The 2006 Central Valley Chinook Age Specific Run Size Estimates

Scale Aging Program
California Department of Fish and Game
475 Aviation Blvd, Suite 130
Santa Rosa, CA 95403

Allen Grover
Senior Biologist
1169 Limerick Lane
Healdsburg, CA 95448
allen.grover@noaa.gov

Brett Kormos
Associate Biologist
475 Aviation Blvd, Suite 130
Santa Rosa, CA 95403
bkormos@dfg.ca.gov

Abstract

Through scale aging, this study produces age structured hatchery and natural escapement estimates for all principal reaches and runs of Chinook salmon (*Oncorhynchus tshawytscha*) in the Central Valley. Sampling methods employed by hatcheries and escapement surveys reflect spatial and temporal differences among fish present throughout the escapement periods. State of the art digital imaging and reading techniques were used. A modified maximum likelihood estimator based on the work of Kimura and Chikuni (1987) was utilized. This method uses known aged coded wire tagged (CWT) salmon scale samples in conjunction with those of unknown aged (non-CWT) fish to create bias corrected age proportions from which age specific run size estimates can be made. While cohort reconstructions will require estimates from future escapement years, preliminary results show there are differences in the age structure of hatchery and natural escapement. In addition, results indicate there are age structure differences among the Chinook life history types present in the Central Valley. Results of this study have shown that scale aging is a valid method for deriving age specific escapement estimates. Both the methods employed and results presented may have broad implications for the future of Chinook salmon management and restoration efforts in the Central Valley.

In accordance with the CALFED Ecosystem Restoration Program directed actions, this project represents the first attempt at assessing age-specific escapement for all major CV Chinook salmon populations. Through the use of age specific escapement data and CWT recoveries with known mark rates, estimates of natural and hatchery abundance can be calculated through the life history of the fish. Once the entire 2006 brood (marked at a constant 25% rate) has reached completion in 2011, age specific ocean harvest rates, maturation rates, survival rates, and stray rates, can be calculated. A continuation of these programs will provide brood specific estimates of these population parameters each year thereafter.

Sacramento River Basin Fall Chinook age composition, 2006.

Escapement	Fish at Age				
Hatcheries	**2**	**3**	**4**	**5**	**TOTAL Escapement**
Coleman National Fish Hatchery	3,756	26,518	26,897	851	58,022
Feather River Hatchery	946	9,672	3,295	121	14,034
Nimbus Fish Hatchery	2,071	3,829	2,796	32	8,728
Hatchery Subtotal	**6,773**	**40,019**	**32,988**	**1,004**	**80,784**
Natural Areas					
Clear Creek	178	3,400	4,844	0	8,422
Battle Creek	1,265	8,872	9,069	287	19,493
Upper Sacramento River	2,308	1,486	51,485	189	55,468
Feather River	610	38,334	36,468	18	75,430
Yuba River	374	1,317	6,540	0	8,231
American River	1,509	5,882	15,428	81	22,900
Natural Area Subtotal	**6,244**	**59,291**	**123,834**	**575**	**189,944**
Total Aged Fall Escapement	**13,017**	**99,310**	**156,822**	**1,579**	**270,728**

Table I: 2006 estimated run size at age of the Sacramento River Fall Chinook hatchery and natural populations where scale samples were obtained. No scale samples were taken from Battle Creek therefore CNFH age proportions were utilized. Other tributaries and escapements without carcass surveys and/or scale collections were not aged.

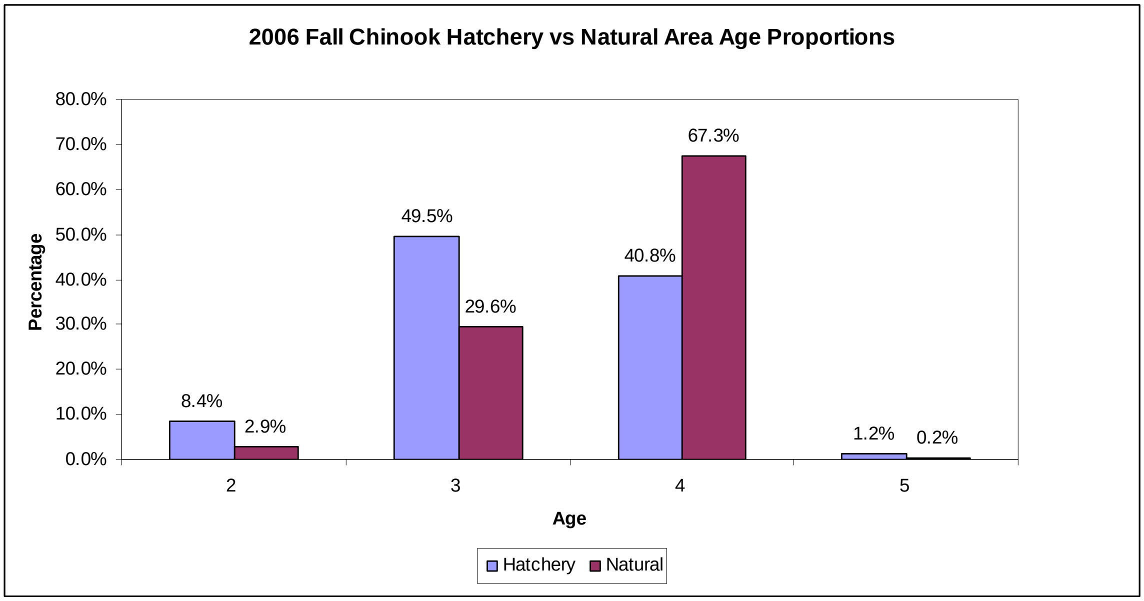

Figure 1: A comparison of the 2006 overall hatchery and natural area run size proportions at age. This illustrates the differences in age proportions for the two areas and contributions from the 2001 through 2004 broods. Battle Creek was removed from the analysis because the age proportions were derived from CNFH.

Central Valley Late Fall, Winter, Spring, and Mokelumne River Fall Chinook age composition, 2006.

Escapement	Fish at Age				
Hatcheries	**2**	**3**	**4**	**5**	**TOTAL Escapement**
Coleman National Fish Hatchery-Late Fall Run	583	703	1,919	42	3,247
Feather River Hatchery-Spring Run	44	1,650	201	166	2,061
Mokelumne River Fish Hatchery-Fall Run	1,535	1,859	744	1	4,139
Hatchery Subtotal	**2,162**	**4,212**	**2,864**	**209**	**9,447**
Natural Areas					
Upper Sacramento River-Winter Run	350	16,367	581	0	17,298
Upper Sacramento River-Late Fall Run	120	1,338	13,837	46	15,341
Butte Creek-Spring Run	118	5,089	1,340	0	6,547
Mokelumne River-Fall Run	96	797	839	0	1,732
Natural Area Subtotal	**684**	**23,591**	**16,597**	**46**	**40,918**
Total Aged Escapement	**2,846**	**27,803**	**19,461**	**255**	**50,365**

Table II: 2006 estimated run size at age for Chinook populations other than Sacramento River Fall Chinook. Spring run are those fish that left the ocean in the spring of 2006 and spawned prior to the Fall run of 2006. Late Fall run are those fish that left the ocean to spawn after the Fall run of 2006 with spawning continuing into 2007. Winter run are those fish that left the ocean during the winter of 2005 and 2006 and spawned prior to the Spring and Fall runs of 2006. Tributaries and escapements without carcass surveys and/or scale collections were not aged.

Introduction

The focus of this work was to develop methods and procedures to produce reliable and timely estimates of CV run size at age. Numerous techniques of estimating fish age based on physical characteristics have been used. Hard parts used for aging fish include otoliths, fin spines, fin rays, cleithra, vertebrae, opercular bones, dentary bones, and scales. Summerfelt and Hall (1987) suggest, from a management perspective, that scale aging provides an excellent means for knowing age class composition of a catch. Using scales to age fish is favored here because of the overall efficiency of collecting, preparing, and reading scales in a production environment as opposed to other aging methods. The project focused on applying modern digital imaging techniques along with computer aided data storage and retrieval methods. These procedures allow for the assessment of reader assigned age bias and apply bias correction through statistical methods. Non-random known age fish can be added to the reading assignments in large enough numbers to make statistically valid assessment of reader bias. These methods are an improvement over the methods of directly reading scale age patterns from either the mounted scales or acetate impressions because reader assignments can be made using easily retrievable digital images and read on staff computers. This work also provides a realistic evaluation regarding the ability to make age specific run size estimates in a production environment along with the required manpower, equipment and associated costs.

Methods

Sampling methods employed at hatcheries and on escapement surveys reflect potential spatial and temporal differences in age structure among fish present throughout the duration of the run. The sample design was selected to achieve a non-biased estimate of age structure for the specific portion of the population where escapement estimates are made without respect to known or unknown age fish. Each survey area and hatchery attempted to collect 550 random scale samples. In addition, at hatcheries almost all of the adipose fin clipped fish were scale sampled to provide a reference collection of as many known age scales as possible. In hatcheries, samples were collected at a constant rate throughout the entire spawning period keeping track of the “random” age sample and the additional “non-random” known age samples. On carcass surveys samples were collected at a constant rate as fish suitable for sampling were encountered throughout the survey periods. Because of the high sample rate for known age scales at hatcheries and the difficulty of sampling on spawning grounds, non-random samples were generally not taken from adipose fin clipped carcasses.

When possible, scales were collected from the preferred scale sampling location. This location is on the left side of the fish, diagonally down and back from the posterior insertion of the dorsal fin and just slightly above the lateral line. Consistency in collection method is important as scale growth rates on different parts of the fish's body can differ and can influence the results of scale pattern analysis (Bugaev 2004).

State of the art mounting, digital imaging and digital reading techniques were used. From each scale sample, numerous scales were cleaned and mounted onto glass microscope slides. The best quality scales were digitized, catalogued, and stored to hard drives. Scale images were selected and arranged into reading assignments for the scale reader. In cases where scale collections were relatively small the entire collections were read. These assignments were specific to each escapement and included both scales from unknown aged non ad-clipped Chinook and known aged scales collected from ad-clipped CWT Chinook. When needed, additional known age samples were added to the reading assignment to increase the sample size of known age fish for improved validation and subsequent bias correction. This was done to better evaluate reader bias in instances where scale collections did not contain adequate numbers of known age samples from each age class. Most of these known age scales were collected at FRH because CNFH and NFH tagged little or no (0%-3% of total production) Fall Chinook salmon produced from brood years 2002 through 2005. The 2001 brood was tagged at a much higher rate however its contribution to the escapement in 2006 was minimal. In 2006 a single basin wide validation matrix was read once and used for Fall run collections lacking in known age fish. Collections that contained insufficient numbers of known age fish were validated by adding those known age fish to the single basin wide matrix. The Butte Creek Spring run validation matrix was augmented using known age samples from the FRH Spring run. The MRFI collection was read following the 2007 season and was validated using a matrix comprised of known age scales from 2006 and 2007. It was determined that readers were unable to distinguish the differences between different brood years at the same age. Therefore it was possible to use known age fish from 2006 and 2007 to improve sample sizes for bias correction. Exact minimum known age sample sizes from each age class needed in a collection have not been established; however maximizing poorly represented age classes when possible is necessary. In 2006 the minimum sample size target for individual known age groups was 20; however this was not always possible.

When possible, readers were provided with training assignments of scales not used in the evaluation of reader bias. Reading assignments were made to reflect the spatial and temporal differences expressed throughout the duration of each run. Without knowledge of the assignment composition the scales were examined for age indicative structures or patterns. Individual ages were determined from scales by counting winter annuli, a standard method for scale aging of Pacific salmon (Bugaev 2004). Annuli can be identified as bands of closely spaced or broken circuli. Scale samples were read by an individual experienced reader and field biological data (sex and length) were taken into consideration only after the initial evaluation of age by the reader. Flain and Glova (1988) demonstrated that aging scales by one experienced reader can be more accurate than aging scales using multiple readers.

A modified maximum likelihood estimator based on the work of Kimura and Chikuni (1987) was used to correct for reader bias identified in each reading assignment.

This method uses the scales read from individual known aged CWT Chinook in the reading assignment to identify and correct for reader bias using a measure of reader accuracy in the form of a validation matrix. This method adjusts the read age proportions based on the reader accuracy of the known age scales identified in the validation matrices (Tables 4a-4o). The known age fish, expanded for sampling, were subtracted from the total escapement estimate. The bias corrected age proportions were then applied to the fraction of the total escapement estimate that was of unknown age. In this way, only the unknown aged portion of the escapement estimate was estimated using the bias corrected age proportions. The known age fish, were then added back into the age specific escapement estimate by their respective age classes. This resulted in the total age specific escapement estimate. See Appendix A for a detailed description of the equation used for application of bias corrected proportions. See Appendix J for a list of sample expansion factors.

Results

A total of 5,937 samples from individual unknown aged Chinook were read. This total was comprised of scales from 15 separate collections originating from 4 hatcheries and 9 carcass surveys. Age assignments were bias corrected using scales from the CWT fish recovered within their respective areas. When there were insufficient numbers of CWT recoveries a combination of Sacramento Basin CWT scales from 2006 were added to the existing CWT fish in the collection. See tables 4a through 4o for individual escapement validation matrices. See Appendices B and C for total numbers of scale samples taken in each hatchery or carcass survey where CWT fish were recovered.

Table I contains the age structured run size estimates for Sacramento River Fall Chinook. These results are presented separate from the other runs in the CV because of their use as the CV Chinook conservation stock by the PFMC for fisheries management. For each estimate the total escapement numbers are the combined jack and adult totals published in the PFMC's "Review of the 2008 Ocean Salmon Fisheries". Those escapement totals were partitioned into separate ages using the bias corrected age proportions from scales. The natural area surveys are those where fish are handled and scales could be collected. In the case of Battle Creek, CNFH age proportions were assumed. In the case of small natural area stream surveys that were based on redd counts or snorkel surveys there were no scales collected so they were not included in the table. However, it would be possible as done for Battle Creek to assume age proportions from the closest survey where scales were collected or a combined stock age proportion. These "minor tributaries" do not normally have a large effect on the total Sacramento River Fall Chinook escapement.

Figure 1 shows a graphic representation of the hatchery versus natural area escapement age structure in 2006. This analysis excluded Chinook that returned to Battle Creek because their age structure was assumed to be the same as CNFH. The graphic shows that in 2006 the hatchery age structure is shifted toward younger aged fish as compared to natural areas.

Table II contains the stocks and tributaries where scale collections were made in addition to the Sacramento River Fall Chinook. Winter run age structure is for hatchery and natural areas combined. This was done due to the fact that Livingston Stone Hatchery takes only a few fish of mostly natural origin, as it is operated as a conservation hatchery. The total escapement is based on the CDFG and USFWS carcass survey which is not reported in the 2006 review tables but is mentioned in the text. FRH Spring run size estimates are based on hatchery counts from 2006. It was not possible to make estimates of naturally spawning Spring run in the Feather River. Smaller populations of wild Spring run in the upper Sacramento River tributaries were not sampled for carcasses throughout the spawning period so scale samples are not available. From the estimates it appears that in general the Winter and Spring run escapement age structures are skewed toward the younger ages. Late Fall stocks are not similarly skewed toward younger ages. Future analyses will be needed to determine if these differences are the result of differences in brood strength, maturation rates, or survival rates.

Appendices H and I present estimate totals for age 2 and ages 3-5 for each escapement in 2006. For comparison, those totals are displayed along with the estimates reported in the PFMC's "Review of the 2008 Ocean Salmon Fisheries" for grilse and adult escapement. Despite differences in the methodology used to derive these estimates, in some cases the totals are comparable. However, notable differences can be found in the Fall hatchery estimates where the total age 2 escapement estimate based on scale aging is roughly double that of the numbers reported in the Review. Other escapement differences are detailed in the aforementioned appendices.

Discussion

This report demonstrates that it is possible to age the CV Chinook escapements from scales collected in hatcheries and on spawning ground surveys. Where possible total escapement was based on estimates made by the individual survey projects and reported in the PFMC's "Review of the 2008 Ocean Salmon Fisheries". Total escapement estimates to the CV of all stocks are made by a combination of many different organizations including State and Federal agencies, private consultants, and utilities. However, not all of these groups were represented in this report. At the time of the report groups not included were the CDFG CV creel survey and the CDFG San Joaquin River escapement surveys. The coordination among all of these diverse interests is difficult. In the future the hope is to receive scale collections from all groups in the CV making escapement estimates so that a comprehensive age determination can be made using the same methods.

The lack of CWT's from CNFH was one of the major sources of difficulty in age determination of the Sacramento River Fall run in 2006. Large numbers of scales will continue to be sampled and imaged from CWT fish until there is a sufficient archive of images from each stock to provide adequate sample sizes for the evaluation of reader bias in age determination. In addition it may be important to characterize the scale patterns from broods that have experienced very low survival such as the 2004 and 2005 broods so the images can be compared to future broods with higher survival. These results also underscore the importance of CWT tagging in the CV. The methods employed here will better facilitate future analyses due to the ease of image retrieval and sharing associated with digital imaging, as compared to past scale aging methodologies.

In 2006, a single basin wide validation matrix was read once and applied to all Fall run collections lacking in known age fish, with the exception of the MRFI collection. While this approach may correct for the general bias associated with an individual reader, it does not necessarily do so for the bias associated with each individual collection. Therefore, in the future this project will include a unique validation matrix in each individual collection assignment so that bias associated with the reader and each collection will be identified and corrected. As 2006 was the pilot year of this project, it is the recommendation of the authors of this report to reread these collections using the aforementioned validation methodology, given the available time and funding.

The cause of differences in the age structure estimates made in this report are difficult to determine based on data from a single return year. The importance of this analysis is in tracking year class strength through time and providing the basic data to make estimates of population and fishery parameters as broods complete their life cycle. However, it is interesting to identify relationships in the data such as the shift in hatchery age structure presented in Figure 1 and to see if these relationships continue into the future. Such analyses may provide the basis for changing hatchery practices to better mimic wild population parameters. The results from the CFM program and the age analysis will provide the best opportunity to manage CV Chinook salmon based on scientifically defendable data. The continuation of these programs is vital to achieving this goal.

List of Acronyms and Abbreviations

Ad-Clipped	Adipose Fin Clipped
CDFG	California Department of Fish and Game
CFM	Constant Fractional Marking
CNFH	Coleman National Fish Hatchery
CWT	Coded Wire Tag
CV	Central Valley
FRH	Feather River Hatchery
MRFI	Mokelumne River Fish Installation
NFH	Nimbus Fish Hatchery
PFMC	Pacific Fisheries Management Council
USFWS	U.S. Fish and Wildlife Service

Literature Cited

Bugaev A.V. 2004. Scale pattern analysis estimates of the age and stock composition of Chinook salmon *Oncorhynchus tshawytscha* in R/V *TINRO* trawl catches in the western Bering Sea in September-October 2002 (NPAFC Doc. 764) 15 p. KamchatNIRO, Kamchatka Fisheries & Oceanography Inst., Fisheries State Commit. of Russia, Naberezhnaja Street 18, Petropavlovsk-Kamchatski, Russia.

Flain, M. and Glova, G. 1988. A test of the reliability of otolith and scale readings of Chinook salmon *(Oncorhynchus tshawytscha). New Zealand Journal of Marine and Freshwater Research, Vol. 22:* 497-500

Kimura, D. K., Chikuni, S. 1987. Mixtures of Empirical Distributions: An Iterative Application of the Age- Length Key. Biometrics 43:23-35

KRTAT (Klamath River Technical Advisory Team). 2007. Klamath River Fall Chinook Age-Specific Escapement, River Harvest, and Run Size Estimates, 2006 Run. Available from the Pacific Fishery Management Council, 770 NE Ambassador Place Suite 101, Portland, OR 97220-1384.

Summerfelt, R. C., and Hall, G. E. 1987. Age and Growth of Fish. The Iowa State University Pres. Ames, Iowa 50010

Acknowledgements

Thanks to the following individuals for their assistance in editing as well as compiling and reviewing data for this report: Joe Duran, Colin Purdy, Michael Mercer, Melodie Palmer Zwahlen, Jennifer Simon, and Marc Heisdorf. Scale collections were provided by the California Department of Water Resources Feather River Program, California Department of Fish and Game, the United States Fish and Wildlife Service, and the East Bay Municipal Utility District. Additional thanks are extended to the following hatcheries and associated staff for their cooperation in this study: Coleman National Fish Hatchery, Feather River Hatchery, Nimbus Fish Hatchery, and the Mokelumne River Fish Hatchery. Finally, thanks go to Alice Low, Melodie Palmer Zwahlen, and Stan Allen for their efforts in facilitating the funding, staffing, and coordination needs of this project. Funding was provided by the CALFED Ecosystem Restoration Program.

Table 4a. 2006 Clear Creek Fall Run scale validation matrices.

Number

		Known Age 2	3	4	5	
	2	46	4	0	0	
Read	3	1	324	22	0	
Age	4	0	27	54	1	
	5	0	0	0	1	Total
	Total	47	355	76	2	480

Percentage

		Known Age 2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.289	0.000
Age	4	0.000	0.076	0.711	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4b. 2006 Upper Sacramento Fall Run scale validation matrices.

Number

		Known Age 2	3	4	5	
	2	46	4	0	0	
Read	3	1	324	22	0	
Age	4	0	27	54	1	
	5	0	0	0	1	Total
	Total	47	355	76	2	480

Percentage

		Known Age 2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.289	0.000
Age	4	0.000	0.076	0.711	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4c. 2006 Upper Sacramento Late Fall Run scale validation matrices.

Number

		Known Age 2	3	4	5	
Read Age	2	36	0	0	0	
	3	0	55	20	0	
	4	1	1	107	1	
	5	0	0	0	1	Total
	Total	37	56	127	2	222

Percentage

		Known Age 2	3	4	5
Read Age	2	0.973	0.000	0.000	0.000
	3	0.000	0.982	0.157	0.000
	4	0.027	0.018	0.843	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4d. 2006 Winter Run scale validation matrices.

Number

		Known Age 2	3	4	5	
Read Age	2	19	8	0	0	
	3	0	192	3	0	
	4	0	11	14	1	
	5	0	0	0	1	Total
	Total	19	211	17	2	249

Percentage

		Known Age 2	3	4	5
Read Age	2	1.000	0.038	0.000	0.000
	3	0.000	0.910	0.176	0.000
	4	0.000	0.052	0.824	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4e. 2006 CNFH Fall Run scale validation matrices.

Number

		Known Age 2	3	4	5	
Read Age	2	46	4	0	0	
	3	1	324	22	0	
	4	0	27	54	1	
	5	0	0	0	1	Total
	Total	47	355	76	2	480

Percentage

		Known Age 2	3	4	5
Read Age	2	0.979	0.011	0.000	0.000
	3	0.021	0.913	0.289	0.000
	4	0.000	0.076	0.711	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4f. 2006 CNFH Late Fall Run scale validation matrices.

Number

		Known Age 2	3	4	5	
Read Age	2	29	1	0	0	
	3	4	49	33	0	
	4	1	2	67	2	
	5	0	0	1	1	Total
	Total	34	52	101	3	190

Percentage

		Known Age 2	3	4	5
Read Age	2	0.853	0.019	0.000	0.000
	3	0.118	0.942	0.327	0.000
	4	0.029	0.038	0.663	0.667
	5	0.000	0.000	0.010	0.333
	Total	1.000	1.000	1.000	1.000

Table 4g. 2006 Butte Creek Spring Run scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	26	1	0	0	
Read	3	1	109	14	0	
Age	4	0	18	76	1	
	5	0	0	1	1	Total
	Total	27	128	91	2	248

Percentage

		Known Age			
		2	3	4	5
	2	0.963	0.008	0.000	0.000
Read	3	0.037	0.852	0.154	0.000
Age	4	0.000	0.141	0.835	0.500
	5	0.000	0.000	0.011	0.500
	Total	1.000	1.000	1.000	1.000

Table 4h. 2006 Feather River scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	72	0	0	0	
Read	3	2	68	21	0	
Age	4	0	38	108	1	
	5	0	0	1	1	Total
	Total	74	106	130	2	312

Percentage

		Known Age			
		2	3	4	5
	2	0.973	0.000	0.000	0.000
Read	3	0.027	0.642	0.162	0.000
Age	4	0.000	0.358	0.831	0.500
	5	0.000	0.000	0.008	0.500
	Total	1.000	1.000	1.000	1.000

Table 4i. 2006 FRH Fall Run scale validation matrices.

Number		Known Age 2	3	4	5	
	2	46	4	0	0	
Read	3	1	324	22	0	
Age	4	0	27	54	1	
	5	0	0	0	1	Total
	Total	47	355	76	2	480

Percentage		Known Age 2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.289	0.000
Age	4	0.000	0.076	0.711	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4j. 2006 FRH Spring Run scale validation matrices.

Number		Known Age 2	3	4	5	
	2	26	1	0	0	
Read	3	1	86	8	0	
Age	4	0	17	69	1	
	5	0	0	1	0	Total
	Total	27	104	78	1	210

Percentage		Known Age 2	3	4	5
	2	0.963	0.010	0.000	0.000
Read	3	0.037	0.827	0.103	0.000
Age	4	0.000	0.163	0.885	1.000
	5	0.000	0.000	0.013	0.000
	Total	1.000	1.000	1.000	1.000

Table 4k. 2006 Yuba River Fall Run scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	46	4	0	0	
Read	3	1	324	22	0	
Age	4	0	27	54	1	
	5	0	0	1	1	Total
	Total	47	355	77	2	481

Percentage

		Known Age			
		2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.286	0.000
Age	4	0.000	0.076	0.701	0.500
	5	0.000	0.000	0.013	0.500
	Total	1.000	1.000	1.000	1.000

Table 4l. 2006 American River Fall Run scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	46	4	0	0	
Read	3	1	324	22	0	
Age	4	0	27	54	1	
	5	0	0	0	1	Total
	Total	47	355	76	2	480

Percentage

		Known Age			
		2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.289	0.000
Age	4	0.000	0.076	0.711	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4m. 2006 NFH Fall Run scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	46	4	0	0	
Read	3	1	324	22	0	
Age	4	0	27	54	1	
	5	0	0	0	1	Total
	Total	47	355	76	2	480

Percentage

		Known Age			
		2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.289	0.000
Age	4	0.000	0.076	0.711	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4n. 2006 Mokelumne River Fall Run scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	46	4	0	0	
Read	3	1	325	22	0	
Age	4	0	27	55	1	
	5	0	0	0	1	Total
	Total	47	356	77	2	482

Percentage

		Known Age			
		2	3	4	5
	2	0.979	0.011	0.000	0.000
Read	3	0.021	0.913	0.286	0.000
Age	4	0.000	0.076	0.714	0.500
	5	0.000	0.000	0.000	0.500
	Total	1.000	1.000	1.000	1.000

Table 4o. 2006 MRFI Fall Run scale validation matrices.

Number

		Known Age				
		2	3	4	5	
	2	62	4	0	0	
Read	3	6	279	41	0	
Age	4	0	48	138	2	
	5	0	0	0	1	Total
	Total	68	331	179	3	581

Percentage

		Known Age			
		2	3	4	5
	2	0.912	0.012	0.000	0.000
Read	3	0.088	0.843	0.229	0.000
Age	4	0.000	0.145	0.771	0.667
	5	0.000	0.000	0.000	0.333
	Total	1.000	1.000	1.000	1.000

Appendix A: Estimation of escapement age-composition from a random sample containing known (CWT) and unknown-age fish where CWT's are expanded for sampling. (KRTAT 2007)

Denote the escapement at age as $\{N_a, a = 2, 3, 4, 5\}$, $N = \sum N_a$, and for the random sample of size $(n + m)$ fish, denote the following quantities:

- † all known age fish: number at age $\{n_a, a = 2, 3, 4, 5\}$, $n = \sum n_a$, $p_a = n_a/n$
- unknown read-age fish: number at age $\{m_a, a = 2, 3, 4, 5\}$, $m = \sum m_a$, $r_a = m_a/m$
- bias-correct unknown read-age proportions: $\{r_a^*, a = 2, 3, 4, 5\}$
- sample expansion factor: $\{s_a, a = 2, 3, 4, 5\}$

Age 2-5 escapement by scales. Estimate N_a as the sample known age a fish plus the unknown age portion of the escapement times the estimated age a proportion (bias-corrected):

$$N_a = np_a + (N - ns_a)r_a^*, \; a = 2, 3, 4, 5.$$

† Known age fish are both those CWT fish that were sampled for scales in their hatchery or stream of origin as well as those not sampled but recovered in their stream or hatchery of origin. Upper Sacramento Fall and Late Fall runs are the exception as fish from CNFH make significant contributions to those escapements. Additionally, known age fish are those that contained a CWT for which release information was obtainable. Sheds and lost tags were not accounted for by expansions and were treated as unknown age fish.

Appendix B: Summary of CWT scale sampled fish and CWT recoveries not sampled for scales for Sacramento Basin Fall run escapements

Fall Run Escapement		**CWT Fish at Age**			
Hatcheries		**2**	**3**	**4**	**5**
Coleman National Fish Hatchery	Sampled	8	222	18	1
	Not Sampled	1	70	18	4
Feather River Hatchery	Sampled	1	38	12	0
	Not Sampled	2	193	76	0
Nimbus Fish Hatchery	Sampled	0	0	0	0
	Not Sampled	0	0	0	0
Hatchery Subtotal		**12**	**523**	**124**	**5**
Natural Areas					
Clear Creek	Sampled	0	0	0	0
	Not Sampled	0	0	0	0
Upper Sacramento River	Sampled	0	0	0	0
	Not Sampled	0	0	0	0
Feather River	Sampled	5	92	117	1
	Not Sampled	7	55	61	0
Yuba River	Sampled	0	0	0	0
	Not Sampled	0	0	0	0
American River	Sampled	0	0	0	0
	Not Sampled	0	0	0	0
Natural Area Subtotal		**12**	**147**	**178**	**1**
Total Fall Escapement		**24**	**670**	**302**	**6**

Note: Estimates are made for only the unknown age portion of each escapement. All CWT fish listed in this table were recovered in the appropriate river respective to their hatchery of origin. CWT fish recovered as strays were not included in this table; however they may have been used in basin wide validation matrices for streams without hatcheries or tagging programs.

Appendix C: Summary of CWT scale sampled fish and CWT recoveries not sampled for scales for Central Valley Late Fall, Winter, Spring, and Mokelumne River Fall runs

Escapement		**CWT Fish at Age**			
Hatcheries		**2**	**3**	**4**	**5**
Coleman National Fish Hatchery-Late Fall Run	Sampled	34	52	101	2
	Not Sampled	545	651	1,559	14
Feather River Hatchery-Spring Run	Sampled	7	78	48	0
	Not Sampled	37	187	153	0
Mokelumne River Fish Hatchery-Fall Run	Sampled	34	10	28	1
	Not Sampled	0	0	0	0
Hatchery Subtotal		**657**	**978**	**1,889**	**17**
Natural Areas					
Upper Sacramento River-Winter Run	Sampled	0	413	18	0
	Not Sampled	1	323	15	0
Upper Sacramento River-Late Fall Run	Sampled	3	6	48	1
	Not Sampled	0	0	0	0
Butte Creek-Spring Run	Sampled	0	24	13	0
	Not Sampled	0	16	9	0
Mokelumne River-Fall Run	Sampled	0	0	1	0
	Not Sampled	0	0	0	0
Natural Area Subtotal		**4**	**782**	**104**	**1**
Total Escapement		**661**	**1,760**	**1,993**	**18**

Note: Estimates are made for only the unknown age portion of each escapement. All CWT fish listed in this table were recovered in the appropriate river respective to their hatchery of origin. CWT fish recovered as strays were not included in this table; however they may have been used in basin wide validation matrices for streams without hatcheries or tagging programs.

Appendix D: Summary of unknown age read fish and their subsequent proportions for Sacramento Basin Fall run escapements

Fall Run Escapement		**Unknown Fish at Age**			
Hatcheries		**2**	**3**	**4**	**5**
Coleman National Fish Hatchery	Read	28	225	152	3
	Proportion	0.069	0.551	0.373	0.007
Feather River Hatchery	Read	34	316	101	2
	Proportion	0.075	0.698	0.223	0.004
Nimbus Fish Hatchery	Read	130	273	144	1
	Proportion	0.237	0.498	0.263	0.002
Hatchery Subtotal	**Read**	**192**	**814**	**397**	**6**
	Proportion	**0.136**	**0.578**	**0.282**	**0.004**
Natural Areas					
Clear Creek	Read	5	106	87	0
	Proportion	0.025	0.535	0.439	0.000
Upper Sacramento River	Read	24	172	388	1
	Proportion	0.041	0.294	0.663	0.002
Feather River	Read	2	154	221	1
	Proportion	0.005	0.407	0.585	0.003
Yuba River	Read	13	105	162	1
	Proportion	0.046	0.374	0.577	0.004
American River	Read	38	243	282	1
	Proportion	0.067	0.431	0.500	0.002
Natural Area Subtotal	**Read**	**82**	**780**	**1,140**	**4**
	Proportion	**0.041**	**0.389**	**0.568**	**0.002**
Total Fall Escapement	**Read**	**274**	**1,594**	**1,537**	**10**
	Proportion	**0.080**	**0.467**	**0.450**	**0.003**

Note: These data are necessary input for the modified maximum likelihood estimator used to derive the bias corrected age proportions.

Appendix E: Summary of unknown age read fish and their subsequent proportions for Central Valley Late Fall, Winter, Spring, and Mokelumne River Fall runs

Escapement		**Unknown Fish at Age**			
Hatcheries		**2**	**3**	**4**	**5**
Coleman National Fish Hatchery-Late Fall Run	Read	2	23	123	3
	Proportion	0.013	0.152	0.815	0.020
Feather River Hatchery-Spring Run	Read	2	314	107	0
	Proportion	0.005	0.742	0.253	0.000
Mokelumne River Fish Hatchery-Fall Run	Read	178	234	95	0
	Proportion	0.351	0.462	0.187	0.000
Hatchery Subtotal	**Read**	**182**	**571**	**325**	**3**
	Proportion	**0.168**	**0.528**	**0.301**	**0.003**
Natural Areas					
Upper Sacramento River-Winter Run	Read	25	366	32	0
	Proportion	0.059	0.865	0.076	0.000
Upper Sacramento River-Late Fall Run	Read	5	153	513	1
	Proportion	0.007	0.228	0.763	0.001
Butte Creek-Spring Run	Read	5	147	60	0
	Proportion	0.024	0.693	0.283	0.000
Mokelumne River-Fall Run	Read	8	75	51	0
	Proportion	0.060	0.560	0.381	0.004
Natural Area Subtotal	**Read**	**43**	**741**	**656**	**1**
	Proportion	**0.030**	**0.514**	**0.455**	**0.001**
Total Escapement	**Read**	**225**	**1,312**	**981**	**4**
	Proportion	**0.089**	**0.520**	**0.389**	**0.002**

Note: These data are necessary input for the modified maximum likelihood estimator used to derive the bias corrected age proportions.

Appendix F: Summary of applied bias corrected proportions

Escapement	Proportions of Fish at Age			
Hatcheries	**2**	**3**	**4**	**5**
Coleman National Fish Hatchery-Fall Run	0.06488	0.45516	0.46526	0.01471
Feather River Hatchery-Fall Run	0.06876	0.68853	0.23388	0.00883
Nimbus Fish Hatchery-Fall Run	0.23733	0.43872	0.32030	0.00365
Coleman National Fish Hatchery-Late Fall Run	0.01468	0.00000	0.89512	0.09020
Feather River Hatchery-Spring Run	0.00000	0.89302	0.00003	0.10696
Mokelumne River Fish Hatchery-Fall Run	0.35379	0.42835	0.21786	0.00000
Natural Areas				
Clear Creek	0.02115	0.40365	0.57520	0.00000
Battle Creek-Fall Run	0.06488	0.45516	0.46526	0.01471
Upper Sacramento River-Fall Run	0.04161	0.02679	0.92819	0.00342
Feather River	0.00544	0.51518	0.47939	0.00000
Yuba River	0.04543	0.16007	0.79451	0.00000
American River	0.06588	0.25686	0.67371	0.00355
Upper Sacramento River-Winter Run	0.02329	0.94465	0.03206	0.00000
Upper Sacramento River-Late Fall Run	0.00765	0.08715	0.90222	0.00298
Butte Creek-Spring Run	0.01817	0.77858	0.20324	0.00000
Mokelumne River-Fall Run	0.05571	0.46033	0.48396	0.00000

Note: This summary displays the bias corrected proportions generated by the modified maximum likelihood estimator that were applied to the total unknown age escapement in each hatchery and natural area.

Appendix G: Summary of final bias corrected proportions

Escapement	Proportions of Fish at Age			
Hatcheries	**2**	**3**	**4**	**5**
Coleman National Fish Hatchery-Fall Run	0.06474	0.45703	0.46357	0.01466
Feather River Hatchery-Fall Run	0.06740	0.68920	0.23478	0.00863
Nimbus Fish Hatchery-Fall Run	0.23733	0.43872	0.32030	0.00365
Coleman National Fish Hatchery-Late Fall Run	0.17962	0.21651	0.59091	0.01296
Feather River Hatchery-Spring Run	0.00000	0.89302	0.00003	0.10696
Mokelumne River Fish Hatchery-Fall Run	0.37095	0.44916	0.17965	0.00024
Natural Areas				
Clear Creek	0.02115	0.40365	0.57520	0.00000
Battle Creek-Fall Run	0.06488	0.45516	0.46526	0.01471
Upper Sacramento River-Fall Run	0.04161	0.02679	0.92819	0.00342
Feather River	0.00809	0.50820	0.48347	0.00023
Yuba River	0.04543	0.16007	0.79451	0.00000
American River	0.06588	0.25686	0.67371	0.00355
Upper Sacramento River-Winter Run	0.02329	0.94465	0.03206	0.00000
Upper Sacramento River-Late Fall Run	0.00781	0.08721	0.90194	0.00303
Butte Creek-Spring Run	0.01800	0.77732	0.20468	0.00000
Mokelumne River-Fall Run	0.05568	0.46006	0.48426	0.00000

Note: This summary displays the final proportions at age based on the total escapement in each hatchery and natural area. These proportions are a product of the application of the bias corrected proportions generated by the modified maximum likelihood estimator to the total unknown age escapement and the subsequent addition of CWT fish at age recovered in each respective hatchery and natural area.

Appendix H: Comparison of Sacramento Basin Fall run bias corrected estimates of escapement (age 2 and ages 3-5) versus PFMC Review length based estimates of grilse and adult escapement

Fall Escapement	**Total Grilse**		**Total Adults**	
Hatcheries	**Age 2**	**Grilse**	**Ages 3-5**	**Adults**
Coleman National Fish Hatchery	3,756	1,056	54,266	56,966
Feather River Hatchery	946	634	13,088	13,400
Nimbus Fish Hatchery	2,071	406	6,657	8,322
Hatchery Subtotal	**6,773**	**2,096**	**74,011**	**78,688**
Natural Areas				
Clear Creek	178	168	8,244	8,254
Battle Creek	1,265	390	18,228	19,103
Upper Sacramento River	2,308	1,924	53,160	53,544
Feather River	610	1,845	74,820	73,585
Yuba River	374	233	7,857	7,998
American River	1,509	1,145	21,391	21,755
Natural Area Subtotal	**6,244**	**5,705**	**183,700**	**184,239**
Total Fall Escapement	**13,017**	**7,801**	**257,711**	**262,927**

Note: These data illustrate the potential that scale aging may be a viable method for deriving more accurate estimates of age 2 or ‘grilse’ and age 3-5 or ‘adult’ escapement.

Appendix I: Comparison of Central Valley Late Fall, Winter, Spring, and Mokelumne River Fall run bias corrected estimates of escapement (age 2 and ages 3-5) versus PFMC Review length based estimates of grilse and adult escapement

Escapement	Total Grilse		Total Adults	
Hatcheries	**Age 2**	**Grilse**	**Ages 3-5**	**Adults**
Coleman National Fish Hatchery-Late Fall Run	583	620	2,664	2,627
Feather River Hatchery-Spring Run	44	9	2,017	2,052
Mokelumne River Fish Hatchery-Fall Run	1,535	1,338	2,604	2,801
Hatchery Subtotal	**2,162**	**1,967**	**7,285**	**7,480**
Natural Areas				
Upper Sacramento River-Winter Run	350	378	16,948	16,920
Upper Sacramento River-Late Fall Run	120	128	15,221	15,213
Butte Creek-Spring Run	118	98	6,429	6,449
Mokelumne River-Fall Run	96	177	1,636	1,555
Natural Area Subtotal	**684**	**781**	**40,234**	**40,137**
Total Escapement	**2,846**	**2,748**	**47,519**	**47,617**

Note: These data illustrate the potential that scale aging may be a viable method for deriving more accurate estimates of age 2 or 'grilse' and age 3-5 or 'adult' escapement.

Appendix J: Sample expansion factors

Escapement	Sample Expansion Factor
Hatcheries	
Coleman National Fish Hatchery-Fall Run	1.00
Feather River Hatchery-Fall Run	1.00
Nimbus Fish Hatchery-Fall Run	N/A
Coleman National Fish Hatchery-Late Fall Run	1.00
Feather River Hatchery-Spring Run	1.00
Mokelumne River Fish Hatchery-Fall Run	1.00
Natural Areas	
Clear Creek	N/A
Battle Creek-Fall Run	N/A
Upper Sacramento River-Fall Run (ARB/BRB)	N/A
Feather River (HFC/LFC)	39.55/17.65
Yuba River	N/A
American River	N/A
Upper Sacramento River-Winter Run	3.09
Upper Sacramento River-Late Fall Run	N/A*
Butte Creek-Spring Run	N/A
Mokelumne River-Fall Run	N/A

Note: Expansion factors are only displayed for those surveys where tags were recovered from the appropriate river respective to their hatchery of origin.
*Upper Sacramento Late Fall sample expansion factors were unknown at the time of this report.