000%	0.2250	0.2355	ND	0.2825
1983	354,497	557,896	303,362	1.3300%	0.1847%	0.0000%	0.0000%	0.0520%	0.5750%	0.004%	0.1389	0.0000	0.0000	0.2929
1984	398,005	341,890	269,913	1.3443%	1.4787%	0.5915%	0.0000%	0.8011%	2.8040%	0.046%	1.1000	0.2109	0.0000	0.5671
1985	409,847	297,368	235,028	2.3122%	0.7152%	0.2177%	0.0311%	1.1085%	2.0840%	0.133%	0.3093	0.1044	0.2338	0.2899
Mean				1.0774%	0.4933%	0.2248%	0.0291%	0.3923%	1.1594%	0.0466%	0.3546	0.4841	1.0689	0.6838
						Sacramento River								
2003	4,890,048	536,134	2,772,352	4.778%	1.239%	0.113%	0.174%	0.000%	0.799%	0.072%	0.2594	0.1410	2.4200	1.5521

2004	4,415,965	1,427,556	2,627,090	7.272%	1.688%	0.000%	0.128%	0.000%	0.743%	0.018%	0.2321	0.0000	7.2697	2.3316
Mean				6.025%	1.4636%	0.0563%	0.1510%				0.2457	0.0705	4.8449	1.9418
EM											0.4079	0.3807	4.8449	0.9634
n											5	8	2	

The following equations were used to estimate the mainstem recovery rates:

Expansions for 1979 to 1985 Estimates Based on TCFF Recoveries

1. To estimate the recoveries in the mainstem Sacramento River in the reaches upstream and downstream from the Red Bluff Diversion Dam between 1979 and 1985, we multiply the TCFF recoveries by the Sacramento River escapement divided by the TCFF escapement.

Expansions for Delta-Bay Releases of Juvenile Salmon

2. From 1986 to 2002 and from 2005 to 2007, the CNFH-based estimates and FRH-based estimates are computed separately for tributary, mainstem, and Delta-Bay releases of juvenile salmon. The CNFH-based estimate for the Delta-Bay releases is computed using the mean (EM) CNFH ratio in Table 5:

$$\frac{\text{Battle Creek + CNFH expanded recoveries of CNFH releases * 3.718 * Sacramento River escapement}}{\text{Battle Creek + CNFH Escapement}}$$

3. The FRH-based estimate for the Delta-Bay releases is computed using separate equations for the FRH and the other hatchery juveniles based on the mean (EM) FRH ratio and Other ratio in Table 5:

$$\frac{\text{Feather River + FRH expanded recoveries of FRH releases * 0.947 * Sacramento River escapement}}{\text{Feather River In-River + FRH Escapement}}$$

$$\frac{\text{Feather River expanded recoveries of other hatchery releases * 1.495 * Sacramento River escapement}}{\text{Feather River In-River + FRH Escapement}}$$

Expansions for Mainstem River Releases of Juvenile Salmon

4. The CNFH-based estimate for the Sacramento River releases is computed using the mean (EM) CNFH ratio in Table 6:

$$\frac{\text{Battle Creek + CNFH expanded recoveries of CNFH releases * 1.308 * Sacramento River escapement}}{\text{Battle Creek + CNFH Escapement}}$$

5. The FRH-based estimate for the mainstem river releases is computed using separate equations for the FRH and the other hatchery juveniles based on the mean (EM) FRH ratio and Other ratio in Table 6:

$$\frac{\text{Feather River + FRH expanded recoveries of FRH releases * 0.047 * Sacramento River escapement}}{\text{Feather River In-River + FRH Escapement}}$$

$$\frac{\text{Feather River + FRH expanded recoveries of other hatchery releases * 0.664 * Sac River escapement}}{\text{Feather River In-River + FRH Escapement}}$$

Expansions for Tributary Releases of Juvenile Salmon

6. The CNFH-based estimate for the Battle Creek releases is computed using the mean (EM) CNFH ratio in Table 7:

$$\frac{\text{Battle Creek + CNFH expanded recoveries of CNFH releases * 0.408 * Sacramento River escapement}}{\text{Battle Creek + CNFH Escapement}}$$

7. The FRH-based estimate for the tributary releases is computed using separate equations for the FRH and the other hatchery juveniles based on the mean (EM) FRH ratio and Other ratio in Table 7:

$$\frac{\text{Feather River + FRH expanded recoveries of FRH releases * 0.381 * Sacramento River escapement}}{\text{Feather River In-River + FRH Escapement}}$$

$$\frac{\text{Feather River + FRH expanded recoveries of other hatchery releases * 4.845 * Sac River escapement}}{\text{Feather River In-River + FRH Escapement}}$$

Expansions for 2003 and 2004 Estimates Downstream of Red Bluff Diversion Dam

8. Carcass survey data are used to estimate the recoveries in the mainstem Sacramento River in the reach upstream of the Red Bluff Diversion Dam in 2003 and 2004. For the reach downstream of the Red Bluff Diversion Dam, we multiply the upstream recoveries by the Sacramento River escapement below the Red Bluff Diversion Dam divided by the Sacramento River escapement above the Red Bluff Diversion Dam.

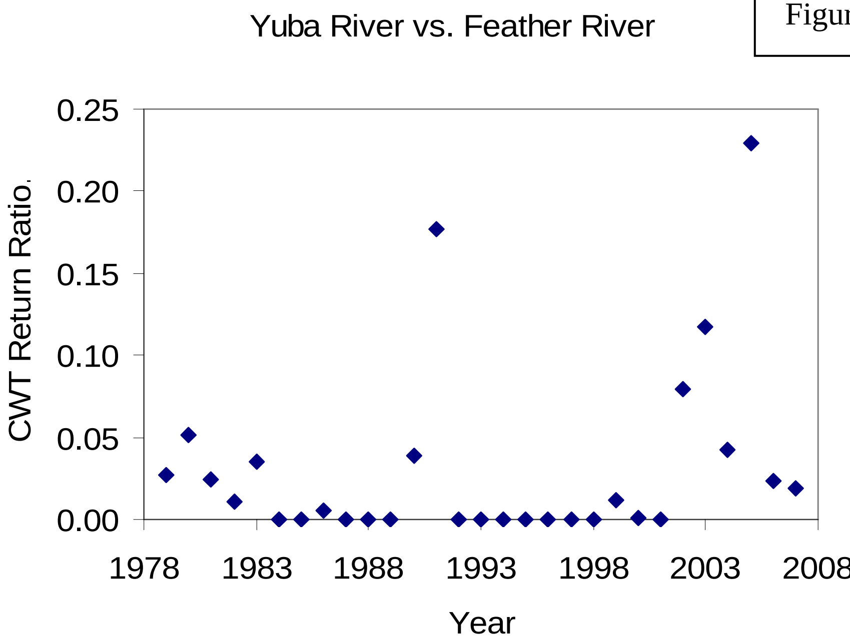
Evaluation of Counts of Number of Carcasses Examined for Ad-Clips in non Hatchery Rivers: A Test of Hypothesis 5

We evaluated the CWT recovery data for the Yuba River relative to the recoveries in the Feather River and we evaluated the recovery data for the Stanislaus and Tuolumne Rivers relative to the recoveries in the Merced River according to whether the juveniles were released in the hatchery river, the mainstem Sacramento/San Joaquin River, Delta-Bay, or from other hatcheries.

Yuba River – We judge the Yuba River recovery data to be relatively accurate for 1991 and 2005, whereas the recovery data collected during all the other carcass surveys are judged to be inaccurate. We base our assessment on the ratio of the number of CWT recoveries in the Yuba River relative to the number of CWT recoveries in the Feather River (FRH and in-river recoveries combined) for juvenile salmon planted in the Delta and Bay. During fall 2005 when CDFG instituted a strict protocol that only fresh carcasses were to be examined for ad-clips (Massa, personal communication, see "Notes"), the ratio is 0.2288. Only 1991 had similar results with a ratio of 0.1770. These ratios are substantially greater than the mean ratio of 0.0181 (range 0 to 0.1176) for all the other years when carcasses were examined (Fig. 5).

The results indicate that the CWT returns to the Yuba River reflect typically high straying rates for juvenile fish trucked to downstream locations. Few FRH fish were released in the Yuba River and so most hatchery fish that returned to the Yuba River were strays. Most CWTs recovered in the Yuba River in 1991 and 2005 were from releases of FRH juveniles in the Delta and Bay and from juveniles produced at the CNFH, NFH, MRFI, and MRH (other hatcheries, Table 12) and these fish would stray at a much higher rate compared to those released in the Feather and Sacramento Rivers. Although there are only two data points, the ranges in the ratios for each release group do not overlap and so the results suggest that Hypothesis 5 is sufficiently true for the purposes of estimating Yuba River CWT recovery rates.

Figure 5



The mean ratio of Yuba River CWT recoveries to Feather River CWT recoveries is 0.3386 for the other hatchery releases, 0.2048 for FRH releases in the Delta and Bay, 0.1426 for FRH releases in the Sacramento River, and 0.0212 (2005 only) for the FRH releases in the Feather River (Table 12). Because the sample sizes are small, we conservatively conclude that the Yuba River estimates for years with relatively inaccurate recovery data should be based on the following four equations for the (1) other hatchery plants, (2) FRH plants in the Delta and Bay, (3) FRH plants in the Sacramento River, and (4) the FRH fish planted in the Feather River, respectively:

FRH expanded recoveries of Other Hatchery Releases * 0.3386

FRH expanded recoveries of FRH releases in the Delta and Bay * 0.2048

FRH expanded recoveries of FRH releases in the Sacramento River * 0.1426

FRH expanded recoveries of FRH releases in the Feather River * 0.0212

Stanislaus And Tuolumne Rivers - The CWT recovery rates in the Stanislaus, Tuolumne and Merced Rivers from 1998 to 2007 do not reflect the expected straying rates. Regardless of which hatchery produced the juvenile salmon or the release location, most CWTs were recovered in the Merced River and relatively few in the Stanislaus River from 1998 to 2007 when the recovery data were most accurate for all three rivers (Table 13).

This is not what we expected considering that the Stanislaus River typically has the highest magnitude attraction pulse flows in October and strays typically enter rivers with the greatest flow (Quinn and Fresh 1984, Quinn 1993). In addition, the MRH fish planted in the San Joaquin River strayed to the Stanislaus and Tuolumne Rivers at a substantially higher rate than the MRH fish planted in the Delta. We also found that the relationships between the CWT recovery rates for the Stanislaus and Tuolumne Rivers and those in the Merced River were weak (Table 14).

There are several different explanations for these unexpected results. First, our assumption that the CWT recovery data for the Stanislaus and Tuolumne Rivers from 1998 to 2007 are

Table 12. The ratio of the number of Yuba River to Feather River CWT recoveries, the number of juvenile fish released for these recoveries (up to four brood years), and the number of CWT recoveries in the Feather and Yuba rivers sorted by juvenile Feather River Hatchery (FRH) salmon released in the Feather River, Sacramento River, and Delta-Bay as well as all other hatchery releases in the Central Valley in 1991 and 2005, when the recovery data were judged to be relatively accurate. The mean used for expanding the missing or inaccurate recovery estimates are presented for each set of ratios.

Year	1991	2005	Mean
FRH releases in Feather River			
#Released	0	482,464	
Feather	0	4,382	
Yuba	0	93	
Ratio		0.0212	0.0212
FRH releases in Sacramento River			
#Released	1,935,548	978,643	
Feather	1,150	1,505	
Yuba	186	186	
Ratio	0.1614	0.1237	0.1426
FRH Delta and Bay Releases			
#Released	477,631	2,501,859	
Feather	581	7,081	
Yuba	104	1,628	
Ratio	0.1797	0.2300	0.2048
Other Hatchery Releases			
#Released	3,412,393	7,843,860	
Feather	74	128	
Yuba	23	47	
Ratio	0.3128	0.3644	0.3386

Table 13. The CWT recovery rates (number recovered/number released) for the Stanislaus, Tuolumne, and Merced rivers segregated by juvenile releases of MRH smolts in the Merced River, San Joaquin River, and Delta, as well as all other hatchery releases in the Central Valley from 1998 to 2007.

	MRH in Merced River			MRH in San Joaquin River			MRH in Delta and Bay			All Other Hatchery Releases		
Year	Stanislaus	Tuolumne	Merced	Stanislaus	Tuolumne	Merced	Stanislaus	Tuolumne	Merced	Stanislaus	Tuolumne	Merced
1998	0.0000%	0.0014%	0.0716%	0.0235%	0.0188%	0.0928%	0.0158%	0.0449%	0.0670%	0.0016%	0.0042%	0.0018%
1999	0.0000%	0.0032%	0.0797%	0.0023%	0.0559%	0.0579%	0.0000%	0.0340%	0.0407%	0.0019%	0.0009%	0.0007%
2000	0.0000%	0.0149%	0.2055%	0.0087%	0.0540%	0.0815%	0.0000%	0.0208%	0.0932%	0.0017%	0.0007%	0.0022%
2001	0.0000%	0.0062%	0.1377%	0.0300%	0.0940%	0.2301%	0.0106%	0.0335%	0.3965%	0.0012%	0.0001%	0.0077%
2002	0.0000%	0.0029%	0.1314%	0.0532%	0.1531%	0.2174%	0.0513%	0.0805%	0.6683%	0.0024%	0.0018%	0.0077%
2003	0.0008%	0.0013%	0.0274%	0.0353%	0.0301%	0.0326%	0.0241%	0.0145%	0.1287%	0.0023%	0.0004%	0.0027%
2004	0.0000%	0.0006%	0.0115%	0.0122%	0.0135%	0.0142%	0.0043%	0.0309%	0.0958%	0.0012%	0.0009%	0.0021%
2005	0.0000%	0.0000%	0.0158%	0.0041%	0.0042%	0.0042%	0.0060%	0.0226%	0.0464%	0.0001%	0.0001%	0.0004%
2006	0.0000%	0.0000%	0.0072%	0.0080%	0.0000%	0.0075%	0.0206%	0.0057%	0.0854%	0.0005%	0.0000%	0.0003%
2007	0.0000%	0.0000%	0.0030%	0.0000%	0.0000%	0.0043%	0.0000%	0.0000%	0.0032%	0.0000%	0.0000%	0.0002%
Mean	0.0001%	0.0030%	0.0691%	0.0177%	0.0424%	0.0742%	0.0133%	0.0287%	0.1625%	0.0013%	0.0009%	0.0026%

Table 14. R^2 and probability (P) values for the linear regression relationships for the number of CWTs recovered between the Stanislaus and Merced rivers (in-river and hatchery combined) and the Tuolumne and Merced rivers for MRH salmon released in the Merced River, San Joaquin River, and Delta as well as CNFH, FRH, NFH and MRFI (Other Hatcheries) releases combined from 1998 to 2007.

	Merced Releases		San Joaquin Releases		Delta Releases		Other Hatchery Releases	
	R^2	P	R^2	P	R^2	P	R^2	P
Stanislaus	0.081	0.425	0.016	0.726	0.000	0.990	0.314	0.073
Tuolumne	0.088	0.405	0.080	0.429	0.000	0.996	0.041	0.577

accurate may be false. However, we believe that the errors would be small because (1) an additional crew member accurately recorded the recovery data on the Tuolumne River; (2) the Merced River recovery data were found to be relatively accurate; and (3) the same sampling protocols were used on all three tributaries. Second, it is possible that Chinook salmon strays actually migrate to the end of a mainstem river before spawning rather than enter a tributary with relatively high flow. This would explain the high recovery rates of CWTs in the effluent from the Los Banos Wildlife Area, which is a waterfowl refuge on the San Joaquin River just upstream from the confluence with the Merced River that provides no salmon spawning habitat. Third, the numbers of CWTs recovered in the Stanislaus and Tuolumne Rivers are relatively small and so small errors in the data could produce relatively large differences in the ratios. Due to these uncertainties, we do not believe that these results falsify Hypothesis 5 for the San Joaquin Basin although they raise doubts about the accuracy of our recovery estimates described below.

There were no CWT recoveries in the Stanislaus River in 1979, 1981, 1982, 1983, 1986, 1992, and 1996 either because no carcass surveys were conducted or the recovery data were inaccurate. The same was true for the Tuolumne River from 1979 to 1982. To provide estimates for the CWT recoveries for the Stanislaus and Tuolumne Rivers for the years without accurate recovery data, we used the ratios of the recovery rates in the Stanislaus and Tuolumne Rivers to those in the Merced River from 1998 to 2007 (Table 15). We computed the expanded recovery estimates for the Stanislaus River for the years

Table 15. Ratios of the number of CWTs recovered in the Stanislaus and Tuolumne rivers relative to the number recovered in the Merced River for MRH smolt releases in the Merced River, San Joaquin River, and Delta, as well as all other Central Valley hatchery releases from 1998 to 2007.

	MRH in Merced River		MRH in San Joaquin River		MRH in Delta and Bay		All Other Hatchery Releases	
Year	Stanislaus	Tuolumne	Stanislaus	Tuolumne	Stanislaus	Tuolumne	Stanislaus	Tuolumne
1998	0.0000	0.0192	0.2532	0.2028	0.2359	0.6699	0.9136	2.3945
1999	0.0000	0.0396	0.0397	0.9659	0.0000	0.8350	2.8083	1.3746
2000	0.0000	0.0726	0.1063	0.6627	0.0000	0.2230	0.7901	0.2972
2001	0.0000	0.0448	0.1302	0.4084	0.0267	0.0846	0.1504	0.0173
2002	0.0000	0.0221	0.2445	0.7042	0.0767	0.1204	0.3163	0.2292
2003	0.0288	0.0479	1.0807	0.9211	0.1874	0.1124	0.8615	0.1657
2004	0.0000	0.0535	0.8583	0.9494	0.0449	0.3221	0.5802	0.4245
2005	0.0000	0.0000	0.9602	0.9927	0.1286	0.4874	0.2033	0.2102
2006	0.0000	0.0000	1.0732	0.0000	0.2415	0.0670	1.6487	0.0000
2007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mean	0.0029	0.0300	0.4746	0.5807	0.0942	0.2922	0.8272	0.5113

with no CWT recoveries (1979, 1981, 1982, 1983, 1986, 1992, and 1996) using the following equations:

Merced expanded recoveries of MRH releases in the Merced River * 0.029

Merced expanded recoveries of MRH releases in the San Joaquin River * 0.475

Merced expanded recoveries of MRH releases in the Delta * 0.094

Merced expanded recoveries of other Central Valley hatchery releases * 0.827

We computed the expanded recovery estimates for the Tuolumne River for the years with few or no CWT recoveries (1979 to 1982) using the following equation:

Merced expanded recoveries of MRH releases in the Merced River * 0.030

Merced expanded recoveries of MRH releases in the San Joaquin River * 0.581

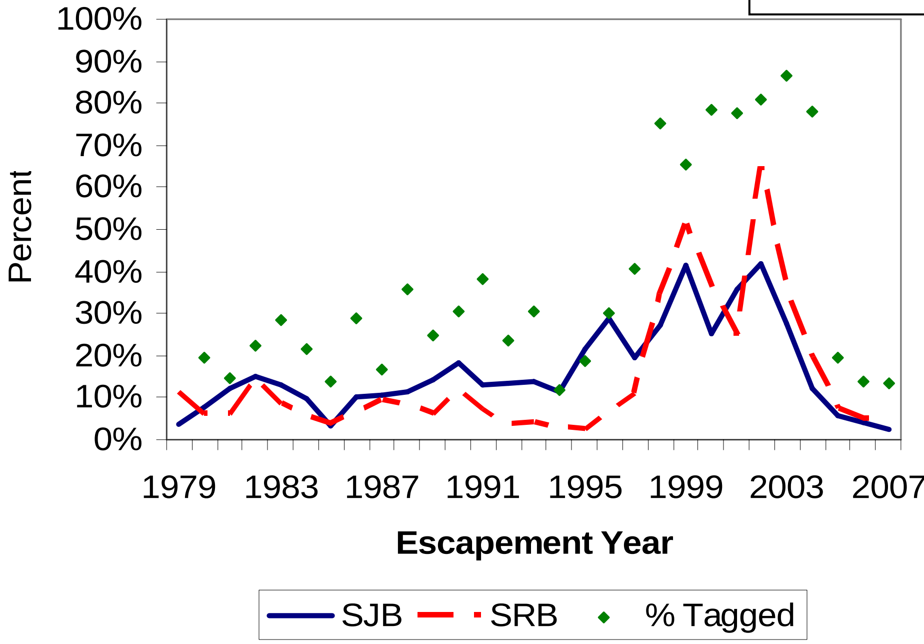
Merced expanded recoveries of MRH releases in the Delta * 0.292

Merced expanded recoveries of other Central Valley hatchery releases * 0.511

Summary of Expanded Estimates

The percentage of Chinook salmon that were released as tagged (CWT) and associated untagged juveniles was as high as 42% in the San Joaquin Basin fall-run Chinook salmon escapements and 65% in the Sacramento River Basin fall-run Chinook salmon escapements during fall 2002, primarily as a result of increased tagging efforts (Fig. 6).

Figure 6



The mean percentage of the tagged and associated untagged juveniles is 37.2% of the total Central Valley Chinook salmon hatchery production for brood years 1977 to 2004, which corresponds to the mean percentages of the tagged and associated untagged recoveries in the escapement of 16.8% and 14.6% for the San Joaquin Basin and the Sacramento River Basin escapements from 1980 to 2007. These results suggest that the mean percentage of hatchery fish in the Central Valley fall-run Chinook salmon escapement is about 42% from 1980 to 2007. The trends in the percentage of hatchery fish tagged and the percentage of tagged fish in the escapement over time depicted in Fig. 6 suggest that the percentage of hatchery fish in the Central Valley fall-run Chinook salmon escapement has been relatively constant from 1980 to 2007; however, a cohort analysis of the escapement returns will be needed to accurately analyze the percentage of hatchery fish in the escapement over time.

The full CWT database will be posted online at www.calfish.org under the Independent Datasets along with a copy of this manuscript.

Conclusion

The Central Valley CWT fall-run Chinook salmon recovery database that we assembled provides data prior to 2000 that were previously unavailable on RMIS, the most accurate available estimates of the number of carcasses examined for ad-clips, and a new method for estimating the total number of CWT recoveries for rivers when the recovery data were either incomplete or nonexistent. Our analyses suggest that for the Central Valley Rivers with hatcheries, the percentages of CWT recoveries in the river are the same as those at the hatcheries, which is consistent with the Null et al. (2003) study on Battle Creek. This result provides the means to verify in-river CWT recovery rates and if necessary use the hatchery data to accurately estimate recovery rates for the rivers. Our analyses also suggest that the CWT recoveries at the TCFF from 1979 to 1985 are the same as those for the mainstem Sacramento River in 2003 and 2004. We also show that the mainstem Sacramento River CWT recoveries are related to the recoveries at the CNFH and the FRH, which provides the means to estimate recovery rates for the Sacramento River from 1979 to 2007. Finally, we show that stray rates are relatively consistent between the Feather and Yuba rivers and between the Stanislaus, Tuolumne, and Merced Rivers to a lesser degree, which provides the means to estimate recovery rates for the Yuba, Stanislaus, and Tuolumne Rivers during years when no accurate recovery data exists.

Our analyses do not conclusively prove that for the Central Valley Rivers with hatcheries, the percentages of CWT recoveries in the river are the same as those at the hatcheries. Conclusive verification studies require that independent crews specifically examine salmon carcasses for ad-clips or CWTs with wands during the in-river carcass surveys and that the number of carcasses examined for ad-clips or CWTs is carefully recorded as was done on Battle Creek by Null et al. (2003). These studies are necessary to improve the level of confidence in the CWT recovery estimates from 1979 to 2007. In particular, we suggest that verification studies should be on the mainstem Sacramento, Yuba, Mokelumne, and Stanislaus Rivers and Cottonwood and Clear Creeks.

We also recommend that for all future carcass surveys and CWT recovery efforts, accurate records must be kept of the number of carcasses examined for ad-clips, which are necessary to compute the total number of CWT returns in the salmon population. This may require additional crew members that have the sole responsibility of examining carcasses for ad-clips, taking the heads from those with ad-clips, and recording the number of fish examined. One possible solution would be to carefully examine a set number of fresh carcasses for ad-clips during the first part of the day, and then stop taking ad-clip data and heads for the remainder of the day. This should not increase the work load of the carcass survey crews but would provide highly accurate data. Another improvement would be to have a protocol for detecting regenerated ad-clips. A functional and effective protocol for collecting CWT recovery data is particularly important for rivers that do not have salmon hatchery data that can be used to verify the in-river recovery data.

ACKNOWLEDGEMENTS

This work was partly funded by the California Department of Fish and Game. We wish to express our appreciation to Tracy McReynolds, Doug Killam, Kevin Niemela, Bob Null, Kyle Hartwigsen, Colleen Harvey Arrison, Mike Healey, Steve Khirihara, Duane Massa, Stephanie Theis, Steve Tsao, Michelle Workman, Bill Mitchell, George Neillands, and Rick Burmester, who assisted us with this paper.

REFERENCES

Bams, R.A. 1976. Survival and propensity for homing as affected by presence or absence of locally adapted paternal genes in two transplanted populations of pink salmon. J. Fisheries Research Board of Canada 33:2716-2725.

McDonald, J.H. 2008. Handbook of Biological Statistics. Sparky House Publishing, Baltimore, Maryland.

McIsaac D.O. and T.P Quinn. 1988. Evidence for a hereditary component in homing behavior of chinook salmon. Can J Fish Aquat Sci 45:2201–2205.

Mesick, C.F. 2001. The effects of San Joaquin River flows and delta export rates during October on the number of adult San Joaquin Chinook salmon that stray. Pages 139-161 in R.L. Brown, editor. Fish Bulletin 179. Contributions to the biology of Central Valley salmonids. Volume 2. California Department of Fish and Game, Sacramento, California.

Quinn, T.P. 1990. Current controversies in the study of salmon homing. Ethology, Ecology & Evolution 2: 49-63.

Quinn, T.P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research. 18:29-44.

Quinn, T.P. 2005. The behavior and ecology of Pacific salmon & trout. American Fisheries Society in association with University of Washington, Press, Seattle.

Quinn, T.P. and K. Fresh. 1984. Homing and straying in Chinook salmon (*Oncorhynchus tshawytscha*) from Cowlitz River Hatchery, Washington. Canadian Journal of Fisheries and Aquatic Sciences 41: 1078-1082.

NOTES

Anonymous. 2001. Feather River salmon spawning escapement: a history and critique. Draft report produced by the Feather River Program, California Department of Water Resources, Sacramento, California. 30 August 2001.

Harvey Arrison, C. 2009. California Department of Fish and Game Fisheries Biologist, Sacramento California. Conducted fall-run Chinook salmon surveys on Battle, Mill, Deer, and Cottonwood creeks. Personal communication with Marston on 13 March 2009.

Healey, M. 2009. California Department of Fish and Game Fisheries Biologist, Sacramento California. Conducted fall-run Chinook salmon surveys on the American River from 2001 through 2008. Personal communication with Mesick on 4 March 2009.

Kano, R.M. 2006. Chinook Salmon Spawner Stocks In California's Central Valley, 2004. Department Of Fish and Game, Habitat Conservation Division, Native Anadromous Fish & Watershed Branch, Inland Fisheries Administrative Report No. 2006-05.

Khirihara, S. 2006. Turlock Irrigation District Fisheries Biologist, Turlock, California. Assisted with the fall-run Chinook salmon surveys on the Tuolumne River from 1983 through 2003. Personal communication with Mesick on 29 June 2006.

Killam, D. 2009. California Department of Fish and Game Fisheries Biologist, Red Bluff, California. Conducted fall-run Chinook salmon surveys on the mainstem Sacramento River above the Red Bluff Diversion Dam and Battle Creek. Personal communication with Marston on 2 March 2009.

Massa, D. 2009. California Department of Fish and Game Fisheries Biologist, Chico, California. Conducted fall-run Chinook salmon surveys on the Yuba River from 2005 through 2007. Personal communication with Mesick on 3 March 2009.

McReynolds, T.R., C.E. Garman, P.D. Ward, and M.C. Schommer. 2005. Butte and Big Chico creeks spring-run Chinook salmon, *Oncorhynchus tshawytscha*, life history investigation 2003-2004. Inland Fisheries Administrative Report No. 2005-1

Neillands, G. 2006. California Department of Fish and Game Fisheries Biologist, Ocean Salmon Project, Yountville California. Personal communications with Rick Burmester, US Fish and Wildlife Service, 2006.

Niemela, K.S. 2009. Program Manager, Hatchery Monitoring & Evaluation, U.S. Fish and Wildlife Service,

Red Bluff, California. Personal communications with Mesick between 12 and 18 March 2009 and on 10 July 2009.

Null, R.E., L. McLaughlin, and K.S. Niemela. 2003. Comparison of methods used to estimate proportions of marked fall Chinook salmon returning to Battle Creek, Anderson, California. U.S. Fish and Wildlife Service Report, Red Bluff, California, February 2003.

Null, R.E. 2009. Hatchery Monitoring & Evaluation, U.S. Fish and Wildlife Service, Red Bluff, California. Personal communications with Marston on 2 March 2009 and Mesick on 10 July 2009.

Pacific States Marine Fisheries Commission. 2008. Constant Fractional Marking/Tagging Program for Central Valley fall-run Chinook salmon. Report produced for the Calfed Ecosystem Restoration Program, Sacramento, CA. Final Project Report P0685610, November 2008.

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.

Theis, S. 2009. MWH Fisheries Biologist, Sacramento, California. Conducted fall-run Chinook salmon surveys on the Yuba River from 1995 through 2004 for Jones and Stokes and the Yuba County Water Agency. Personal communication with Mesick on 3 March 2009.

Tsao, S. 2009. California Department of Fish and Game Fisheries Biologist, La Grange California. Conducted fall-run Chinook salmon surveys on the Merced River from 2005 through 2008. Personal communication with Mesick on 23 March 2009.

Weber, P.K., R. Barnett-Johnson, and R.B. MacFarlane. 2009. Proposal to evaluate Chinook salmon otoliths to determine hatchery or natural origin in the Mokelumne River watershed in the California Central Valley: An integrated microchemistry/microstructure approach. Draft final report prepared for the U.S. Fish and Wildlife Service Anadromous Fish Restoration Program. Stockton, CA.

Workman, M. 2009. East Bay Municipal Utility District Fisheries Biologist, Lodi, California. Conducted fall-run Chinook salmon surveys on the Mokelumne River from 2003 through 2008. Personal communications with Mesick on 4 March and 23 June 2009.

LIST OF FIGURE LEGENDS

Figure 1. Map of major Central Valley rivers and the Feather River Hatchery (FRH), Tehama Colusa Fish Facility (TCFF), Coleman National Fish Hatchery (CNFH), Mokelumne River Fish Installation (MRFI), Merced River Hatchery (MRH), and the Nimbus Fish Hatchery (NFH).

Figure 2. Relationship between the returns of fall-run Chinook salmon at the Feather River Hatchery (x) and the fall-run Chinook salmon escapement (y) in the Feather River from 2000 to 2007. The linear regression model is displayed and shown graphically as a solid line with an R^2 value of 0.3381.

Figure 3. Relationship between Yuba River escapement and Feather River escapement from 2000 to 2007. The linear regression model is displayed and shown graphically as a solid line with an R^2 value of 0.3909.

Figure 4. Relationship between Stanislaus River and Merced River escapements from 1997 to 2007. The linear regression model is presented and shown graphically as a solid line with an R-square value of 0.7405.

Figure 5. The ratio of the percentage of expanded CWT recoveries in the Yuba River to those for the Feather River (FRH and in-river escapements combined) for juvenile releases in the Delta and Bay from 1979 to 2007.

Figure 6. The percentage of tagged (CWT) and associated untagged salmon that returned to the San Joaquin Basin (SJB) and the Sacramento River Basin (SRB) from 1979 to 2007 based on the methods described here and the percentage of tagged and associated untagged salmon relative to the total number of juvenile salmon released from Central Valley hatcheries (% Tagged) from 1980 to 2007 delayed by 2 years when the Age 3 fish would have returned in the escapement.