Provisional Draft

Relationships Between Fall-Run Chinook Salmon Recruitment to the Major San Joaquin River tributaries and Streamflow, Delta Exports, the Head of the Old River Barrier, and Tributary Restoration Projects From the early 1980s to 2003

Preliminary Analyses

by

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Introduction

The combined fall-run Chinook salmon (*Oncorhynchus tshawytscha*) escapement to the San Joaquin River (SJR) tributaries, which includes the Stanislaus, Tuolumne, and Merced rivers (Figure 1), historically exceeded 100,000 salmon per year (California Department of Fish and Game - Grand Tab). Today, the salmon run averages less than 10,000. The decline in SJR salmon escapement may be attributable to several factors including (1) reduced instream flows, (2) harvest of adult fish, (3) degradation of spawning and rearing habitat, and (4) degraded water quality.

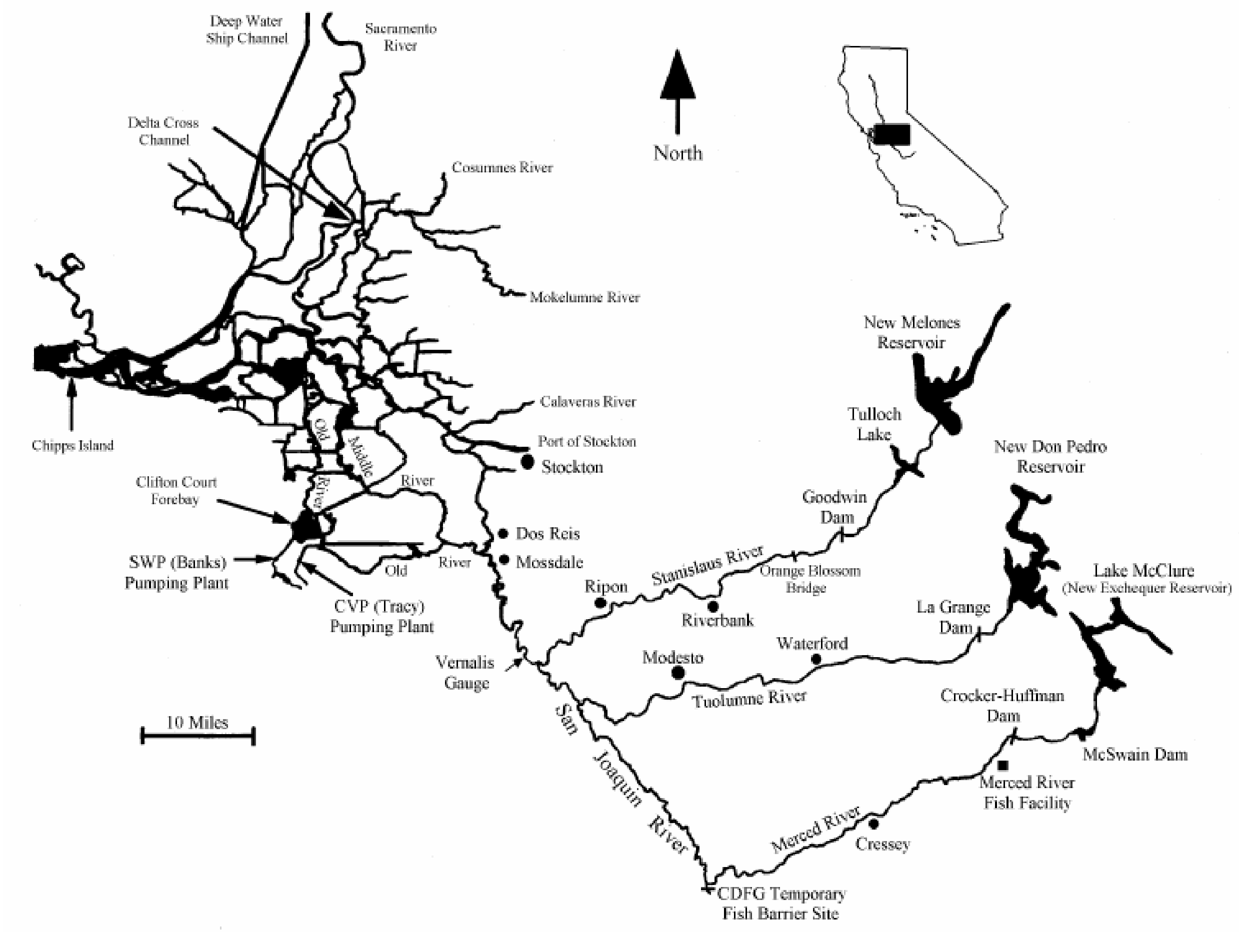

Figure 1. Map of the Stanislaus, Tuolumne, Merced and San Joaquin rivers and the Sacramento-San Joaquin Delta.

Since 1987, various protective measures and restoration actions have been implemented in the SJR Basin to increase the production and survival of juvenile fall-run Chinook salmon and thereby increase adult escapement into the Stanislaus, Tuolumne, and Merced rivers. The Vernalis Adaptive Management Plan (VAMP) has the objective of testing the effectiveness of (1) increased spring pulse flows which began in 1997, (2) reduced Delta exports which began in 1996, and (3) periodically installing the Head of the Old River Barrier (HORB) which began in 1992 to increase the survival of juvenile salmon smolts migrating through the lower San Joaquin River and Delta (SJRGA 2005). CALFED, the Anadromous Fish Restoration Program, and the Four-Pumps Mitigation Agreement have been funding salmonid habitat restoration projects in the San Joaquin tributaries since 1990. Fishery base flow releases have been increased in the Stanislaus River since 1987 (Stanislaus River Fish Group 2004), the Tuolumne River since 1996 (Turlock Irrigation District and Modesto Irrigation District 2005), and the Merced River since 2002[1].

Theoretically, trends in the escapement of adult salmon to the major tributaries of the SJR, which include the Stanislaus, Tuolumne, and Merced rivers, should provide a useful evaluation of how the salmon have responded to various potential limiting factors responsible for the historical decline as well as the corrective measures implemented since 1987. With the exception of the harvest of adult salmon in the ocean fishery, most of the potential limiting factors would affect the survival of juvenile fish in the SJR Basin. Therefore, trend analyses typically begin by segregating the escapement estimates, which consists of a mixture of Age 2 to Age 5 fish, into cohorts (a.k.a. broods) of same-age juveniles. Fishery biologists further standardize these estimates, which are called Recruitment, by determining the number of fish that survived to Age 2 but were harvested or died in the ocean before they could return to spawn as Age 3 to Age 5 fish (Ricker 1975).

Recruitment is relatively difficult to estimate in the San Joaquin Basin, because the age composition of escapement is not routinely determined for the adult fish ($\geq$ Age 3), the ocean harvest rates are estimated only for the combined Central Valley populations (Pacific Fishery Management Council 2005), and there are no data to directly estimate annual variation in natural ocean mortality rates or incidental mortalilty resulting from fishing activity.

Due to these difficulties, many researchers have used different methods to estimate recruitment to the San Joaquin River basin (CDFG 1972, 1987; Reisenbichler 1986, 1989; Kope and Botsford 1988, 1990; EA Engineering, Science, and Technology 1992; Speed 1993; CMC 1994, 1996; Speed and Ligon 1997; Baker and Morhardt 2001; San Joaquin River Group Authority 2003). However in spite of the variety of techniques used, almost all of these researchers have reached similar conclusions that streamflow, stock (a.k.a. abundance of spawners), and/or ocean harvest are important factors that influence the number of fish that survive to adulthood. This suggests that in spite of the errors and uncertainty associated with the escapement and recruitment estimates, it is possible to reach general conclusions about the effectiveness of management actions and conduct initial assessments of their relative influence upon salmon recruitment to the San Joaquin River basin.

[1] Memorandum of Understanding between California Department of Fish and Game and Merced Irrigation District regarding October instream flows, other interim instream flows and fishery studies in the lower Merced River, August 2002.

The primary purpose of this paper is to determine if segregating annual escapements into estimates of recruitment and then assessing correlations between recruitment and a variety of dependent variables can explain how flow, Delta conditions, ocean factors, and/or habitat restoration affect SJR Basin salmon production. Our study variables include flow and water quality estimates throughout the SJR Basin, combined export rates at the State's Harvey O. Banks pumping facilities and Federal Central Valley Project pumping facility at Tracy and the Contra Costa Canal, two indices of ocean productivity, and the abundance of spawners. We tested a variety of flow estimates throughout the SJR Basin and different time periods because we assumed that these estimates would help test the importance of the various potential factors that control juvenile salmonid survival, such as:

- Relatively strong correlations with tributary flows would imply that habitat conditions in the tributaries would be the most important determinant of juvenile salmonid survival.

- Relatively strong correlations with San Joaquin River flows at Vernalis would imply that Delta conditions as well as tributary conditions would be important.

- Relatively strong correlations with either flow, dissolved oxygen concentration, or water temperature in the Stockton deep-water ship channel would imply that the Head of the Old River Barrier, which concentrated the San Joaquin River flow into the deep-water ship channel, was an important determinant of juvenile survival.

- Relatively strong correlations with flows near Jersey Point (a.k.a. QWest) would suggest that export rates up to 10,000 cfs at the SWP and CVP facilities and the operation of the Delta Cross Channel (DCC), which diverts an average net flow of 4,000 cfs through the lower Mokelumne River into the South Delta when the DCC gates are open (Okamoto 2001) would be important determinants of juvenile survival.

- Relatively strong correlations with absolute export rates or the ratio of Vernalis flows to Delta exports would indicate that juvenile mortality in the canals leading to the pumps or entrainment of juveniles at the pumps were important.

- Relatively strong correlations with ocean productivity indices including the mean November to March values of Pacific interdecadal oscillation (PDO) and the mean May to July values of the Pacific Fisheries Environmental Laboratory coastal upwelling index (PFEL Upwelling Index) for the San Francisco area (interpolated values to a latitude of 37.5 North) would suggest that ocean conditions may be more important than instream flow.

- Relatively strong correlations with conditions between early April and mid-June period would suggest that smolt outmigration may be the most important factor, whereas strong correlations between early February and mid-June may indicate that both juvenile rearing and outmigration are important factors.

- Relatively strong correlations between ocean harvest (Central Valley Harvest Index) and escapement would suggest that ocean harvest is a greater limiting factor than other variables such as spring flow.

- Shifts in the correlations between recruitment and flow variables during the 1990s may reflect the effect of SJR tributary habitat restoration projects.

In the Discussion section, we discuss the implication of our study toward prioritizing management actions in SJR tributaries, South Delta, and/or ocean to substantially increase abundance of SJR salmon recruits.

Methods

The analyses were done by first deconvolving the escapement estimates into cohorts of same-aged fish. Then, recruitment was estimated by expanding the age based escapement estimates to account for ocean harvest and non-landed hooking mortality (a.k.a., shaker mortality). Estimates of spawner abundance were standardized to Age 3 equivalent fish to account for age related differences in fecundity and high proportions of male two-year-old fish. Finally, correlations were tested between recruitment, spawner abundance and the various habitat variables.

<u>Escapement and Age Composition</u>

We deconvolved the CDFG Region IV escapement estimates for the Tuolumne River from 1981 to 2006 and the Stanislaus and Merced rivers from 1984 to 2006 using a combination of methods (Mesick and Marston 2007). We used scales and length frequency analyses to determine Age 2 percentages for all three study rivers. We have a substantial scale analysis for the age determination for the Tuolumne River, but not for the Stanislaus or Merced rivers. For the Stanislaus and Merced rivers, we developed a new method of using age ratios from the Tuolumne River age determinations derived from scale analyses to estimate the Age 3 and older percentages for 90% of escapement estimates for the Stanislaus River, 57% of the Merced River estimates, and 20% of the Tuolumne River estimates (Mesick and Marston 2007).

Our analyses did not include escapement estimates for the Tuolumne River prior to 1981 or for the Stanislaus and Merced rivers prior to 1984 due to the absence of length-frequency data that was needed to accurately estimate the abundance of Age 2 fish. During the early escapement surveys, it was incorrectly assumed that all Age 2 fish in the San Joaquin Basin were smaller than 24 inches. Scale and length-frequency analyses from the more recent surveys indicate that the nadir that separates the Age 2 fish from the older fish is a mean of 25.2 inches (64.0 cm) for females and a mean of 27.4 inches (69.7 cm) for males in the San Joaquin Basin. In some years, the 24-inch criterion resulted in gross errors in the Age 2 estimates for the San Joaquin Basin (Mesick and Marston 2007).

We adjusted the CDFG escapement estimates for the Stanislaus River from 1993 to 1996 so that the methods, and presumably the estimates, would be more comparible to the other surveys. One problem is that escapement surveys were not conducted in near Goodwin Dam and Two-Mile Bar from 1993 to 1995 and mark-recapture estimates from 1986 to 1989 indicated that about 13% of the total escapement occurred at Goodwin Dam and Two-Mile Bar. Therefore, we increased the 1993 to 1995 estimates by 13%. We also assumed that the 1996 estimate was grossly underestimated since few fish were tagged, no marked fish were recovered due to high flow conditions, and the estimates for the Tuolumne and Merced rivers were relatively high. Therefore, we increased the 1996 Stanislaus River estimate from 168 fish to 3,000 fish to approximate the escapement trends observed in the Tuolumne and Merced rivers. The escapement, age composition, adjusted Age 2 percentages and age ratios are presented in Appendix A.

Recruitment

Using the age composition estimates in Appendix A, we estimated recruitment using the following equation:

$$\text{Recruitment}_{(we)} = \text{Age } 2_{(i+1)}/(1-((SCVI*1.122)+(TCVI*0.118))) + \text{Age } 3_{(i+2)}/(1-((SCVI*1.122)+(TCVI*1.118))) + \text{Age } 4_{(i+3)}/(1-((SCVI*1.122*0.54)+(TCVI*1.118))) + \text{Age } 5_{(i+4)}/(1-((SCVI*1.122*0.54)+(TCVI*1.118)))$$

where,

SCVI = Sport Harvest fraction of the Central Valley Index; and
TCVI = Troll Harvest fraction of the Central Valley Index.

The Central Valley Indices of sport harvest (SCVI) and troll harvest (TCVI) from 1980 to 2005 are presented in Appendix A.

Spawners

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

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

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

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

The adjustment factor for five-year-olds is 1.40. It was computed as the expected number of eggs produced by five-year-olds, which was about 8,700 eggs for relatively large females averaging about 88 cm (CDFG 1990), divided by the number of eggs produced by three-year-olds. Spawner estimates for the Stanislaus, Tuolumne, and Merced Rivers are presented in Appendix A.

Spawner-Recruitment Relationships

Speed (1993) reported clear evidence of a density-dependent relationship for the combined Chinook salmon populations in the Stanislaus, Tuolumne, and Merced rivers, but was also unable to distinguish between the Ricker and Beverton-Holt form of curves. His analyses indicated that a curve midway between the two standard types of curves, which levels out at a threshold abundance of stock, was most predictive.

To test the validity of applying stock-recruit relationships to the Tuolumne River salmon population, spawner-recruitment relationships using rotary screw trap estimates of juvenile production and survival relative to adult recruitment in the Stanislaus River and to a lesser extent the Tuolumne River was assessed. We assume that spawner abundance would only affect recruitment if there were relationships between the number of juveniles produced in the upper river, the number of juveniles leaving the river, and the number of adult recruits. However, there are limited rotary screw trap data on the number of juveniles produced in the upper Tuolumne River and there are no usable screw trap estimates for the Merced River. Therefore, we also tested the spawner-recruitment relationships by forcing estimates of spawner abundance and a square of the estimated spawner abundance ($spawners^2$) into the linear regression analysis that also included the most highly correlated habitat variables. We then graphically plotted these spawner-recruitment relationships to determine whether they were linear.

Flow Estimates

We evaluated reservoir release flows in the tributaries and flow in the San Joaquin River at Vernalis, Stockton deep-water ship channel, and near Jersey Point. The estimates of flow releases in the tributaries were made at Goodwin Dam in the Stanislaus River (US Geological Survey gauge 11302000), La Grange in the Tuolumne River (US Geological Survey gauge 11289650), and Snelling in the Merced River (California Department of Water Resources gauge MSN, formerly BO-5170). The flow estimates in the San Joaquin River near Vernalis are based on the U.S. Geological Survey gage 11303500 as provided by California Department of Water Resources Dayflow Program.

We evaluated flows, dissolved oxygen, and water temperatures near Stockton to help test the hypothesis that the Head of the Old River Barrier improves juvenile salmon survival by concentrating all of the San Joaquin River flow through the deep-water ship channel. Deep-water ship channel flows were estimated with two different models. One model, which is a submodel of Dayflow that is called DSM2, was developed by the California Department of Water Resources Delta Monitoring Section[2]. The second is a simple linear regression model that was developed by Jassby (2005) that used Vernalis flows, exports, and the presence of the Head

[2] The DSM2 estimates were provided by Parviz Nader-Tehrani, who was the supervisor of the California Department of Water Resources Delta Modeling Section, in January 2006. Information on the DSM2 model can be obtained at http://modeling.water.ca.gov/delta/models/dsm2/index.html

of the Old River to predict flow measurements that were made in the San Joaquin River just upstream of the ship channel with an Ultrasonic Velocity Meter by the U.S. Geological Survey since 1995. Although Jassby's model is highly predictive of the measured flows (Jassby 2005), his model suggests that no more than 40% of the flows at Vernalis remained in the deep-water ship channel regardless of whether the Head of the Old River Barrier (HORB) was installed. This is counterintuitive since the purpose of the HORB, which has had 2 to 6 large operational culverts installed since 1997, when flow levels are less than 7,000 cfs, is to prevent most of the flow (and juvenile salmon) in the mainstem San Joaquin River from being diverted into the Old River. In contrast, the DSM2 model predicts that a majority of the Vernalis flow remains in the deep-water ship channel when the HORB is installed as would be expected. Because we could not determine which model was most accurate, we tested both flow estimates against salmon recruitment estimates.

Hourly estimates of dissolved oxygen and water temperature near Burns Cutoff (station RSAN058) in the deep-water ship channel from 1983 to 2002 were obtained from the Interagency Ecological Program web site[3]. Water temperature measurements near Burns Cutoff that were taken at 15-minute intervals in 2003 were also obtained from this site. Dissolved oxygen measurements near Rough and Ready Island (station RRI) that were taken in 15-minute intervals in 2003 were obtained from the California Data Exchange Center web site. The average of the measurements made from May 1 to June 15 was used for these analyses.

We also evaluated flows in the San Joaquin River near Jersey Point to test the hypothesis that either high export rates, which can create a net negative flow near Jersey Point, or closing the Delta Cross Channel gates to protect Sacramento Basin juvenile salmonids, which reduces flows in the lower Mokelumne River by about 4,000 cfs (Okamoto 2001), would reduce San Joaquin Basin juvenile salmonid survival. The California Department of Water Resources Dayflow Program is used to estimate flows near Jersey Point, which is called QWest. We also used the export rates at the CVP and SWP facilities and the log of the ratio of export rates to Vernalis flows. The Dayflow output of CVP and SWP export rates was obtained at http://iep.water.ca.gov/dayflow/output/index.html.

For each flow variable, we tested monthly averages from January through June as well as averages for the April 15 to May 15 VAMP period, March 1 to May 31 period, March 1 to June 15 period, and February 15 to June 15 period. The mean monthly flow estimates, and water quality data, used herein are presented in Appendix B.

<u>Delta Exports</u>

South Delta flow levels, and quality, are influenced by flows into the Delta from the Sacramento and San Joaquin River basins and by operation of the State and Federal Pumps. Delta pumping has been in existence since 1949 with completion of the Tracy Pumping Plant[4]. The State pumping facility (Banks Pumping Plant) came on-line in 1967[5]. Both the State and Federal pumping facilities maintain databases regarding historical pumping rates. Average daily

[3] http://iep.water.ca.gov/cgi-bin/dss/dss1.pl?station=RSAN058
[4] Information obtained from: http://www.usbr.gov/dataweb/html/cvpdelta.html#Historic
[5] Information obtained from: http://sdelta.water.ca.gov/web_pg/CCF/Facilities_Operation.htm

pumping rate data was obtained from the California Department of Water resources (DWR) and the U.S. Bureau of Reclamation via the Inter-Agency Ecological Program Website accessible database. Correlation analyzes were conducted with the combined State and Federal pumping rates and a ratio of Vernalis flows to the combined Delta exports.

Head of Old River Barrier

To protect out-migrating fall-run Chinook salmon and steelhead from the SJR as they migrate through the South Delta, a temporary barrier is placed at the Head of Old River and is commonly referred to as the Head of Old River Barrier (HORB) for 30 to 45 days from mid-April to the end-of May. The duration and timing of HORB installation depends on entrainment levels of Delta smelt (*Hypomesus transpacificus*) at the pumps. The premise behind the barrier is that out-migrating juvenile salmonids would remain in the mainstem SJR and not migrate into the Old River where they would be susceptible to entrainment by the State and Federal Pump Projects. The HORB was first installed in 1992. Since 1992 it has been installed in 1994, 1996, 1996, 2000, 2001, 2002, 2003, and 2004 (SJRGA 2005). The HORB cannot be installed at flows in excess of approximately 5,000 cfs, and is operable up to flows (as Measured at Vernalis) less than 7,000 cfs.

To determine if the HORB improved juvenile salmon out-migration from the SJR as evidenced by elevated adult recruitment, average April and May flows were correlated against SJR adult salmon recruitment for years with the HORB installed, and for years where the HORB was not installed, when flows were less than 7,000 cfs daily average for the April and May time period. For comparison, the average spring flow (April and May time period) was also correlated with SJR adult salmon recruitment for years 1980 to 2002.

Ocean Productivity Indices

Two indices of ocean productivity conditions, which include the mean November to March values of the Pacific Interdecadal Oscillation (PDO) and the mean of the May to July values of the Pacific Fisheries Environmental Laboratory coastal upwelling index (PFEL Upwelling Index) for the San Francisco area (interpolated values to a latitude of 37.5 degrees North) were used in this analysis. Mean November to March values of the Pacific Interdecadal Oscillation (PDO) were obtained from a web site maintained by the Joint Institute for the study of the Atmosphere and Ocean at the University of Washington[6]. Coastal upwelling indices were obtained from the Pacific Fisheries Environmental Laboratory's web site[7]. The mean May to July values were obtained for the area near Fort Bragg (latitude 39 degrees North) and San Luis Obispo (latitude 36 degrees North) and then averaged to estimate conditions near San Francisco (latitude of 37.5 degrees North).

The mean November to March values of the Pacific interdecadal Oscillation (PDO) are defined by Steven Hare as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N since 1900). The PFEL Upwelling Index is a measure of the intensity of large-scale, wind-induced coastal upwelling along the West Coast and is based

[6] http://jisao.washington.edu/pdo/PDO.latest
[7] http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/data_download.html

on estimates of offshore Ekman transport driven by geostrophic wind stress (PFEL 2001). We used a mean index value for the May through July period because MacFarlane and Norton (2002) reported that this was when juvenile Chinook salmon entered the Gulf of the Farallones in 1997. We conducted correlation analyzes between PDO and PFEL upwelling indices and adult recruitment to determine if a link between ocean productivity and SJR salmon abundance exists.

Central Valley Harvest Index

Ocean harvest includes both fish that are successfully harvested and the non-landed (shaker) mortality, in both sport and commercial ocean salmon fisheries. CDFG estimates the total number of Central Valley Chinook salmon harvested in the sport and commercial troll fisheries off the coast of California, south of Point Arena, which is about 130 miles north of San Francisco. The Central Valley Index (CVI) of ocean harvest is estimated each year by the Pacific Fishery Management Council (PFMC 2006) by dividing total harvest south of Point Arena by the total hatchery and natural escapement to all Central Valley rivers. It is an index of the percentage of Central Valley Chinook salmon that are harvested each year. The CVI does not include the Central Valley fish that are landed north of point Arena and but it does include fish that originate from northern populations (e.g., the Klamath River) that are harvested south of point Arena. It is assumed that the number of Klamath River fish landed south of Pt. Arena is proportionate to the number of Central Valley fish landed north of Pt. Arena. We conducted correlation analyzes between CVI and both Sacramento and San Joaquin River adult spawner escapement. For purposes of these correlation analyzes, we assumed that both Sacramento and San Joaquin River fall-run chinook salmon are equally vulnerable to both sport and commercial ocean harvest.

San Joaquin River Tributary Restoration Projects

Restoration projects to enhance and restore spawning and rearing habitats have been implemented in the San Joaquin River tributaries since 1990. The early projects focused on adding gravel to restore habitats destroyed by instream gravel mining and the substantially reduced gravel recruitment caused by the upstream dams. More recent work in the Tuolumne and Merced rivers have also restored or isolated several captured mine pits that supported large populations of predatory fish. Although these projects represent a substantial financial investment by CALFED, the Central Valley Project Improvement Act-Anadromous Fish Restoration Program, the Four-Pumps Mitigation Agreement, and other sources, no more than 15% of the degraded habitats were restored by spring 2002 in any of the three tributaries.

In the Merced River, there have been two predator isolation-channel reconstruction projects were constructed during the summer between 1996 and 1999 and a total of 13,595 cubic-yards of gravel were added to enhance spawning and rearing habitats that would have affected juvenile production and survival (i.e., adult recruitment) since 1990. We assume that the predator isolation project would have had the most substantial effect on juvenile salmon since spring 1997 because the gravel addition projects added gravel to only a few sites every one to two years (Stillwater Sciences 2002).

Merced River Projects	Gravel Volume Added (yd^3)	Year Construction Completed
Gravel Placement below Crocker-Huffman Dam Phase I, early	4,200	Summer 1990
Gravel Placement below Crocker-Huffman Dam Phase II, early	3,400	Summer 1991
Magneson Pond	Predator Isolation	Summer 1996
Gravel Placement below Crocker-Huffman Dam Phase I and II recent	3,328	Summer 1996-1997
Ratzlaff	Predator Isolation	Summer 1999

In the Tuolumne River, there were three predator isolation projects implemented and a total of 19,250 cubic yards of gravel were added to enhance spawning and rearing habitats between 1993 and 2001. We assume that the restoration actions would have had the most substantial effect on juvenile salmon since spring 2000 because the gravels added in 1993 and 1994 were flushed into degraded channels during the 1995 and 1997 floods (McBain and Trush 2000).

Tuolumne River Projects	Gravel Volume Added (yd^3)	Year Construction Completed
First Ruddy Project	Predator Isolation	1993
La Grange Gravel Addition Project, early	6,750	1994
La Grange Gravel Addition Project, Phases I and II	12,500	1999-2003
Special Run Pool 10 dike reconstruction	Predator Isolation	2001
Special Run Pool 9	Predator Isolation	2001

In the Stanislaus River, a total of 18,837 cubic yards of gravel were added to enhance spawning and rearing habitats between 1994 and 2002. we assume that the Knights Ferry Gravel Replenishment Project (KFGRP) implemented in summer 1999 would have had the most substantial effect on juvenile salmon production and survival since spring 2000, because the 1994 project sites were poorly used by adult spawners (Mesick 2001) and the Goodwin Canyon project added gravel to only one to two sites each year and the gravels were flushed into the downstream areas after one to two years.

Stanislaus River Projects	Gravel Volume Added (yd^3)	Year Construction Completed
Stanislaus River Gravel Addition, near Horseshoe Road	3,070	1994
Goodwin Canyon Gravel Addition	7,407	1997-2004
Knights Ferry Gravel Replenishment Project	8,360	1999

Statistics

There are two statistical approaches that have been used to test relationships between recruitment and habitat variables. Linear regression analysis is commonly used to derive a mathematical relationship between recruitment and the environment including stock. There are two particularly important assumptions of this method that may be violated in investigations of salmon recruitment. One assumption is that the relationship between recruitment and the environmental variables is linear. Populations of fish and other organisms rarely repond to their environment in a linear fashion and it is necessary to plot the relationships to test this assumption.

Another assumption necessary to be met in the use of linear regressions is that for any given value of the habitat variable (e.g., streamflow), the estimates of recruitment must be independent (Sokal and Rohlf 1995). Statisticans suggest that this assumption is violated for population time series such as this salmon recruitment analysis (Speed 1993). For example, the number of spawners in year 0 may affect the number of eggs deposited in year 0 and thereby affects the number of recruits in year 2. Therefore, they argue that the estimates of recruitment are not independent; a problem referred to as "autocorrelation". In this case, they typically use "extremely complex" discrete-time simulation models to evaluate trends in salmon recruitment (Speed 1993).

Speed and Ligon (1997) suggest that it is better to resolve the autocorrelation problem by using fitted spawner-recruit curves and then incorporating the environmental variables into a model. However, Speed (1993) concluded that this method was no better than a simple linear regression analysis for assessing the effects of flow and stock on recruitment. We assessed the autocorrelation problem by evaluating the influence of stock on recruitment in two ways: first by evaluating the influence of spawner abundance, total juvenile production, and the number of smolt sized fish migrating from the tributaries on adult recruitment using rotary screw trap data, and second, by forcing quadratic terms for spawner abundance into the correlation models. The calibration models used to expand the daily catch data for the Tuolumne River traps at Grayson and Shiloh are presented in Appendix C.

STATISTIX 8, a statistical software program created by Analytical Software, was used to compute a partial correlation matrix of the number of recruits in each of the three tributaries versus flow estimates in the tributaries and the Delta. Plots of recruitment with each variable were checked for non-linear relationships.

Unweighted least squares multiple linear regression procedures were performed with *STATISTIX 8* for each of the three rivers using the spawner and the flow variables that had the highest partial correlation for all three populations. In addition to STATISTIX 8, Microsoft Excel was used for some linear regression correlation analyzes described herein.

It was not possible to conduct a four-way factorial ANOVA to separately evaluate the effectiveness of each protective measure and restoration measure because there were missing values in several of the treatment combinations. An ANOVA design requires that each treatment should have been implemented separately in a random fashion, whereas most of the protective measures and restoration actions have occurred simultaneously since 1994. For example, both pulse flows and export reductions have occurred since 1997 and restoration projects cannot be "undone" to verify their effect.

Instead, *STATISTIX 8* was used to conduct *F*-tests to determine whether recruitment-flow correlations had changed in different years that corresponded to different management actions.

Results

The following results should be considered preliminary until rotary screw trap evaluations of juvenile production in the Tuolumne and Merced rivers and separate analyses for naturally produced fish and hatchery reared fish are completed.

Effects of Low Spawner Abundance

We intend to directly assess the effects of low spawner abundance on recruitment by comparing rotary screw trap estimates of juvenile production and survival with spawner abundance. However, we have a complete rotary screw trap data set only for the Stanislaus River and so only partial analyses can be presented for the Tuolumne and Merced rivers at this time.

We found no direct relationship between spawner abundance greater than 500 Age 3 equivalent fish and the number of adult recruits for the Stanislaus River based on rotary screw trap data collected by Cramer Fish Sciences (formally known as S.P. Cramer and Associates) from 1996 to 2005. The number of spawners was not positively correlated with either the total number of all sizes of juvenile out-migrants (Figure 2) or smolt-sized (fish $\geq$ 70 mm fork length) outmigrants (Figure 3) at Caswell State Park (RM 5) [8]. Similarly, the total number of juveniles migrating past Oakdale (RM 40), which provides an index of juvenile production, was not correlated with the total number of juvenile outmigrants (Figure 4), smolt-sized outmigrants (Figure 5), or adult recruits (Figure 6). On the other hand, the number of adult recruits was relatively well correlated (adj-$R^2 = 0.74$, $P = 0.004$) with the number of smolt outmigrants (Figure 7).

[8] The estimates of the number of outmigrants passing Oakdale and Caswell rotary screw trap sites are preliminary because rotary screw trap capture efficiency models have not been finalized (Cramer Fish Sciences, unpublished data)

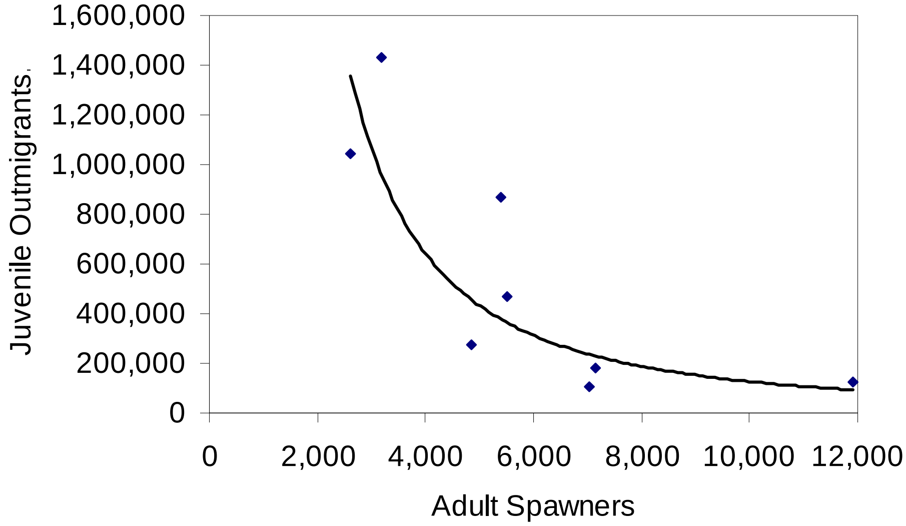

Figure 2. The relationship between the number of Age 3 equivalent spawners and the number of juvenile Chinook salmon outmigrants passing the Caswell State Park rotary screw trap site (RM 5) in the Stanislaus River from 1998 to 2005. Note: Figure 2 to be revised with new data in the next draft.

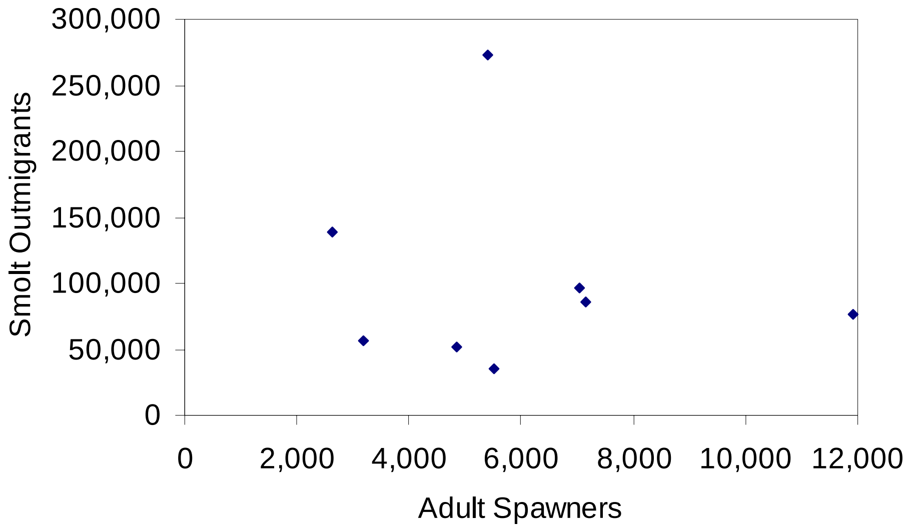

Figure 3. The relationship between the number of Age 3 equivalent spawners and the number of smolt-sized Chinook salmon outmigrants (fish $\geq$ 70 mm fork length) passing the Caswell State Park rotary screw trap site (RM 5) in the Stanislaus River from 1998 to 2005. Note: Figure 3 to be revised with new data in the next draft.

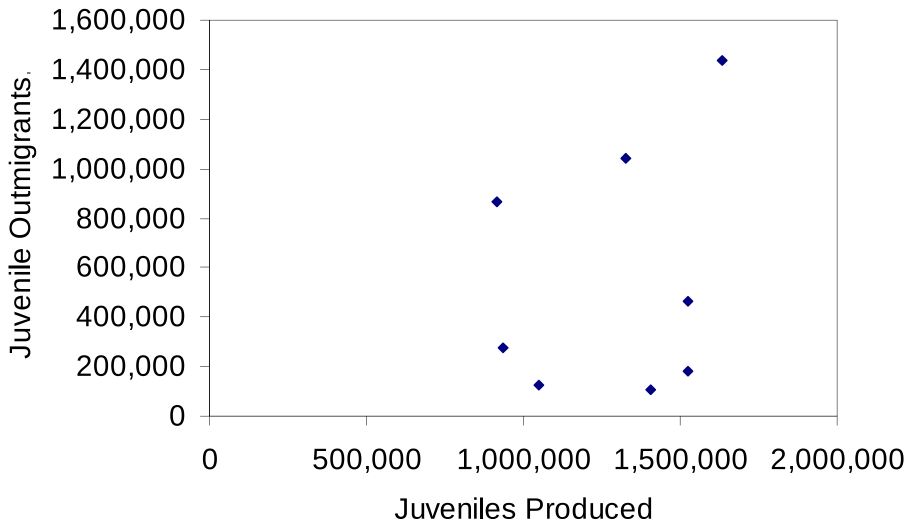

Figure 4. The relationship between the number of juvenile Chinook salmon that passed the Oakdale rotary screw trap site (RM 40), which serves as an index of the number of juveniles produced, and the number of juvenile Chinook salmon outmigrants passing the Caswell State Park rotary screw trap site (RM 5) in the Stanislaus River from 1998 to 2005. Note: Figure 4 to be revised with new data in the next draft.

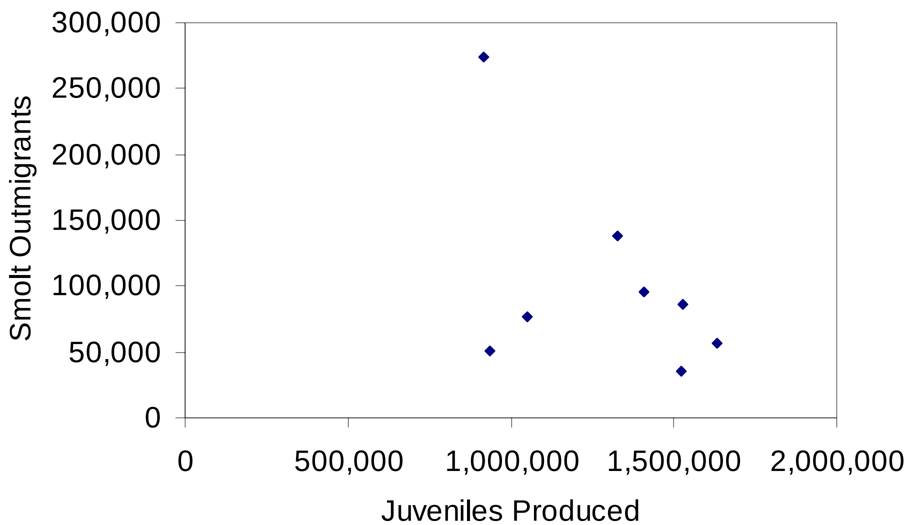

Figure 5. The relationship between the number of juvenile Chinook salmon that passed the Oakdale rotary screw trap site (RM 40), which serves as an index of the number of juveniles produced, and the number of juvenile Chinook salmon smolt-sized outmigrants (fish $\geq$ 70 mm fork length) passing the Caswell State Park rotary screw trap site (RM 5) in the Stanislaus River from 1998 to 2005. Note: Figure 5 to be revised with new data in the next draft.

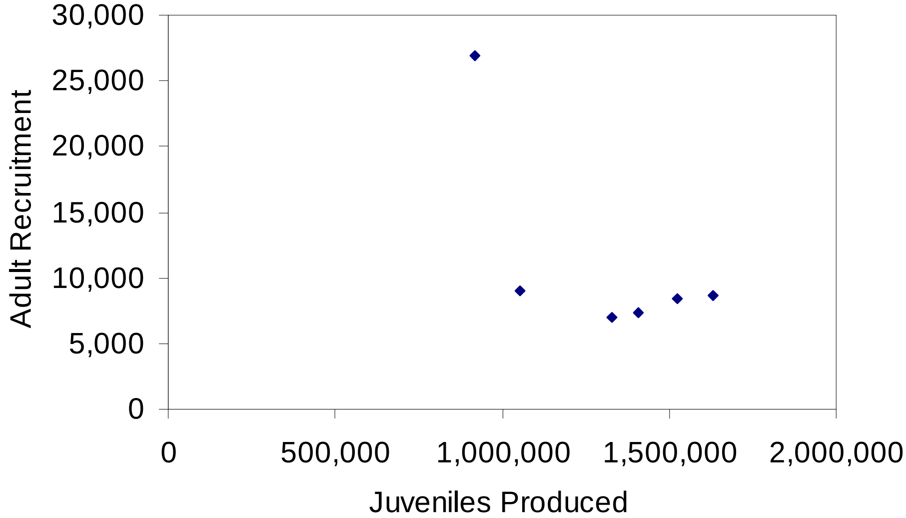

Figure 6. The relationship between the number of juvenile Chinook salmon that passed the Oakdale rotary screw trap site (RM 40), which serves as an index of the number of juveniles produced, and adult recruitment in the Stanislaus River from 1998 to 2003. Note: Figure 6 to be revised with new data in the next draft.

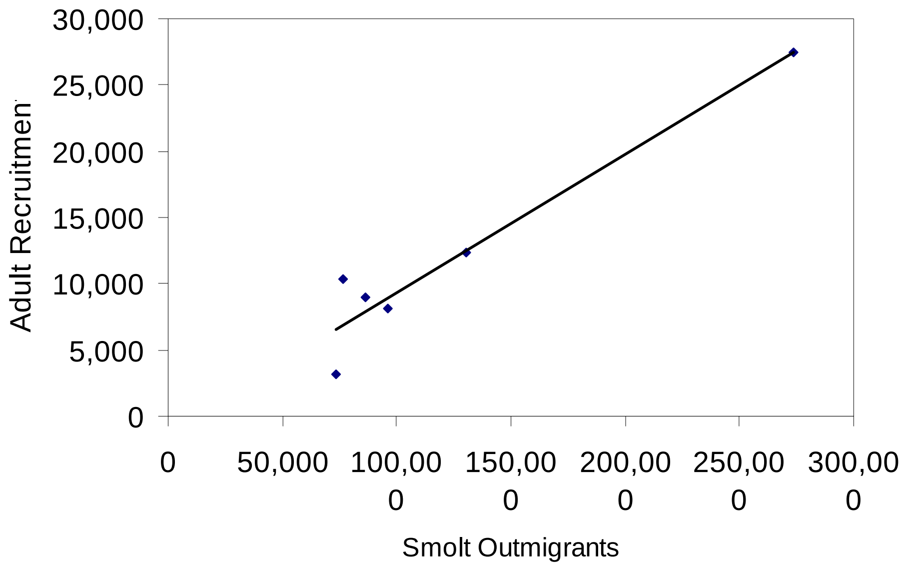

Figure 7. The relationship between the number of smolt-sized Chinook salmon outmigrants (fish $\geq$ 70 mm fork length) that passed the Caswell State Park rotary screw trap site (RM 5) and adult recruitment in the Stanislaus River from 1998 to 2003. Note: Figure 7 to be revised with new data in the next draft.

These results suggest that adult recruitment in the Stanislaus River may be unaffected by spawner abundance as long there is a sufficient number of spawners to produce at least 300,000 smolts, which is about the highest number observed in the Stanislaus River at Caswell State Park from 1996 to 2005. About 250 female spawners can produce 300,000 smolt-sized juveniles based on the conservative assumptions that three-year-old females have 5,000 viable eggs, 40% of the eggs survive to emergence, and 60% of the juveniles survive to a smolt-size during high spring flows. These estimates are reasonable considering that three-year-old females at the Merced River hatchery have an average of about 6,000 eggs (CDFG 1990), the average egg survival to emergence was 46% for five spawning areas in the Stanislaus River in fall 2004 (KDH, unpublished data) and juvenile survival between the Oakdale and Caswell State Park rotary screw traps ranged between 74% and 95% from 1998 to 2000 when spring flows were high (Cramer Fish Sciences, unpublished data).

The limited rotary screw trap surveys on the Tuolumne River also suggest that there may be no relationship between spawner abundance and adult recruitment when spawner abundance exceeds 500 fish. Although rotary screw trapping at the upstream 7/11 site (RM 39) was conducted between January and May only during 1999 and during a shortened period during spring 2000, these estimates suggest that juvenile production was substantially higher on the Tuolumne River than on the Stanislaus River. During 1999, the estimated number of juveniles passing the 7/11 site was 7,297,177 fish, which equals 1,130 juveniles produced per spawner. In spring 2000, the number of juveniles was estimated at 3,481,884 fish from January 10 to February 27, which represents the time period when about 80% of the juveniles passed the Oakdale trap on the Stanislaus River in spring 2000. In contrast, no more than 1,631,600 juveniles were produced in the Stanislaus River from 1996 to 2005 at a mean rate of 270 juveniles per spawner.

The Tuolumne River rotary screw trap data also suggests that the number of adult recruits is relatively well correlated (adj-R^2 = 0.96, P = 0.0004) with the number of smolt outmigrants (Figure 8) as occurred on the Stanislaus River.

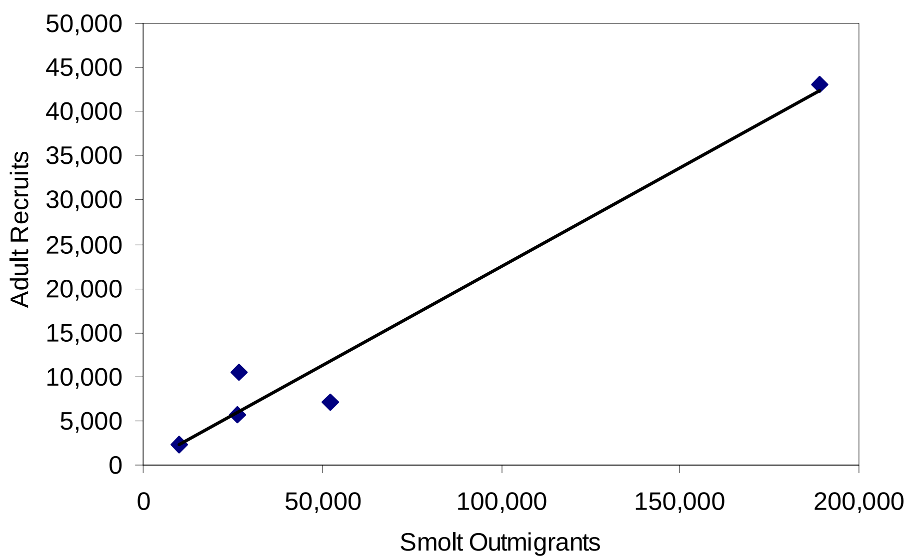

Figure 8. The relationship between the number of smolt-sized Chinook salmon outmigrants (fish $\geq$ 70 mm fork length) that passed the Grayson rotary screw trap site (RM 5) and adult recruitment in the Tuolumne River from 1998 to 2003. The screw trap estimates are preliminary because the trap efficiency models have not been finalized (CDFG unpublished data).

Based on these rotary screw trap data for the Stanislaus and Tuolumne rivers, we assumed that 500 spawners would be sufficient to saturate the rearing habitat with juvenile fish in each of the three study rivers. We also assumed that limiting the analysis to years when spawner abundance exceeded 500 fish would improve the utility of correlation evaluations to detect relationships between recruitment and the flow variables as well as test for density dependent relationships between spawner abundance and recruitment (Ricker 1975).

Density Dependent Spawner Recruit Relationships

The spawner-recruit relationships were density dependent for the Tuolumne and Merced rivers; whereas the estimated spawner-recruit relationship for the Stanislaus River was atypical compared to other salmon populations and substantially different from the spawner-juvenile relationship derived from rotary screw trap data near the mouth of the Stanislaus River (Figure 9). The spawner-recruit analyses were conducted by evaluating several iterations of correlation matrices, graphical plots, and multiple linear regressions that indicated that recruitment for all three study rivers was highly correlated with extended spring flows, particularly those in the San Joaquin River at Vernalis from March 1 through June 15. Then we estimated the spawner-recruit relationships by constructing linear regression models that included Vernalis flows from March 1 through June 15 and a quadratic function for the abundance of spawners (two variables for spawners and spawners^2). The models for Tuolumne and Merced rivers also contained categorical variables that we called “Population Shift” to account for the population change that occurred sometime between 1987 and 1994 in the Tuolumne River and spanned the period from 1995 to 1998 in the Merced River.

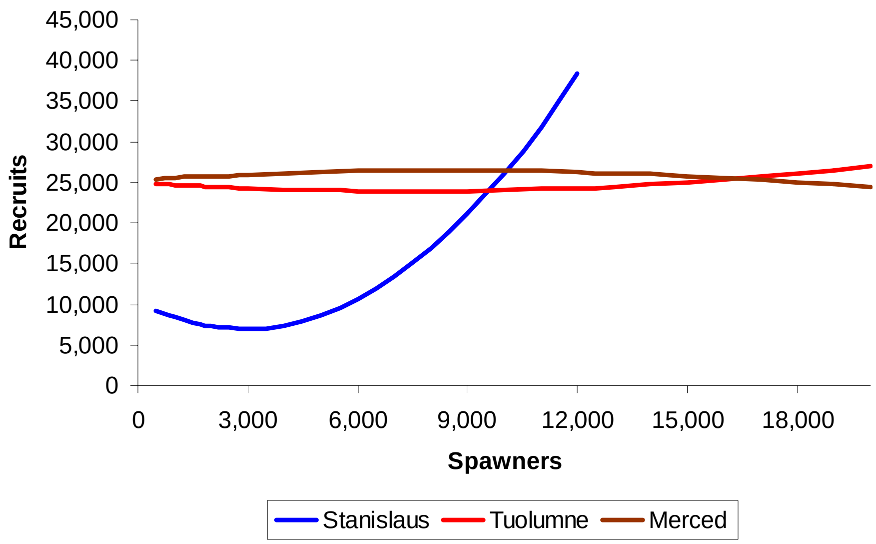

Figure 9. Spawner-recruit relationships for the Stanislaus, Tuolumne, and Merced rivers based on regression models of recruits, quadratic spawner terms, and a mean Vernalis flow of 7,000 cfs from March 1 through June 15. A categorical variable called “Population Shift” was used in the Tuolumne and Merced river models to account for a shift in recruitment that occurred sometime between 1987 and 1994 in the Tuolumne River and during the period from 1995 to 1998 in the Merced River.

The spawner-recruitment relationship for the Stanislaus River (Figure 9) is markedly different from the relationship between spawner abundance and the number of juveniles passing the rotary screw trap at Oakdale on the Stanislaus River from 2000 to 2004 (Figure 10). We suspect that this atypical relationship is the result of several factors, which may include (1) the propensity for hatchery strays to return to the Stanislaus River, which typically has the highest fall flows in the San Joaquin Basin, (2) changes in the suitability of the salmon habitat resulting from floods and/or habitat restoration, and (3) the lack of Stanislaus River scale analyses that would improve the accuracy of the estimates spawner abundance and recruitment estimates. These issues will be evaluated more thoroughly in a future draft of this manuscript.

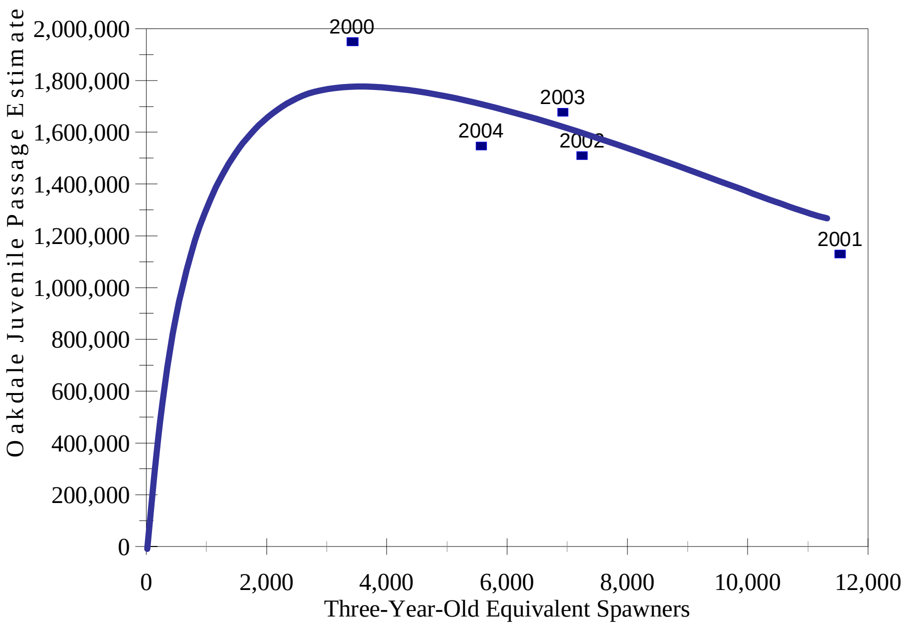

Figure 10. The relationship between the estimated number of juvenile fall-run Chinook salmon passing the Oakdale screw trap 2000 through 2004, and the number of three-year-old equivalent spawners that produced them from 1999 to 2003. The regression line was drawn by hand.

Population Declines

There appears to be a shift in the relationship between recruitment and the mean Vernalis flow from March 1 to June 15 for the Tuolumne River that occurred sometime between 1987 and 1995 (Figure 12) and in the Merced River that temporarily occurred between 1995 and 1998 (Figure 13). The elevation of the Tuolumne River regression for the period from 1998 to 2003 was significantly lower ($P = 0.02$) than for the period from 1980 to 1994 based on a two-tailed F-test. The variances of the regressions were not significantly different ($P = 0.168$), which is a statistical requirement for comparing regression slopes and elevations, and the slopes were not significantly different either ($P = 0.273$). The differences in the elevations of the Tuolumne River regressions were significantly different for the two periods ($P \leq 0.026$), regardless of whether the shift occurred in 1990 or 1995. Therefore, we arbitrarily chose 1995 as the shift point for the Tuolumne River analyses reported below.

The elevation of the Merced River regression for the period from 1995 to 1998 was significantly lower ($P = 0.000$) than for the periods from 1983 to 1994 and from 1999 to 2003 based on a two-tailed F-test. The variances of the regressions were not significantly different at the 95% level

(P = 0.061), which is a statistical requirement for comparing regression slopes and elevations, and the slopes were not significantly different at the 95% level either (P = 0.053).

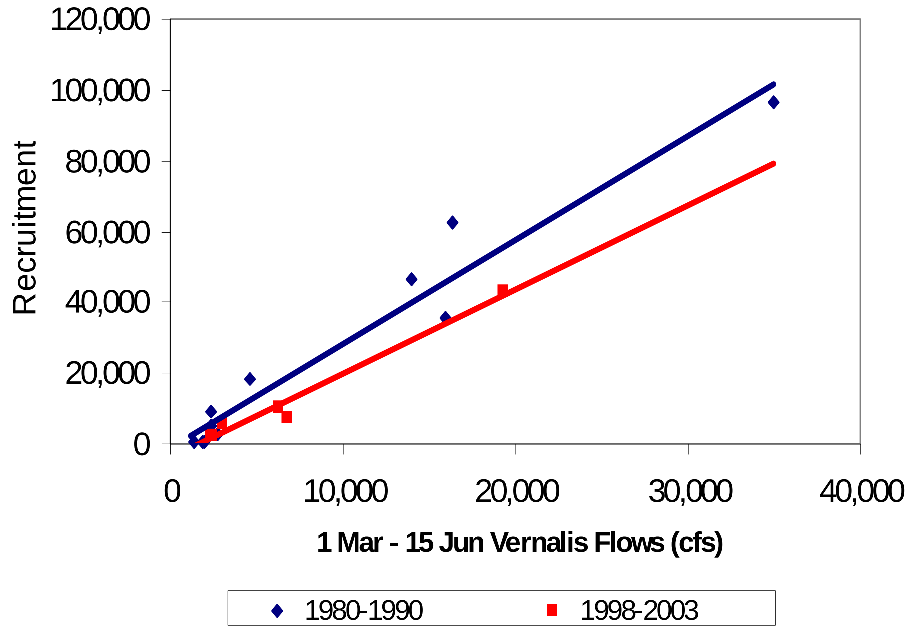

Figure 12. The relationships between Tuolumne River fall-run Chinook salmon recruitment and the mean flow in the San Joaquin River at Vernalis during March 1 through June 15 during two periods: 1980 to 1990 and from 1998 to 2003. Estimates were excluded for which spawner abundance was less than 500 Age 3 equivalent fish to minimize the effect of spawner abundance on the relationship between flow and recruitment; these data include 1981 and 1991 to 1994.

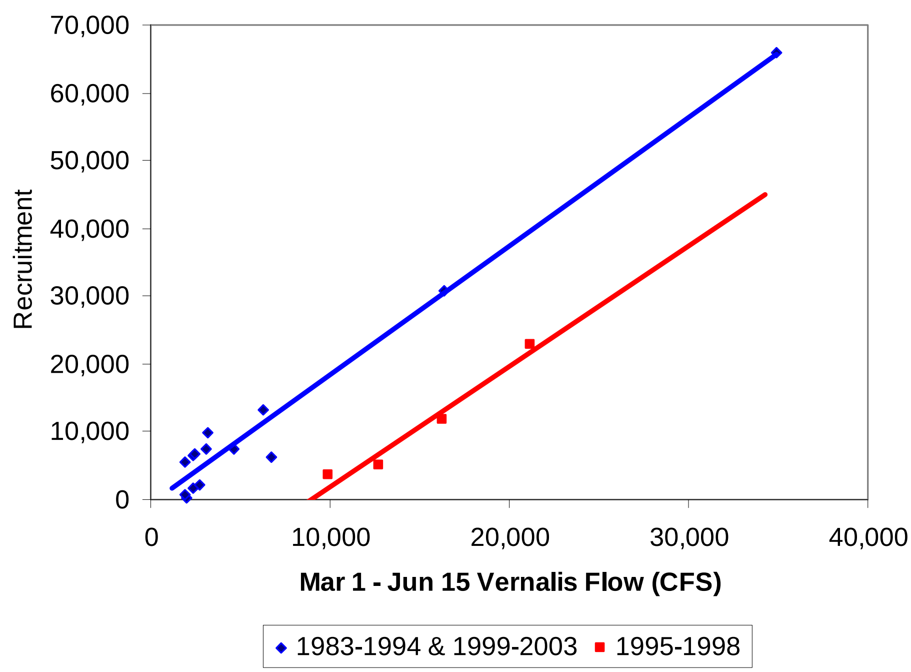

Figure 13. The relationships between Merced River fall-run Chinook salmon recruitment and the mean flow in the San Joaquin River at Vernalis during March 1 through June 15 during two periods: 1983 to 1994 and 1999 to 2003 versus 1995 to 1998. Estimates were excluded for which spawner abundance was less than 500 Age 3 equivalent fish to minimize the effect of spawner abundance on the relationship between flow and recruitment; these data include 1990 to 1992.

Although the Stanislaus River population does not appear to have declined from 1995 to 2003 (Figure 14) as occurred in the Tuolumne River, this could not be verified with two-tailed F-tests, because the variance terms for these periods were significantly different ($P \leq 0.002$).

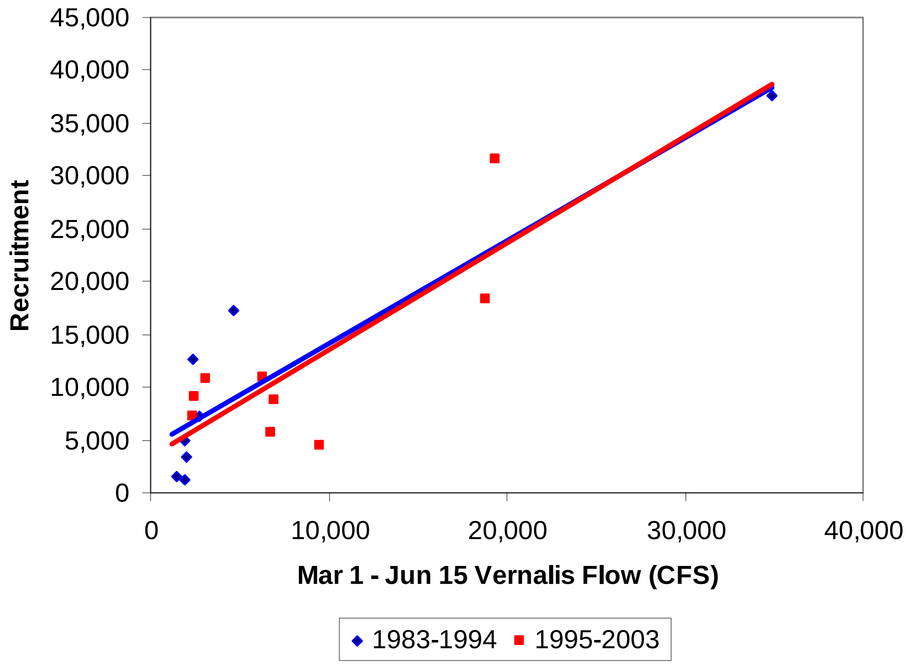

Figure 14. The relationships between Stanislaus River fall-run Chinook salmon recruitment and the mean flow in the San Joaquin River at Vernalis during March 1 through June 15 during two periods: 1983 to 1994 and 1995 to 2003. Estimates were excluded for which spawner abundance was less than 500 Age 3 equivalent fish to minimize the effect of spawner abundance on the relationship between flow and recruitment; these data include 1990 to 1992. The data from 1986 data were also excluded due to the likely confounding effect of unusually high numbers of hatchery reared fish in the escapement.

Correlations With Flow

The number of recruits in the Stanislaus and Merced rivers from 1983 to 2003 and the Tuolumne River from 1980 to 2003 are most highly correlated with the spring Delta flow variables based on partial correlation coefficients controlled for quadratic spawner abundance terms for the Tuolumne, Merced, and Stanislaus rivers and categorical “Population Shift” variables for the Tuolumne and Merced rivers (Table 1). The mean San Joaquin River flow at Vernalis from March 1 through June 15 was one of the strongest correlations for all three tributaries and so we selected this variable for our population models. Jassby’s (2005) estimates of the San Joaquin flows near Stockton are highly correlated with the Vernalis flows (adj-R^2 = 0.999) and so a distinction cannot be made between these two variables.

Table 1. Partial correlation coefficients for the relationships between the numbers of fall-run Chinook salmon recruits and the mean monthly flows during the year when the fish migrated to the ocean as smolts for the Stanislaus and Merced rivers from 1983 to 2003 and for the Tuolumne River from 1980 to 2003, when spawner abundance exceeded 500 fish. The correlations were controlled for spawner abundance (linear for the Tuolumne River and quadratic terms for the Merced and Stanislaus rivers) and the population shifts in the Tuolumne and Merced rivers. The categorical "Population Shift" variable for the Tuolumne River equaled "1" for years prior to 1995 and "2" for years since 1995. The categorical "Population Shift" variable for the Merced River equaled "2" for all years from 1995 to 1998 and "1" for all other years. Flows tested include the San Joaquin River near Vernalis, Stockton (Jassby estimates and DSM2 model estimates), and Jersey Point (QWest), the ratio of the combined CVP, SWP and CCC Delta exports to Vernalis flows, and tributary releases. Periods tested include the months of January through June, the April 15 to May 15 VAMP period, March 1 to May 31 period, March 1 to June 15 period, and February 1 to June 15 period.

	Partial Correlation Coefficients		
Variables	Stanislaus	Tuolumne	Merced
Vernalis Flows Feb to mid-Jun	0.7762	0.985	0.9819
Stockton Jassby Flows Feb to mid-Jun	0.7766	0.985	0.9846
Stockton Jassby Flows Mar to May	0.7865	0.9827	0.9756
Stockton Jassby Flows Mar to mid-Jun	0.7782	0.9822	0.9735
QWest Flows Feb to mid-Jun	0.8001	0.981	0.9818
Vernalis Flows March to May	0.7874	0.9804	0.9733
Vernalis Flows Mar to mid-Jun	0.7786	0.9803	0.9704
QWest Flows Mar to mid-Jun	0.7765	0.9793	0.9615
Stockton DSM2 Flows Feb to mid-Jun	0.7754	0.9791	0.973
QWest Flows March to May	0.7801	0.9788	0.9601
Stockton DSM2 Flows Mar to mid-Jun	0.7784	0.9738	0.9627
QWest Flows VAMP	0.6745	0.9723	0.9268
Stockton DSM2 Flows Mar to May	0.7836	0.9711	0.9612
QWest Flow May	0.6216	0.97	0.8936
QWest Flows Apr	0.7907	0.9645	0.9501
Vernalis Flows Mar	0.8157	0.9643	0.9507
Stockton Jassby Flows Mar	0.8247	0.9621	0.9529
QWest Flows Mar	0.8245	0.9619	0.9395
SJ Water Year Type	0.7534	0.9612	0.9064
Stockton Jassby Flows May	0.6535	0.9541	0.9232
Vernalis Flows May	0.6695	0.9519	0.9218
Stockton DSM2 Flow Mar	0.8177	0.9495	0.9256
Stockton Jassby Flows Apr	0.8057	0.9481	0.967
Tributary Releases VAMP	0.5073	0.945	0.9076

Variables	Stanislaus	Tuolumne	Merced
QWest Flows Jun	0.6801	0.9446	0.9109
Stockton DSM2 Flows Apr	0.8174	0.9433	0.9546
Vernalis Flows Apr	0.807	0.9415	0.9646
Stockton DSM2 Flows May	0.6364	0.9409	0.9205
Stockton DSM2 Flows Jun	0.7076	0.9399	0.9232
Tributary Releases Mar to May	0.7024	0.9362	0.9478
Vernalis Flows Jun	0.699	0.936	0.9246
Stockton Jassby Flows VAMP	0.7225	0.9329	0.9638
Stockton Jassby Flows Jun	0.6919	0.9328	0.9251
Vernalis Flows VAMP	0.7378	0.9279	0.961
Tributary Releases Jan	0.1855	0.9275	0.1413
Tributary Releases Mar	0.7657	0.9244	0.8968
Stockton DSM2 Flows VAMP	0.7052	0.9219	0.9405
Tributary Releases Mar to mid-Jun	0.6941	0.9045	0.9431
Tributary Releases Apr	0.5909	0.8934	0.9479
Tributary Releases May	0.5208	0.8693	0.8465
Stockton DSM2 Flows Feb	0.6287	0.8671	0.7718
Tributary Releases Jun	0.584	0.854	0.8299
QWest Flows Feb	0.6882	0.8537	0.7599
Vernalis Flows Feb	0.5862	0.8361	0.7287
Stockton Jassby Flows Feb	0.5838	0.8218	0.7145
Tributary Releases Feb	0.3205	0.7192	0.5007
Min DO at Burns Cutoff	0.3931	0.692	0.5666
Mean DO at Burns Cutoff	0.3717	0.6864	0.5321
Stockton DSM2 Flows Jan	0.3481	0.5296	0.3535
Vernalis Flows Jan	0.3328	0.4975	0.3254
QWest Flows Jan	0.3257	0.4858	0.2998
Stockton Jassby Flows Jan	0.3224	0.4831	0.3029
Tributary Releases Feb to mid-Jun	0.6842	0.4158	0.9794
Pacific interdecadal Oscillation Index	0.2724	0.1511	0.0892
PFEL Upwelling Index	-0.2915	0.0793	-0.0787
Exports Jan	-0.0588	-0.0372	0.1225
Exports Jun	0.0881	-0.0459	-0.1533
Exports Feb	-0.2811	-0.1625	0.0308
Exports May	0.2399	-0.2624	-0.0768
Max Temperature at Burns Cutoff	-0.5457	-0.5574	-0.5516
Exports Mar	-0.6878	-0.5748	-0.5149
Exports/Vernalis Flows Jan	-0.4554	-0.5826	-0.4163
Mean Temperature at Burns Cutoff	-0.653	-0.6267	-0.5741
Exports/Vernalis Flows Feb	-0.6035	-0.6267	-0.5515

Variables	Stanislaus	Tuolumne	Merced
Exports/Vernalis Flows Mar	-0.6608	-0.635	-0.5807
Exports Feb to mid-Jun	-0.4654	-0.6449	-0.4045
Exports VAMP	0.0446	-0.6851	-0.1294
Exports/Vernalis Flows Feb to mid-Jun	-0.6255	-0.7219	-0.6299
Exports/Vernalis Flows Apr	-0.5271	-0.7355	-0.5928
Exports/Vernalis Flows March to May	-0.59	-0.7618	-0.6231
Exports/Vernalis Flows Mar to mid-Jun	-0.6142	-0.776	-0.6458
Exports/Vernalis Flows Jun	-0.7309	-0.7871	-0.7546
Exports Mar to mid-Jun	-0.4463	-0.8001	-0.4809
Exports Mar to May	-0.4565	-0.8211	-0.4755
Exports Apr	-0.3818	-0.8467	-0.4107
Exports/Vernalis Flows VAMP	-0.3691	-0.8588	-0.4638
Exports/Vernalis Flows May	-0.3995	-0.9076	-0.5299

Early rearing flows during March, and possibly February, may be particularly important factors controlling adult recruitment in the SJR Basin because adult recruitment is highly correlated with the number of smolt-sized out-migrants from the Tuolumne (Figure 8) and Stanislaus rivers (Figure 7); juvenile abundance estimates are not yet available for the Merced River. This suggests that rearing conditions in the tributaries may be as important as smolt-out-migration conditions in the lower tributaries and Delta. Furthermore, the number of smolt-sized out-migrants leaving the Tuolumne (Figure 15) and Stanislaus rivers (Figure 16) is moderately to highly correlated with flows from March 1 through June 15, which is similar to the relationships observed with adult recruits.

The multiple regression models for recruitment, which include Vernalis flow from March 1 to June 15, quadratic terms for spawner abundance, and population shifts for the Tuolumne and Merced rivers, are statistically significant for the Stanislaus (adj-R^2 = 0.66, P = 0.000), Tuolumne (adj-R^2 = 0.96, P = 0.000), and Merced rivers (adj-R^2 = 0.93, P = 0.000). The coefficients and probably levels are presented in Table 2. If only linear spawner terms were used for the Stanislaus and Merced river models, the spawner variable would have been significant for the Tuolumne River model (P = 0.009) and the Stanislaus River model (P = 0.006), but not significant for the Merced River model (P = 0.951). We used the quadratic terms because they better reflect the spawner-recruit and flow-recruit relationships.

Table 2. Least squares linear regression coefficients and probabilities, which are shown in parentheses, for the Stanislaus, Tuolumne, and Merced River models with mean Vernalis flow from February 1 to June 15, quadratic terms for the estimated number of Age-3 equivalent spawners, categorical "Population Shift" variables for the Tuolumne and Merced rivers, and a constant term.

	Vernalis Flow	Spawners	Spawners^2	Pop Shift	Constant
Stanislaus	1.369 (0.000)	-2.202 (0.39)	3.788×10^{-4} (0.07)	none	602 (0.93)
Tuolumne	2.739 (0.000)	-0.280 (0.56)	1.887×10^{-5} (0.07)	-5,991 (0.023)	5,779 (0.19)
Merced	1.834 (0.000)	0.275 (0.73)	-1.606×10^{-5} (0.73)	-13,587 (0.000)	12,452 (0.01)

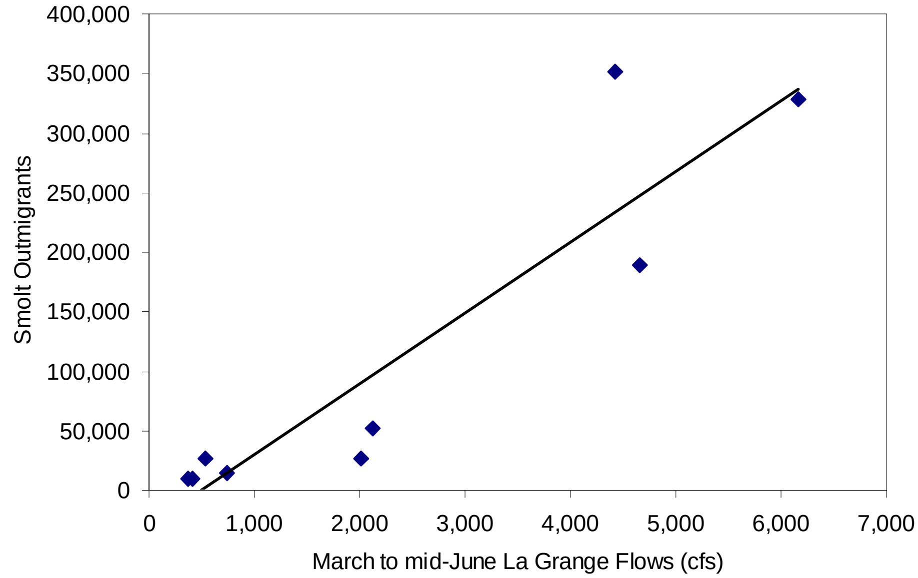

Figure 15. The Number of smolt-sized Chinook salmon outmigrants (FL ≥ 70 mm) passing the Grayson rotary screw trap site (RM 5) plotted with flows at La Grange between March 1 and June 15 in the Tuolumne River from 1998 to 2006. The regression model has an adj-R^2 of 0.82 and a probability level of 0.0005. The estimates of the number of smolt outmigrants are preliminary (CDFG unpublished data).

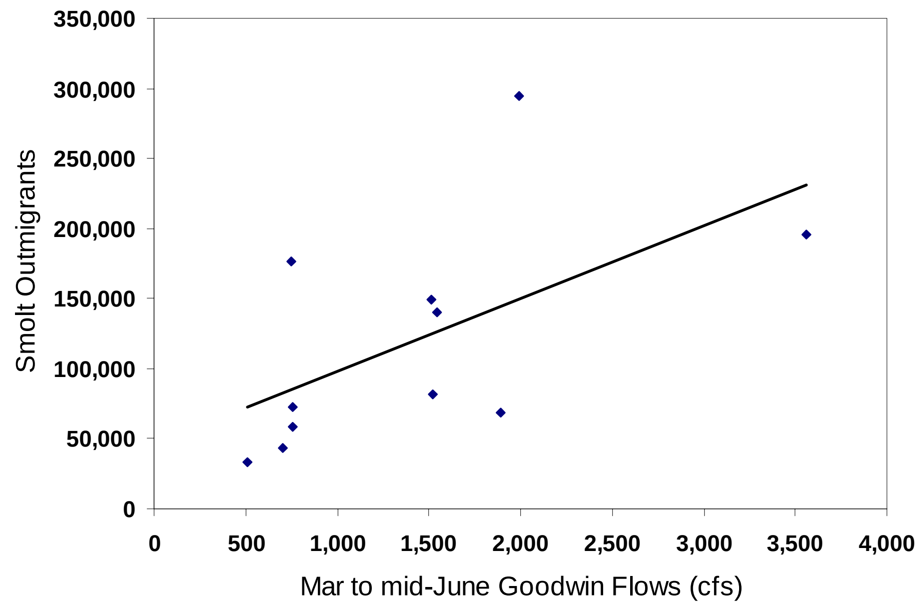

Figure 16. The Number of smolt-sized Chinook salmon outmigrants (FL ≥ 70 mm) passing the Caswell State Park rotary screw trap site (RM 8) plotted with flows at Goodwin Dam between March 1 and June 15 in the Stanislaus River from 1996 to 2006. The adj-R^2 = 0.25 and P = 0.06 for the regression. The estimates of the number of smolt outmigrants are preliminary (Cramer Fish Sciences unpublished data).

Ocean Productivity

The PDO is highly correlated with sea surface temperatures and the ocean harvest of pacific salmon off the Alaska coast and the West coast (Mantua and others 1997). When sea surface temperatures are warm off the entire northeastern Pacific rim, PDO tends to be positive, Alaska landings of sockeye and pink salmon are relatively high, and West Coast landings of spring-run Chinook and coho salmon are low (Mantua and others 1997). Long-term records indicate that there are 15- to 25-year cycles of warm and cool periods that are strongly correlated with marine ecosystem productivity (Mantua and others 1997; Hollowed and others 2001). Cool productive cycles prevailed from 1947-1976 and a new cycle began in 1998, whereas warm unproductive cycles dominated from 1925-1946 and from 1977-1997 (Mantua and others 1997; Mantua and Hare 2002). The coastal warming that occurred in the mid-1970s is believed to have caused increased stratification in the California Current, a sharper thermocline with less vertical displacement of nutrient rich water due to coastal upwelling, a reduction in the duration of upwelling, conditions, and a reduction in nutrients and/or zooplankton abundance carried by the California Current (Francis and others 1998). In addition, the abundance of coastal euphausiids (*Thysanoessa spinifera*) declined whereas oceanic euphausiids (*T. pacifica*) increased (Francis and others 1998). Such changes are thought to affect salmon early in the marine life history (Hare and Francis 1995) and coastal invertebrate species are important prey for ocean-type juveniles, such as Central Valley fall-run Chinook salmon.

However, the PDO productivity cycles are not be highly correlated with fall-run Chinook salmon production in the Central Valley. We compared the USFWS ChinookProd estimates[9], which sums the escapement and ocean harvest estimates, for the entire Central Valley between the productive and unproductive ocean periods. The mean in-river Central Valley wide Chinook production during the productive cool cycles was 31.1% and 139.3% higher for the 1952 to 1976 period and the 2000 to 2004 period, respectively, than during the unproductive warm cycle between 1979 and 1997 (Table 3). However, the higher production estimates during the 1952 to 1976 period may not be meaningful since a majority of the estimates (pre-1973) are not based on currently utilized mark-recapture techniques and so it is possible that the 31.1% increase is an artifact of different escapement survey methods. In addition, the higher production estimates during the 2000 to 2004 period are based on unusually large increases in several tributaries to the Sacramento Basin, including Battle Creek (592%), Clear Creek (198%), Butte Creek (438%), Feather River (150%), and American River (273%), that may be due to extensive habitat restoration, improved flow releases, and/or hatchery production. The increase in the San Joaquin Basin during the 2000 to 2004 period was only 19%, which may be a result of improved base flows, habitat restoration, and hatchery production in the Mokelumne and Merced rivers. Therefore, we tested correlations between adult salmon recruitment and the corresponding PDO and Upwelling indices for specific years rather than accounting for 15- to 25-year cycles in productivity. The result was that PDO and Upwelling do not explain the variability in adult recruitment (adjusted R-square values of 0.005 and -0.015 respectively).

[9] USFWS Chinook Prod Spreadsheet is available at http://www.delta.dfg.ca.gov/afrp/

Table 3. Fall-run Chinook salmon production, Sacramento Basin Water Year Index (WYI), San Joaquin Basin Water Year Index (WYI) for the unproductive ocean cycle between 1979 and 1997 and the productive cool ocean cycles between 1952 and 1976 and between 2000 and 2004.

	Central Valley Production	Sacramento Basin WYI	San Joaquin Basin WYI	Percent Change in Central Valley Production between Warm and Cool Period	Percent Change in Sacramento WYI between Warm and Cool Period	Percent Change in San Joaquin WYI between Warm and Cool Period
Warm Unproductive (1979-1997)	204,266	8.09	3.40	--	--	--
Cool Productive (1952-1976)	267,980	8.77	3.23	+31%	+8%	-5%
Cool Productive (2000-2004)	488,984	7.35	2.59	+139%	-9%	-24%

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References

Amweg, E.L. D.P. Weston, and N.M. Ureda. 2005. Use and toxicity of pyrethroid pesticides in the Central Valley, California, USA. Environmental Toxicology and Chemistry 24(4): 966-972.

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

Brandes, P.L. and J.S. McLain. 2001. Juvenile Chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. In: Brown, R.L., editor. Fish Bulletin 179: Contributions to the biology of Central Valley salmonids. Volume 2. Sacramento (CA): California Department of Fish and Game. Pages 39-138.

[CDFG] California Department of Fish and Game. 1972. Report to the California State Water Resources Control Board on effects of the New Melones Project on fish and wildlife resources of the Stanislaus River and Sacramento-San Joaquin Delta. Produced by Region 4, Anadromous Fisheries Branch, Bay-Delta Research Study, and Environmental Services Branch.

[CDFG] California Department of Fish and Game. 1987. The status of San Joaquin Drainage Chinook salmon stocks, habitat conditions and natural production factors (DFG Exhibit 15). Prepared for the State Water Resources Control Board Bay/Delta Hearing Process Phase we: Determination of Beneficial Uses and Determination of Reasonable Levels of Protection. September 1987. Fresno, CA.

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

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

[CDFG et al.] California Department of Fish and Game, California Department of Water Resources, and the U.S. Fish and Wildlife Service. 2001. Initial Study and Environmental Assessment for the Merced River Salmon Habitat Enhancement Project and Robinson Reach Phase. March 2001.

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

[CMC] Carl Mesick Consultants. 1996. The effects of minimum instream flow requirements, release temperatures, Delta exports, and stock on fall-run chinook salmon production in the Stanislaus and Tuolumne rivers. Draft report prepared for Thomas R. Payne & Associates, Neumiller & Beardslee, and the Stockton East Water District. 10 May 1996. El Dorado, CA.

[CMC] Carl Mesick Consultants. 2002. Knights Ferry Gravel Replenishment Project, Final Report. Report produced for the CALFED Bay Delta Program. El Dorado, California.

Dettman, D.H. and D.W. Kelley. 1987. The roles of Feather River and Nimbus salmon and steelhead hatcheries and natural reproduction in supporting fall-run Chinook salmon populations in the Sacramento River basin. Report prepared for the California Department of Water Resources. July 1987. Newcastle, CA.

[EA] EA Engineering, Science, and Technology. 1992. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project.

Francis RC, Hare SR, Hollowed AB, Wooster W.S. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fish. Oceanogr. 7: 1-21.

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

Hare S.R. and R.C. Francis. 1995. Climate change and salmon production in the northeast Pacific Ocean. In: Beamish RJ, editor. Climate change and northern fish populations. Can Spec Publ Fish Aquat Sci 121. p 357–372.

Hare S.R., N.J. Mantua, and R.C. Francis. 1999. Inverse production regimes: Alaska and West Coast Pacific Salmon. Fisheries 24(1):6-14.

Hollowed, A.B., S.R. Hare, and W.S. Wooster. 2001. Pacific-Basin climate variability and patterns of Northeast Pacific marine fish production. Prog. Oceanogr. 49: 257-282.

Jassby, A.D. 2005. Phytoplankton regulation in a eutrophic tidal river (San Joaquin River, California). San Francisco Estuary and Watershed Science. Volume 3, Issue 1 (March 2005), Article 3.

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

Kope, R.G. 1987. Separable virtual population analysis of Pacific salmon with application to market Chinook salmon, *Oncorhynchus tshawytscha*, from California's Central Valley. Can. J. Fish. Aquat. Sci. 44:1213-1220.

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

Kope, R.G. and L.W. Botsford. 1990. Determination of factors affecting recruitment of Chinook salmon *Oncorhynchus tshawytscha* in Central California. Fishery Bulletin, U.S. 88:257-269.

Lehman, P.W. and S. Waller. 2003. Microcystis blooms in the Delta. IEP Newsletter. Volumne 16(1): 18-27.

Leitritz, E. 1959. Trout and salmon culture (hatchery methods). State of California, Department of Fish and Game, Fish Bulletin 107: 11-68

Mantua, N.J. and S.R. Hare. 2002. The Pacific Decadal Oscillation. Journal of Oceanography 58:35-44.

Mantua, N.J, S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069-1079.

Marston, Dean. 2005. San Joaquin River Fall-run Chinook Salmon Population Model. Final Draft Report. California Department of Fish & Game Report.

McBain and Trush. 2000. Habitat restoration plan for the lower Tuolumne River corridor. Report prepared for the Tuolumne River Technical Advisory Committee. March 2000. Arcata, California. 240 pages.

Mesick, C.F. 2001. Studies of spawning habitat for fall-run Chinook salmon in the Stanislaus River between Goodwin Dam and Riverbank from 1994 to 1997. In: Brown, R.L., editor. Fish Bulletin 179: Contributions to the biology of Central Valley salmonids. Volume 2. Sacramento (CA): California Department of Fish and Game. Pages 217-252.

Mesick, C.F., D. Marston, and T. Heyne. 2006. Difficulties in conducting trend analyses with fall-run Chinook salmon escapement data from the San Joaquin River Basin. Draft report. August 2006.

Okamoto, A.R. 2001. Scrutinizing the Delta Cross Channel. Science in Action. News from the Calfed Bay-Delta Science Program. Calfed Bay Delta Authority. June 2001.

Quinn, T.P. and K. Fresh. 1984. Homing and straying in Chinook salmon from Cowlitz River Hatchery, Washington. Can. J. Fish. Aquat. Sci. 41:1078-1082.

[PFMC] Pacific Fisheries Management Council. 2006. Preseason Report we: stock abundance analysis for 2005 ocean salmon fisheries. February 2006. Portland, OR.

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

Reisenbichler RR. 1989. Utility of spawner-recruit relations for evaluating the effect of degraded environment on the abundance of Chinook salmon, *Oncorhynchus tshawytscha*, p. 21-32, *In* C.D. Levings, L.B. Holtby, and M.A. Henderson [ed.] Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105.

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

[SJRGA] San Joaquin River Group Authority. 2001. 2000 annual technical report.on implementation and monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan. Prepared for the California State Water Resources Control Board in compliance with D-1641. January 2001.

[SJRGA] San Joaquin River Group Authority. 2002. 2001 annual technical report.on implementation and monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan. Prepared for the California State Water Resources Control Board in compliance with D-1641. January 2002.

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

[SJRGA] San Joaquin River Group Authority. 2005. 2004 annual technical report.on implementation and monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan. Prepared for the California State Water Resources Control Board in compliance with D-1641. January 2005.

Sokal R.R, and F.J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. W.H. Freeman and Company, New York.

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

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

Stanislaus River Fish Group. 2004. A Summary of Fisheries Research In The Lower Stanislaus River. Draft report prepared 10 March 2004.

Stillwater Sciences. 2002. Merced River Corridor Restoration Plan. Berkeley, California. February 2002. 245 pages.

Turlock Irrigation District and Modesto Irrigation District. 2005. 2005 Ten Year Summary Report pursuant to paragraph (G) of the 1996 FERC Order issued July 31, 1996. Report submitted to the US Federal Energy Regulatory Commission to meet license requirements for the New Don Pedro Project (FERC No. 2299). April 2005.

Unwin, M.J. and T.P. Quinn. 1993. Homing and straying patterns of Chinook salmon from a New Zealand hatchery: spatial distribution of strays and effects of release date. Can. J. Fish. Aquat. Sci. 50:1168-1175.

U.S. Fish and Wildlife Service. 2005 Monitoring of restoration projects in the Merced River using 2-dimensional modeling methodology. Prepared by the Thergy Planning and Instream Flow Branch 18 January 2005. Sacramento California.

Appendix A. Estimates of escapement (CDFG), percentages of Age 2, 3, 4, and 5 fish, sport harvest fraction of the Central Valley Index, troll harvest fraction of the Central Valley Index, recruitment, three-year-old equivalent spawners, and age ratios used to segregate escapement estimates into cohorts.

Stanislaus River

Year	Escapement	%Age 2	%Age 3	%Age 4	%Age 5	Sport Harvest	Troll Harvest	Recruitment	Spawners	A3/A2	A4/A3	A5/A4
1983	10,000	76.2%	14.8%	9.0%	0.01%	0.141	0.475	37,597	5,237	2.736	0.196	0.003
1984	11,439	62.4%	37.5%	0.1%	0.02%	0.150	0.424	17,274	5,454	0.562	0.008	0.002
1985	13,473	15.7%	76.8%	7.5%	0.01%	0.182	0.318	12,645	7,015	1.449	0.236	0.118
1986	6,497	21.6%	52.6%	23.3%	2.50%	0.125	0.545	77,856	12,364	1.615	0.146	0.161
1987	6,292	68.0%	27.7%	3.8%	0.55%	0.185	0.542	7,252	5,992	1.240	0.069	0.023
1988	10,212	9.4%	87.9%	2.7%	0.00%	0.106	0.674	3,453	3,701	2.099	0.156	0.000
1989	1,510	5.2%	62.7%	32.1%	0.00%	0.196	0.545	1,195	9,669	0.981	0.054	0.000
1990	480	6.8%	69.4%	23.3%	0.40%	0.198	0.591	1,474	1,558	4.214	0.118	0.004
1991	394	13.3%	51.5%	35.2%	0.01%	0.138	0.564	2,432	483	6.173	0.416	0.000
1992	255	26.0%	49.7%	23.9%	0.50%	0.213	0.511	4,929	389	2.420	0.300	0.009
1993	765	23.0%	47.8%	29.2%	0.05%	0.197	0.515	4,284	227	5.521	1.764	0.006
1994	1,079	18.2%	65.0%	16.5%	0.30%	0.262	0.459	4,864	701	3.993	0.487	0.014
1995	1,165	29.2%	45.8%	25.0%	0.02%	0.264	0.499	18,361	994	2.724	0.415	0.001
1996	3,000	60.4%	35.1%	4.5%	0.01%	0.162	0.437	4,437	1,013	3.094	0.253	0.001
1997	5,583	12.4%	79.4%	8.2%	0.01%	0.189	0.436	8,860	1,903	2.445	0.435	0.004
1998	3,147	42.9%	36.9%	20.2%	0.01%	0.177	0.343	31,602	5,246	1.681	0.143	0.001
1999	3,610	26.3%	64.5%	9.2%	0.02%	0.100	0.339	11,015	2,438	1.727	0.284	0.001
2000	11,854	6.1%	83.7%	9.7%	0.50%	0.134	0.411	5,678	3,088	10.460	0.491	0.179
2001	6,857	13.0%	33.0%	53.8%	0.20%	0.068	0.196	10,726	11,657	3.121	0.371	0.012
2002	7,735	14.6%	26.2%	59.1%	0.10%	0.104	0.242	7,322	7,045	2.265	2.020	0.002
2003	5,800	13.4%	70.9%	15.3%	0.42%	0.078	0.267	10,073	7,952	3.640	0.438	0.005
2004	4,068	30.2%	42.3%	27.3%	0.20%	0.201	0.417		5,505	2.210	0.270	0.009
2005	3,315	7.1%	78.9%	13.7%	0.33%	0.123	0.341		3,531	2.126	0.264	0.010
Average	5,153	26%	54%	20%	0.27%	0.161	0.439	13,492	3,265	2.978	0.406	0.025

Tuolumne River

Year	Escapement	%Age 2	%Age 3	%Age 4	%Age 5	Sport Harvest	Troll Harvest	Recruitment	Spawners	A3/A2	A4/A3	A5/A4
1980	559	78.8%	19.9%	1.3%	0.00%	0.139	0.531	46,505	1,085	1.407	0.150	0.004
1981	14,253	9.8%	83.6%	6.6%	0.00%	0.127	0.498	9,368	509	24.730	0.543	0.000
1982	7,126	76.2%	14.7%	9.1%	0.00%	0.161	0.549	35,727	7,323	0.530	0.165	0.000
1983	14,836	62.4%	37.6%	0.0%	0.00%	0.141	0.475	96,282	6,787	3.118	0.226	0.000
1984	13,689	7.8%	81.8%	8.4%	1.90%	0.150	0.424	18,369	8,093	0.455	0.000	0.000
1985	40,322	9.4%	45.5%	42.7%	2.40%	0.182	0.318	5,140	8,391	3.861	0.661	NA
1986	7,404	92.8%	5.3%	1.4%	0.46%	0.125	0.545	62,351	39,347	1.064	0.096	0.052
1987	14,751	10.2%	89.8%	0.0%	0.00%	0.185	0.542	3,081	7,675	1.130	0.063	0.022
1988	5,779	4.9%	30.7%	63.9%	0.53%	0.106	0.674	697	6,338	0.379	0.000	0.000
1989	1,275	19.4%	68.6%	12.0%	0.00%	0.196	0.545	329	5,412	0.661	0.157	NA
1990	96	15.0%	68.5%	16.5%	0.00%	0.198	0.591	329	1,402	1.052	0.029	0.000
1991	77	61.7%	25.2%	13.0%	0.10%	0.138	0.564	2,008	87	2.840	0.192	0.000
1992	132	20.2%	70.6%	9.2%	0.00%	0.213	0.511	1,814	72	2.877	0.325	0.010
1993	459	30.6%	50.0%	19.3%	0.10%	0.197	0.515	3,339	85	3.978	1.268	0.000
1994	513	33.5%	53.2%	13.3%	0.00%	0.262	0.459	5,170	410	2.762	0.306	0.012
1995	743	69.1%	27.4%	3.6%	0.00%	0.264	0.499	26,351	436	2.519	0.385	0.000
1996	4,550	14.1%	80.3%	5.6%	0.00%	0.162	0.437	11,630	608	5.003	0.409	0.000
1997	7,131	36.8%	42.6%	20.7%	0.00%	0.189	0.436	18,898	2,634	1.821	0.323	0.000
1998	7,916	22.8%	64.8%	12.4%	0.00%	0.177	0.343	43,119	6,588	3.352	0.286	0.000
1999	8,730	6.1%	82.2%	11.0%	0.76%	0.100	0.339	10,506	6,438	1.943	0.321	0.000
2000	16,420	20.2%	30.5%	49.1%	0.20%	0.134	0.411	7,185	7,712	6.779	0.319	0.115
2001	9,222	14.9%	36.2%	48.9%	0.00%	0.068	0.196	5,626	16,212	2.816	0.336	0.010
2002	7,125	10.0%	69.0%	20.2%	0.85%	0.104	0.242	2,225	8,983	1.389	1.239	0.000
2003	2,900	37.6%	33.7%	28.5%	0.26%	0.078	0.267	2,178	7,165	1.889	0.227	0.007
2004	1,634	19.9%	71.9%	8.0%	0.20%	0.201	0.417		2,847	1.900	0.233	0.007
2005	719	78.8%	19.9%	1.3%	0.00%	0.123	0.341		1,348	0.842	0.105	0.003
Average	7,245	31.4%	51.3%	17.0%	0.31%	0.158	0.449	16,777	5,923	3.119	0.322	0.010

Merced River

Year	Escapement	%Age 2	%Age 3	%Age 4	%Age 5	Sport Harvest	Troll Harvest	Recruitment	Spawners	A3/A2	A4/A3	A5/A4
1983	16,453	76.6%	19.0%	4.4%	0.00%	0.141	0.475	65,938	2,966	6.298	0.458	0.000
1984	27,640	62.4%	37.6%	0.0%	0.00%	0.150	0.424	7,397	8,784	0.824	0.002	0.000
1985	14,841	3.0%	88.0%	9.0%	0.00%	0.182	0.318	1,666	16,945	0.757	0.129	0.013
1986	6,789	6.9%	24.6%	65.0%	3.50%	0.125	0.545	30,828	14,832	3.751	0.338	0.178
1987	3,168	91.4%	6.3%	1.3%	1.10%	0.185	0.542	2,218	7,476	0.426	0.024	0.008
1988	4,135	18.4%	81.6%	0.0%	0.00%	0.106	0.674	146	1,396	1.166	0.003	0.004
1989	345	3.6%	60.1%	36.2%	0.00%	0.196	0.545	622	3,664	0.273	0.037	0.000
1990	33	31.3%	30.6%	38.1%	0.00%	0.198	0.591	1,809	362	0.805	0.061	0.000
1991	78	16.7%	73.6%	9.7%	0.00%	0.138	0.564	4,235	29	5.568	0.750	0.000
1992	618	29.9%	52.8%	16.5%	0.76%	0.213	0.511	8,544	71	25.096	1.779	0.620
1993	1,058	32.6%	65.2%	2.3%	0.00%	0.197	0.515	9,863	526	3.728	0.073	0.000
1994	2,022	20.3%	72.3%	7.4%	0.00%	0.262	0.459	5,646	849	4.238	0.217	0.000
1995	1,958	26.2%	65.2%	6.7%	1.90%	0.264	0.499	11,691	1,797	3.105	0.089	0.249
1996	2,840	41.0%	52.0%	7.1%	0.00%	0.162	0.437	3,531	1,681	2.877	0.157	0.000
1997	2,699	9.8%	84.6%	5.6%	0.00%	0.189	0.436	5,047	2,159	1.964	0.102	0.000
1998	3,354	24.1%	36.7%	39.1%	0.00%	0.177	0.343	22,884	2,565	4.649	0.575	0.000
1999	3,022	44.7%	51.2%	4.1%	0.00%	0.100	0.339	13,295	3,115	1.913	0.100	0.000
2000	7,179	8.8%	85.3%	5.9%	0.00%	0.134	0.411	6,205	2,209	4.535	0.276	0.000
2001	9,181	16.6%	38.5%	44.8%	0.10%	0.068	0.196	7,436	6,875	5.626	0.671	0.022
2002	8,829	16.6%	27.1%	56.3%	0.05%	0.104	0.242	6,497	9,061	1.569	1.406	0.001
2003	2,800	14.4%	70.9%	13.8%	0.90%	0.078	0.267	6,389	8,917	1.357	0.161	0.005
2004	4,112	33.4%	41.6%	24.9%	0.15%	0.201	0.417		2,638	4.252	0.514	0.016
2005	2,100	7.7%	79.9%	12.2%	0.22%	0.123	0.341		3,467	1.221	0.150	0.005
Average	5,446	27.7%	54.1%	17.8%	0.38%	0.161	0.439	7,797	4,519	3.739	0.351	0.049