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The Bay Institute

by email and hand delivery

April 6, 2009

Charles Hoppin, Chair
c/o Chris Carr
State Water Resources Control Board
(bay-delta@waterboards.ca.gov)
Division of Water Rights
P.O. Box 2000
Sacramento, CA 95812-2000

RE: AMENDMENTS TO THE 2006 BAY-DELTA PLAN SAN JOAQUIN RIVER FLOW OBJECTIVES

Dear Chairman Hoppin,

This letter is submitted as the comments of the Bay Institute regarding the consideration of potential amendments to the 2006 Water Quality Control Plan (WQCP) for the San Francisco Bay/ Sacramento-San Joaquin Delta Estuary relating to San Joaquin River flow objectives.

In our March 21, 2005, comments to the Board regarding review of the 1995 WQCP, we documented that the Plan's San Joaquin River flow objectives were not protective of fish and wildlife and estuarine habitat beneficial uses; described the criteria we used to develop alternative, more protective flow objectives; and recommended the adoption of these more protective flow objectives for the February – June period. Unfortunately, the Board did not choose to revise the Vernalis flow objectives, and fish populations and habitat conditions have continued to decline since adoption of the 2006 WQCP. We resubmit our 2005 comments (included as an attachment to this letter) and urge the Board to reconsider adoption of the recommended flow objectives. This letter is intended to supplement the analysis contained in our 2005 comments.

Continuing failure of current Vernalis flow objectives to protect beneficial uses

San Joaquin fall run Chinook salmon populations are experiencing a precipitous decline in abundance. According to the California Department of Fish and Game's (CDFG) GRANDTAB database, the cohort replacement rate has fallen below 1 for six consecutive years and below .15 for the past two years. In short, San Joaquin salmon have exhibited negative population growth for two generations and a nearly 90% decline in abundance in a single generation. This rate of population decline is a strong indicator of impending population collapse and high risk of extinction (Lindley et al, 2007; see Table 1, Footnote B).

This population decline appears to be highly related to San Joaquin flow conditions. A recent, exhaustive review by CDFG (CDFG, 2008) concluded that the current Vernalis flow objectives are inadequate due to:

> "1) the lack of substantive VAMP spring flow improvement (by water year type) as compared to that which historically occurred (pre-year 2000)…; 2) the narrowness of the pulse flow protection window (e.g. 31 days is too short a duration); 3) the infrequent occurrence of elevated flow objective levels (e.g., no 7,000 cfs flow levels have occurred in the first 9 years of VAMP…); and 4) the frequent occurrence of reduced flow objective levels (e.g., in the first 9 years of VAMP the 3200 and 4450 flow levels have occurred in 6 out of the 7 official VAMP study years…)" (p. 5).

DFG also noted that:

> "…non-flow parameters had little, or no, relationship to the long term population abundance of fall-run Chinook salmon in the SJR basin. Instead, spring flow (e.g., magnitude, duration, and frequency) appeared to have a significant influence upon SJR fall run Chinook salmon abundance returning to the SJR basin" (p. 5) and that "the spring outflow in the SJR system is the primary factor controlling the production of juvenile thence adult fall-run Chinook salmon" (p. 3).

TBI's recommended amendments to the Vernalis flow objectives would address the problems identified by CDFG primarily by extending pulse flow conditions to cover the entire February – June period (TBI, 2005). The Board should also consider improving flow requirements during the 31-day VAMP period as well, per CDFG's findings.

Although much of the analysis in our 2005 comments was focused on the relationship between Vernalis flows and transport of delta smelt and Chinook salmon from the South Delta to downstream habitat areas, and CDFG's population model was designed for

Chinook salmon, these same relationships are likely to apply to longfin smelt larvae and juveniles, to steelhead smolts, and to sturgeon juveniles, all of which are normally present during the February – June period and would also benefit from transport flows. The Board should analyze, or request CDFG to analyze, these relationships, including those between longfin, Vernalis flows, and export pumping.

Additional benefits from improving the Vernalis flow objectives

Improving flow conditions during this period is also likely to help prevent or reduce the occurrence of low dissolved oxygen (DO) conditions in the lower San Joaquin River. These low DO conditions arise as an interaction of anthropogenic biological and chemical inputs from upstream (agricultural return flows, wastewater treatment effluent), high temperatures, and low flow conditions. Low DO conditions (below the WQCP objective of 5mg/L) occur in every month of the year in the Stockton Deepwater Ship Channel, and are believed to impair survival and migration success for a variety of fish species (see Figure 1 below, from "Dissolved Oxygen Concentrations in the Stockton Deepwater Ship Channel Conceptual Models" (http://www.sjrdotmdl.org/concept_model/bioeffects_model/lifestage.htm). Sturgeon and salmon are particularly susceptible to the impacts of low DO. The frequency of impaired DO conditions increases through the spring – in June, these conditions occur more than 50% of the time. Reducing the frequency of low DO conditions in June will also be particularly important to ensure the successful restoration of spring-run Chinook salmon to the San Joaquin River system (Stipulation of Settlement in NRDC et al. v. USBR et al. CIV NO. S-88-1658 - LKK/GGH at page 17 paragraph 14) because returning spring run adults would be expected to migrate through the lower San Joaquin primarily during May and June. Improving flows will help to eliminate or reduce the frequency of low DO conditions and increase transport of salmon and other organisms through the affected area.

Figure 1 also shows that temperatures during the April – June period in the lower San Joaquin frequently exceed 20 degrees C, a level that causes indirect and direct temperature-related mortality in Chinook salmon, delta smelt, and steelhead. Longfin smelt may also be affected by high temperatures in this range (based on analysis using the DRERIP Longfin Smelt Conceptual Model). Furthermore, temperatures greater than 11 degrees C (currently occurring almost continuously throughout the year) may impair steelhead smoltification (see US EPA 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids with special reference to Chinook salmon. US Environmental Protection Agency, Region 10, July 1999). Indeed, CDFG has proposed listing the lower San Joaquin as water temperatire-impaired for salmon and steelhead (CDFG, 2008, Appendix 6). Improved Vernalis flow objectives would decrease exposure to sub-lethal and lethal temperatures along the lower San Joaquin and increase the rate of transport of all these species to colder water habitat areas downstream in the western Delta and Suisun Bay.

Thank you for your consideration of these comments. Please contact us if you have any questions regarding this letter.

Sincerely,

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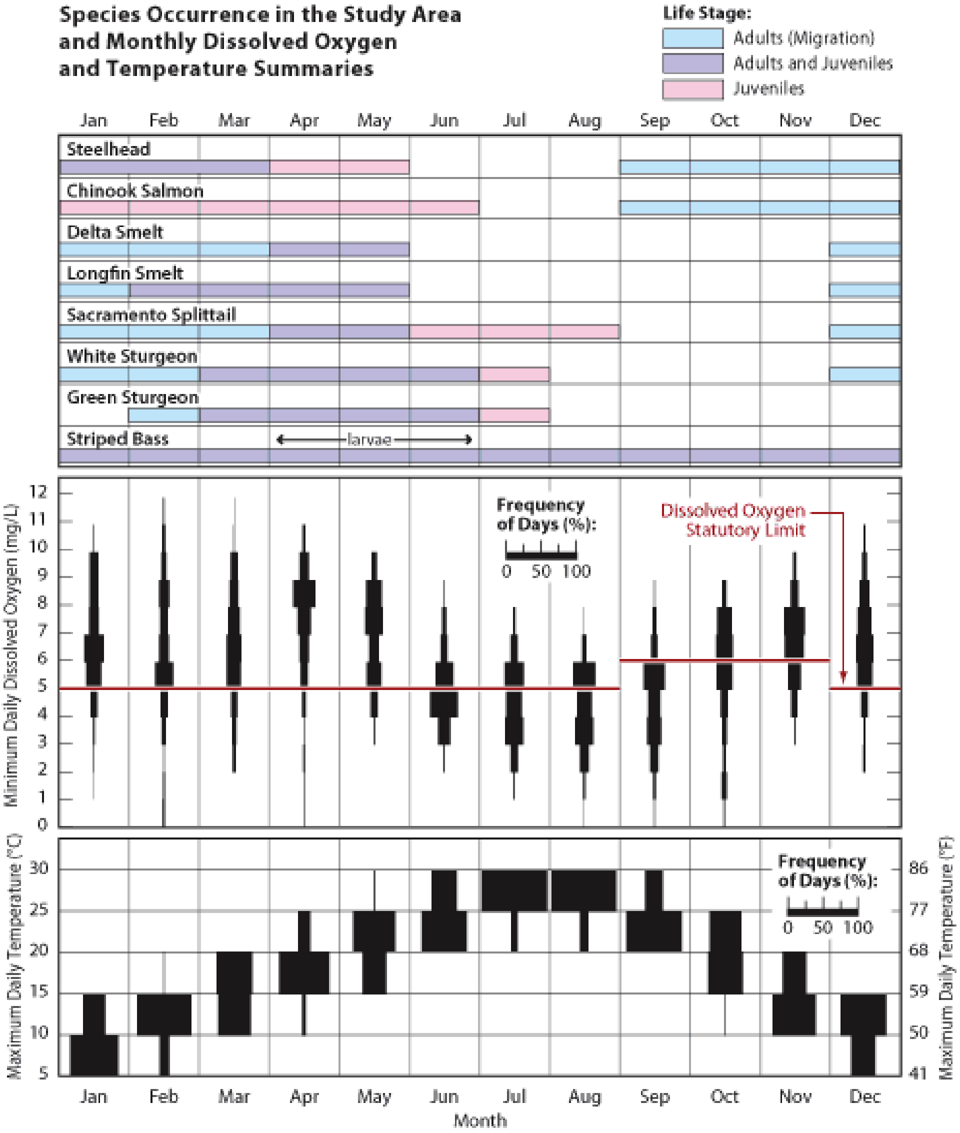
Attachments:

The Bay Institute. 2005. Letter to Arthur Baggett, Jr., Chair, State Water Resources Control Board, re: Bay-Delta Plan periodic review/Vernalis flows. March 21, 2005.

California Department of Fish and Game. 2008. San Joaquin River fall-run Chinook salmon population model peer review: Response to peer review comments: Initial response. August 22, 2008.

Lindley, S.T., et al. 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. *San Francisco Estuary and Watershed Science,* Vol. 5, Issue 1 [February 2007], Article 4.

FIGURE 1


Species Occurrence in the Study Area and Monthly Dissolved Oxygen and Temperature Summaries
Life Stage:
Adults (Migration)
Adults and Juveniles
Juveniles
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Steelhead
Chinook Salmon
Delta Smelt
Longfin Smelt
Sacramento Splittail
White Sturgeon
Green Sturgeon
Striped Bass
larvae
Minimum Daily Dissolved Oxygen (mg/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
Frequency of Days (%):
0 50 100
Dissolved Oxygen Statutory Limit
Maximum Daily Temperature (°C)
5
10
15
20
25
30
Maximum Daily Temperature (°F)
41
50
59
68
77
86
Frequency of Days (%):
0 50 100
Month

The Bay Institute

March 21, 2005

Arthur G. Baggett, Jr., Chair
State Water Resources Control Board
P. O. Box 100
Sacramento, CA 95812-0100

RE: BAY-DELTA PLAN PERIODIC REVIEW/VERNALIS FLOWS

Dear Mr. Baggett,

This letter is submitted as the opening comments of the Bay Institute regarding Workshop Topic 8 (River flows: San Joaquin River at Airport Way Bridge, Vernalis: February – April 14 and May 16 – June) for the State Water Resources Control Board's (SWRCB) public workshops to consider potential amendments or revisions of the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan).

We recommend that the SWRCB adopt more protective Vernalis flow objectives during the February – April 14 and May 16 – June period.

Ensuring adequate San Joaquin River flows at Vernalis during the February – April 14 and May 16 – June period provides fundamental and critical protections for San Joaquin Basin anadromous fishes (including fall-run Chinook salmon and Central Valley steelhead) and for estuarine habitat in the southern and central Delta, which is essential for many native resident fishes (including delta smelt).[1] The Bay-Delta Plan objective requires monthly minimum flow levels based on San Joaquin watershed hydrology (e.g., water year type) and monthly Delta outflow conditions (which are based on Sacramento-San Joaquin watershed hydrology and Bay-Delta Plan Delta outflow objectives). The ecological benefits of requiring flows during this period are to improve estuarine habitat conditions, particularly in the southern and central Delta, and to facilitate downstream

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[1] Central Valley steelhead and delta smelt are both listed as "threatened" under the federal Endangered Species Act (ESA). Fall-run Chinook salmon is a candidate species under the ESA.

movement and improve survival of larval and juvenile delta smelt and juvenile San Joaquin basin Chinook salmon.

1. The Bay-Delta Plan's February – April 14 and May 16 – June Vernalis flow objectives do not sufficiently protect anadromous and native resident fishes and estuarine habitat.

The Vernalis flow objectives apply during the ecologically critical spring spawning, rearing and outmigration period. This is also the period of the year when San Joaquin Basin flows are subject to the greatest degree of alteration as a result of upstream water management operations. Figure 1 shows hydrographs for actual Vernalis flows and unimpaired flows for the four major San Joaquin Basin rivers for Water Years 2000 – 2004.[2] During these years, February-June flows were reduced by 61% (2000, an "above normal" year) to 82% (2003, a "below normal" year), compared to unimpaired flows.

Storage and diversion of San Joaquin Basin runoff and the associated drastic reduction in flow reaching the lower San Joaquin River have resulted in a significant reduction in the relative contribution of the San Joaquin Basin to freshwater inflows to the Delta and San Francisco Bay. Historically, the San Joaquin Basin contributed an average of 22.8% of the total runoff from the Sacramento-San Joaquin watershed. Actual flows from the San Joaquin are significantly less, averaging 12.6% of total Delta inflows, and have declined significantly during the 1930 – 2004 period (regression analysis, $p<0.05$).[3] Figure 2 shows the percent contribution of San Joaquin Basin runoff to total runoff and of actual Vernalis flows to total Delta inflow. For the two most recent years, the percent contribution of the San Joaquin Basin to total Delta inflow was the third and fourth lowest measured for the 75-year period (6.4% for 2003, 6.2% for 2004).

San Joaquin Basin Chinook Salmon Populations
For San Joaquin Basin fall-run Chinook salmon, flow conditions in the lower San Joaquin River during the spring are directly related to three of the four criteria for a "viable salmonid population": population abundance, population growth, and diversity (McElhany et al., 2000).

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[2] Data for actual flows are from Dayflow, California Department of Water Resources (CDWR). San Joaquin Basin unimpaired flows are calculated as the sum of unimpaired flows of the four major San Joaquin basin rivers (Stanislaus, Tuolumne, Merced, and San Joaquin Rivers), available from CDEC (CDWR).

[3] Percent contribution of the San Joaquin Basin runoff calculated annually for the 1930-2004 period as: (sum of annual unimpaired runoff from the four rivers in the San Joaquin Basin/sum of the annual runoff of the ten largest rivers in the greater water shed)*100. The ten rivers are: Sacramento, Feather, Yuba, American, Mokelumne, Cosumnes, Stanislaus, Tuolumne, Merced and San Joaquin. Data for unimpaired flows are from CDEC (CDWR). Percent contribution of the San Joaquin Basin for actual flows was calculated similarly using Vernalis flows and total Delta inflow, using data from Dayflow (CDWR).

Since the early 1950s, San Joaquin Basin fall-run Chinook salmon populations have fluctuated dramatically, exceeding 50,000 fish in some years and falling to a few hundred fish in other years. Figure 3 shows escapement and return ratios for fall-run Chinook salmon that spawn in San Joaquin tributaries upstream of Vernalis.[4] During the most recent five-year period, average escapement was 21,267 fish, just 58% of the doubling goal set by the U. S. Fish and Wildlife Service (USFWS, 1995a).[5] Further, salmon escapement in these rivers has been declining for five years and the return ratio[6] dropped substantially below 1.0 in 2003 and 2004, indicating the species is experiencing a multi-year population decline. For these last two years, the numbers of salmon returning to San Joaquin River tributaries has been substantially less than the 1967 – 1991 average upon which the doubling goal is based.

The persistent low numbers and multi-year population decline observed for San Joaquin Basin Chinook salmon are markedly different from the population trends observed for the same period for Sacramento Basin fall-, winter-, and spring-run Chinook salmon. While most of the Sacramento Basin populations remain below the doubling goals, and some are still at critically low levels, many populations have exhibited fairly consistent population growth, a response that is generally attributed to favorable ocean conditions and improvement in upstream habitat and flow conditions (Figure 4). Given that Chinook salmon from both basins spend similar amounts of time in the Pacific Ocean, these different population responses between the two basins strongly indicate that freshwater habitat conditions in the San Joaquin Basin are a limiting factor.

Flow conditions in the lower San Joaquin River (and in its tributaries) during the spring are directly related to San Joaquin Basin fall-run Chinook salmon population abundance. Higher Vernalis flows during the March-June period, when juvenile salmon migrate downstream to the ocean, correspond to larger numbers of adult salmon returning to spawn in San Joaquin Basin tributaries 2.5 years later (Figure 5). This statistically significant relationship (based on 47 years of data) has continued to be strong during the years since the Bay-Delta Plan was implemented (see Figure 5, open symbols).

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[4] The salmon-producingstreams tributary to the San Joaquin River upstream of Vernalis are the Stanislaus, Tuolumne, and Merced Rivers.

[5] Escapement data for San Joaquin Basin Chinook salmon are from "Grandtab", a regularly updated spreadsheet file maintained by the California Department of Fish and Game (CDFG) that compiles escapement data from all salmon-producing streams on the Central Valley. The salmon "doubling" goals for the Stanislaus, Tuolumne, and Merced Rivers are from USFWS (1995a).

[6] The return ratio, or cohort replacement rates, is calculated as the number of adults returning to spawn in a given year divided by the number of adults that produced them three years earlier.

Population growth of San Joaquin Basin Chinook salmon is also related to Vernalis flows during the spring: in 94% of years with average March-June flows greater than or equal to 5000 cfs, the return ratio is greater than 1.0 (indicating positive population growth), while in 60% of years with average March-June flows less than 5000 cfs, the return ratio is less than 1.0, indicating population decline (Figure 6). Based on this analysis, it is clear that average springtime Vernalis flows during each of the past four years, which ranged from 2380 cfs (2002) to 3270 cfs (2003), have been insufficient to protect San Joaquin Basin Chinook salmon. San Joaquin Basin Chinook salmon escapement measured in 2003 and 2004 confirm this finding for Water Years 2001 and 2002: return ratios for salmon that migrated downstream under these low Vernalis flow conditions were substantially less than 1.0 for both population cohorts (see Figure 6, open symbols and text annotation).

The effect of Vernalis flows on salmon populations is also related to export rates at the Central Valley Project (CVP) and State Water Project (SWP) Delta pumps. Figure 7 shows the effect of the ratio of March – June Vernalis flows to exports on return ratios for San Joaquin Basin Chinook salmon. In 95% of years with a Vernalis flow:export ratio greater than 1.0 (i.e., Vernalis flow is higher than the combined CVP and SWP export rate), the return ratio is greater than 1.0 (positive population growth). In contrast, in 67% of years in which the March-June Vernalis flow:export ratio is less than 1.0 (exports exceed Vernalis flow), the return ratio is less than one and the salmon population declines. On this basis, Vernalis flow:export ratios for the past four years (range: 0.71 in 2001 and 2002 to 0.34 in 2003) have been insufficient to protect San Joaquin salmon, a finding supported by the lower population abundance and negative population growth measured for the 2003 and 2004 adult returns (see Figure 7, open symbols and text annotation).

Central Valley Steelhead Populations

Juvenile Central Valley steelhead, which also migrate out of San Joaquin Basin tributaries during the February – June period, have environmental requirements that are very similar to those for Chinook salmon (McEwan, 2001; Moyle, 2002). The limited data available regarding the status of steelhead populations in the San Joaquin Basin suggests that the population is critically low (McEwan, 2001). In their Working Paper on Restoration Needs (USFWS, 1995a), the Anadromous Fish Restoration Program (AFRP) Core Group generally determined that flow conditions which were limiting factors and insufficient to support San Joaquin Basin fall-run Chinook salmon were similarly harmful to steelhead in the basin. Further, flow conditions designed to benefit and facilitate doubling of Chinook salmon recommended to the USFWS by the Core Group would also benefit steelhead.

Salmonid Outmigration Timing and Duration
Both fall-run Chinook salmon and Central Valley steelhead migrate out of their natal rivers to the mainstem San Joaquin, the Delta, and the ocean over a period of several months during the spring (Moyle, 2002; McEwan, 2001; USFWS, 1995b; Healy, 1991). Chinook salmon smolts have been collected from the lower San Joaquin River (Mossdale) from April through July. Younger salmon (i.e., fry) have been collected from the mainstem San Joaquin River (at various locations downstream of the Merced River confluence) in January, February, and March. Timing of outmigration varies from year to year, often triggered by an increase in river flows and turbidity. In some years, there may be multiple pulses of outmigration among juvenile fish, which, based on spawning timing and duration during the previous fall, may vary in age by more than a month. This variation in outmigration timing is an important component of the genetic and phenotypic diversity of the population, the third of the four criteria for a viable salmonid population (McElhany et al., 2000). Populations with reduced genetic and phenotypic diversity are less capable of responding evolutionarily to adverse environmental changes and are more vulnerable to extinction. Present Vernalis flow conditions (and associated Delta export conditions), which are essentially intolerable except during the 31-day pulse flow period (April 15 – May 15) during most years, restrict juvenile salmonid outmigration to a narrow and fixed window during the spring. This has (and has had) the effect of "selecting" for a subset of the population that is genetically or phenotypically programmed to outmigrate during this specific four-week period in the spring; juvenile fish that attempt to migrate either before or after the 31-day pulse flow are subject to lethally inadequate flows in their natal tributaries (except possibly for the Stanislaus River, where additional water releases to meet Vernalis flow and salinity objectives may be made), the mainstem San Joaquin (e.g., where chronic, flow-related, low dissolved oxygen conditions exist in the Stockton Deep Water Ship Channel), and the Delta (where the Vernalis flow:export ratio is usually substantially below 1.0 (see Figure 8, and also our January 18, 2005, comments on Workshop Topic 6, Export Limits).

Estuarine Habitat and Native Resident Fishes
Fish assemblage structure, especially the prevalence and distribution of non-native species, is an accepted indicator of impaired aquatic habitat conditions, which are usually the result of altered flow regimes, toxic urban and agricultural runoff, and reduced habitat (Wang and Lyons, 2003; May and Brown, 2002; Brown, 2000). Table 1 shows the average of percentage of fishes collected by the California Department of Fish and Game's (DFG) Fall Midwater Trawl Survey (FMWT) in each of four regions within the Delta that are native species. Based on these results, the central and southern Delta , the areas of the estuary most

influenced by lower San Joaquin River flows where few to virtually no native fishes are found, are severely impaired.

Table 1. Percentage of fishes collected in different regions of the Delta that are native species. Data from DFG Fall Midwater Trawl Survey (FMWT), 1967-2001.

Region	**% of fishes that are native species** mean (±1 standard error)
South Delta	0.3% (±0.4)
Central Delta	10% (±2)
North Delta	29% (±3)
West Delta	49% (±4)

In a more detailed study focusing on the southern Delta, Freyer and Healey (2003) found that flow conditions in the lower San Joaquin River and in several southern Delta channels that receive flow from the mainstem river were the most reliable predictor of fish assemblage structure in the southern Delta. Over an 8-year period (1992 – 1999), the authors conducted monthly surveys (March – November, in most years) of fishes at several spatially distinct locations in Old River, Middle River, Grant Line Canal, and lower San Joaquin River in order to characterize fish assemblages and their associations with environmental variables. Of the 33 species collected, only 24% were native species and of more than 70,000 fishes collected, only 0.5% were native species. These results are similar with those of the larger scale FMWT survey, which is conducted later in the year (September – December) when San Joaquin River flows are even lower (see Table 1). Further, compared to fish surveys conducted thirty years earlier (Turner and Kelley, 1966, cited by Freyer and Healey, 2003), present estuarine habitat conditions as measured by the fish community are markedly worse: between the mid-1960s and the 1990s, two native species (hitch and starry flounder) were apparently extirpated from the southern Delta and eight non-native species have established reproducing populations. Freyer and Healey (2003) also found that the south Delta fish assemblage was structured along an environmental gradient of river flow: the few native species collected were strongly and significantly associated with areas of higher flows while the non-native species were associated with areas of lower flows.

For many estuarine species, freshwater inflows to the southern Delta (as well as export conditions) during the weeks before and after the 31-day pulse flow period are as, and for some species possibly more, important as the pulse flow period itself. For example, young delta smelt are present in the southern Delta as early as March (for example results of the DFG 20-mm survey and further discussion of this issue, see our January 18, 2005 comments on Workshop Topic

6, Export Limits) and as late as July (based on CVP and SWP fish salvage data). The multi-year population decline and the record low population abundance measured for delta smelt in 2004 (Figure 9) coincides with chronically low and worsening freshwater inflows from the San Joaquin River into the Delta (see Figures 1, 2, and 8).

2. Criteria used to develop recommendations for revising the Bay-Delta Plan's February – April 14 and May 16 – June Vernalis objectives.

Vernalis flows recommended by the Anadromous Fish Restoration Program

In 1995, the AFRP Core Group developed a set of recommended monthly flows for the San Joaquin River at Vernalis that, based on statistical analyses of San Joaquin fall-run Chinook salmon population trends (Stanislaus and Tuolumne Rivers only), historical actual and unimpaired Vernalis flows, and Delta export rates, were predicted to be necessary to achieve the salmon doubling goal for this run (USFWS, 1995a). Table 2 compares those flow recommendations for the February-June period to flows presently required by the Bay-Delta Plan and the San Joaquin River Agreement (VAMP).[7] Clearly, the Core Group concluded that higher flows than those required by the Bay-Delta Plan would be needed to achieve and maintain San Joaquin salmon populations at levels mandated by the Central Valley Project Improvement Act (CVPIA) and by the Bay-Delta Plan's narrative salmon protection objective. It is also apparent, based on recent trends in San Joaquin Basin salmon population abundance and population growth rates, that flow objectives in the Bay-Delta Plan are insufficiently protective, at least in average (i.e., "below normal") and drier water year types.

Table 2. Comparison of Vernalis flow objectives from the Bay-Delta Plan to flow recommendations developed by the Anadromous Fish Restoration Program (AFRP) Core Team to double San Joaquin Basin Chinook salmon populations. Water year types based on San Joaquin 60-20-20 Index: W=wet; AN=above normal; BN=below normal; D=dry; and C=critically dry. VAMP flows are based on unimpaired hydrology prior to April, but values presented in this table are assumed to reflect overall water year type.

Month	**Bay-Delta Plan (and SJRA)** (monthly average, cfs)					**AFRP Recommended Flow** (monthly average, cfs)				
	W	AN	BN	D	C	W	AN	BN	D	C
Feb	2130 or 3420	2130 or 3420	1420 or 2280	1420 or 2280	710 or 1140	5000	3900	2150	1450	1050
March	2130 or	2130 or	1420 or	1420 or	710 or	5350	3900	2750	2100	1850

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[7] Flow levels recommended by the AFRP in Table 2 are taken from Table 3-Xd-10 in USFWS (1995a).

	3420	3420	2280	2280	1140					
April	2130 or 3420	2130 or 3420	1420 or 2280	1420 or 2280	710 or 1140	12000	8250	7300	5850	4450
Apr. 15 to May15	VAMP (7000)	VAMP (5700)	VAMP (4450)	VAMP (3200)	VAMP (2000)					
May	2130 or 3420	2130 or 3420	1420 or 2280	1420 or 2280	710 or 1140	18600	13700	10200	7400	5200
June	2130 or 3420	2130 or 3420	1420 or 2280	1420 or 2280	710 or 1140	17300	9750	7650	4600	2950

Additional criteria for February – April 14 and May 16 – June Vernalis flow objectives
Based on our analyses above, the more detailed analyses conducted by the AFRP Core Team (USFWS, 1995a, b), and the Vernalis Adaptive Management Plan experimental design developed by the San Joaquin River Agreement planning team (SJRGA, 2005), we suggest that flow objectives for the lower San Joaquin River during the February – April 14 and May 16 – June period should, at a minimum, be based on the following criteria:

i. Required flow levels should be based on or, at a minimum, reflect variation in annual and monthly hydrology in the upper watershed.

ii. Required flows level should increase the relative contribution of the San Joaquin Basin to <u>total minimum required</u> Delta freshwater inflows during the February-June period to no less than 20% during all below normal, dry, and critically dry years. Required flow levels should be no less that 10% of <u>total actual</u> Delta freshwater inflows during the February-June period in all wet, above normal, and below normal years.
iii. Required flows levels should provide an average of 5000 cfs for at least three consecutive months (not including the 31-day pulse flow) in all wet and above normal years, and for a minimum of two consecutive months (not including the 31-day pulse flow) in all below normal years.

iv. Required flows levels in all months and all water year types should be greater than or equal to 1500 cfs, a level that should be sufficient to provide tolerable dissolved oxygen conditions in the Stockton Deep Water Ship Channel.

v. Minimum required flow levels in wet and above normal years should be capped at 7000 cfs to allow installation of the Head of Old River Barrier for the protection of outmigrating juvenile salmonids (as based on recommendations by the state and federal fisheries agencies).

vi. Required flows levels should be linked to maximum Delta export rates to provide an average Vernalis flow:export ratio for the March – June period that is greater than or equal to 1.0.

Recommendation: The SWRCB should revise the Bay-Delta Plan to adopt the more protective Vernalis flow objectives contained in Table 3.

Based on the clear evidence of population declines of anadromous and estuarine fishes and poor estuarine habitat conditions, indicating that the fish and wildlife beneficial uses are not being adequately protected, and on the criteria discussed above, we recommend that the SWRCB adopt more protective Vernalis flow objectives during the February – April 14 and May 16 – June period. These proposed new monthly Vernalis flow objectives, presented in Table 3 and for Water Years 2000 – 2004 in Figure 10, were developed assuming, and should be considered in conjunction with, the new export limits recommended in our January 18, 2005 comments on Workshop Topic 6, Export Limits.

Table 3. Proposed Vernalis flows (monthly average) for the protection of estuarine habitat and resident and migratory fishes during the February – April 14 and May 16 – June period for each water year type. Water year types based on San Joaquin 60-20-20 Index: W=wet; AN=above normal; BN=below normal; D=dry; and C=critically dry.

Month	**Water Year Type**[a]				
	W	**AN**	**BN**	**D**	**C**
February	3420	3420	2280	2280	1500
March	5000	5000	3420	2280	1500
April 1-14	7000	5000	5000	5000	2000
April 15-May 15	31-day flow objective as determined by VAMP experimental design				
May 16-31	7000	5000	5000	3420	2000
June	5000	5000	3420	2280	1500

[a] Water year type in the San Joaquin Basin to be determined using the 60-20-20 San Joaquin Valley Index with preliminary determinations of year type classification to be made in February, March, and April, with a final determination made in May. Monthly flow objectives should be based on monthly updates of San Joaquin Basin unimpaired runoff and water year type forecasts using the 50% exceedence.

It should be noted that implementing new Vernalis flow objectives before and after the 31-day pulse flow period will not affect the VAMP experiment, because outmigrant survival rates are measured for marked hatchery-produced salmon released at specific locations during the 31-day period rather than for wild juvenile salmon migrating out of the tributaries. Furthermore, improved flow conditions will also contribute significantly to improving dissolved oxygen and salinity conditions during the February – June period.

Finally, it is important to re-emphasize that the SWRCB should not constrain the adoption of a fully protective Vernalis flow objective, based on the best available science regarding protection of the fish and wildlife beneficial uses, as a result of perceived constraints on the amount of CVP water available to meet San Joaquin Basin and Delta flow requirements. (See our February 5, 2004, letter regarding the periodic review of the Bay-Delta Plan for further discussion of this issue).

Thank you for considering our recommendations regarding potential amendments and revisions to the Bay-Delta Plan objective for Vernalis flows during the February – April 14 and May 16 – June period. Please contact us if you have any questions regarding these comments.

Sincerely,

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References

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Framework for Assessing Viability of Threatened and Endangered Chinook Salmon and Steelhead in the Sacramento-San Joaquin Basin

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ABSTRACT

Protected evolutionarily significant units (ESUs) of salmonids require objective and measurable criteria for guiding their recovery. In this report, we develop a method for assessing population viability and two ways to integrate these population-level assessments into an assessment of ESU viability. Population viability is assessed with quantitative extinction models or criteria relating to population size, population growth rate, the occurrence of catastrophic declines, and the degree of hatchery influence. ESU viability is assessed by examining the number and distribution of viable populations across the landscape and their proximity to sources of catastrophic disturbance.

Central Valley spring-run and winter-run Chinook salmon ESUs are not currently viable, according to the criteria-based assessment. In both ESUs, extant populations may be at low risk of extinction, but these populations represent a small portion of the historical ESUs, and are vulnerable to catastrophic disturbance. The winter-run Chinook salmon ESU, in the extreme case, is represented by a single population that spawns outside of its historical spawning range. We are unable to assess the status of the Central Valley steelhead ESU with our framework because almost all of its roughly 80 populations are classified as data deficient. The few exceptions are those populations with a closely associated hatchery, and the naturally-spawning fish in these streams are at high risk of extinction. Population monitoring in this ESU is urgently needed.

Global and regional climate change poses an additional risk to the survival of salmonids in the Central Valley. A literature review suggests that by 2100, mean summer temperatures in the Central Valley region may increase by 2-8°C, precipitation will likely shift to more rain and less snow, with significant declines in total precipitation possible, and hydrographs will likely change, especially in the southern Sierra Nevada mountains. Warming at the lower end of the predicted range may allow spring-run Chinook salmon to persist in some streams, while making some currently utilized habitat inhospitable. At the upper end of the range of predicted warming, very little spring-run Chinook salmon habitat is expected to remain suitable.

In spite of the precarious position of Central Valley salmonid ESUs, there are prospects for greatly improving their viability. Recovering Central Valley ESUs may require re-establishing populations where historical populations have been extirpated (e.g., upstream of major dams). Such major efforts should be focused on those watersheds that offer the best possibility of providing suitable habitat in a warmer future.

KEYWORDS

Central Valley, Chinook salmon, steelhead, *Oncorhynchus tshawytscha, Oncorhynchus mykiss,* population viability, conservation, recovery planning, catastrophes, climate change, endangered species, biocomplexity

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INTRODUCTION

Numerous evolutionarily significant units (ESUs) of Pacific salmon and steelhead are listed as threatened or endangered species under the US Endangered Species Act (ESA) of 1973. The ESA, as amended in 1988, requires that recovery plans have quantitative, objective criteria that define when a species can be removed from the list, but does not offer detailed guidance on how to define recovery criteria. Logically, some of the recovery criteria should be biological indicators of low extinction risk. Recovery plans prepared since the 1988 amendment typically have about six recovery criteria, but only about half of these are quantitative or clearly related to biological information (Gerber and Hatch 2002). Gerber and Hatch (2002) found a positive relationship between the number of well-defined biological recovery criteria and the trend in abundance for the species. This empirical finding supports our intuition that well-defined recovery goals are important for recovering species.

Recovery planning seeks to ensure the viability of protected species. Viability of populations and ESUs depends on the demographic properties of the population or ESU, such as population size, growth rate, the variation in growth rate, and carrying capacity (e.g., Tuljapurkar and Orzack 1980). In the short term, the demographic properties of a population depend largely on the quality and quantity of habitat. In the longer term, genetic diversity, and the diversity of habitats that support genetic diversity, become increasingly important (McElhany et al. 2000; Kendall and Fox 2002; Williams and Reeves 2003). Consequently, McElhany et al. (2000) suggested that the viability of Pacific salmon populations should be assessed in terms of abundance, productivity, spatial structure, and genetic and life-history diversity. ESUs can be assessed in these same terms. While providing a useful conceptual framework for thinking about viability of Pacific salmon, McElhany et al. (2000) did not provide quantitative criteria that would allow one to assess whether particular populations or ESUs are viable.

Developing objective, quantitative, and biologically meaningful recovery criteria for Pacific salmonid ESUs is difficult. Ideally, these criteria would be population- and ESU-specific, taking into account the constraints in some factors that influence viability. For example, quantity of suitable habitat will usually set some limit on the size of a population, and populations with less habitat will need to have higher intrinsic growth rates (or less variable growth) than populations with more habitat, if they are to have similar viability. Unfortunately, population-specific information is frequently unavailable. One way out of this problem is to forego population-specific goals and develop biologically relevant criteria that are generic to *Oncorhynchus* species. Conservation biologists have developed a number of such criteria for the related task of identifying and prioritizing species in need of conservation (Mace and Lande 1991; IUCN 1994; Gärdenfors et al. 2001), and these taxonomically general criteria have been modified for application to Pacific salmonids (Allendorf et al. 1997).

If extinction risks of populations were independent, assessing the extinction risk of the ESU would be straightforward—the extinction risk of the ESU would be the product of the extinction risks of all its populations. We expect the extinction risks of populations to be correlated, however, because normal environmental influences affecting the population dynamics of salmonids are spatially correlated. Perhaps even more importantly, the effects of catastrophes (defined as rare environmental perturbations with very strong negative effects on afflicted populations) can be quite widespread. Finally, in cases like the Central Valley, all populations must use certain small areas (e.g., San Pablo Bay) where a single event such as a toxic spill could affect all populations even though they are widely dispersed for most of their life cycle. In some cases, it may be possible to explicitly examine the vulnerability of ESUs to catastrophic risks. We are unlikely to be able to identify all possible sources of risk, however, so we should also think of managing risk by maximizing diversity within ESUs.

In this report, we develop an approach for assessing the viability of Pacific salmonid populations and ESUs, and apply it to listed ESUs in California's Central Valley domain. In the "Assessment Framework" section below, we extend the criteria-based approach of Allendorf et al. (1997) to account for the effects of hatchery fish on the extinction risk of naturally-spawning populations, and explicitly define a "low" extinction risk category. This low-risk definition can serve as a default goal for recovering populations for which too little data exist for more detailed goals to be developed. ESU viability is addressed in two ways. In the first, risk-spreading is assessed by examining how viable populations are spread among geographically-defined regions within the ESU. In the second, we attempt to account explicitly for the spatial structure of the ESU and the spatial structure of various catastrophic risks, including volcanos, wildfires, and droughts. In the "Application to Central Valley Salmonids" section, we apply the analyses to Central Valley spring-run Chinook salmon (*Oncorhynchus tshawytscha)*, Sacramento River winter-run Chinook salmon (*O. tshawytscha)*, and Central Valley steelhead (*Oncorhynchus mykiss)*. As these methods implicitly assume that the future will be like the recent past, we review the likely effects of climate variation and climate change in "Climate Variability and Change." The "Summary and Recommendations" section summarizes our findings and makes some recommendations for recovery planners.

ASSESSMENT FRAMEWORK

Population Viability

Risk Categories

The goal of our population-level viability assessment is to classify populations into one of six categories, including "extinct," "extinct in the wild," "high," "moderate," and "low" extinction risk, or "data deficient," following the general approach of the IUCN (1994) as modified for Pacific salmonids by Allendorf et al. (1997). The goal of recovery activities should be to achieve at least a low risk of extinction for focal populations. We assume that a 5% risk of extinction in 100 years is an acceptably low extinction risk for populations (Thompson, 1991). Many salmonid populations are capable of achieving much lower risk levels and can provide additional benefits to ecosystems (Schindler et al. 2003) and people (e.g., by providing fishing opportunities) at these higher levels of abundance and productivity.

For Chinook salmon, we infer that populations are extinct if all of their historically utilized spawning habitat is blocked by impassable dams. *O. mykiss* pop-

Table 1. Criteria for assessing the level of risk of extinction for populations of Pacific salmonids. Overall risk is determined by the highest risk score for any category. (Modified from Allendorf et al. 1977)

	Risk of Extinction		
Criterion	High	Moderate	Low
Extinction risk from PVA	$> 20\%$ within 20 years	$> 5\%$ within 100 years	$< 5\%$ within 100 years
	– or any ONE of –	– or any ONE of –	– or ALL of –
Population size[a]	$N_e \le 50$	$50 < N_e \le 500$	$N_e > 500$
	–or–	–or–	–or–
	$N \le 250$	$250 < N \le 2500$	$N > 2500$
Population decline	Precipitous decline[b]	Chronic decline or depression[c]	No decline apparent or probable
Catastrophe, rate and effect[d]	Order of magnitude decline within one generation	Smaller but significant decline[e]	not apparent
Hatchery influence[f]	High	Moderate	Low

[a] Census size N can be used if direct estimates of effective size N_e are not available, assuming $N_e/N = 0.2$.

[b] Decline within last two generations to annual run size ≤ 500 spawners, or run size > 500 but declining at $\ge 10\%$ per year. Historically small but stable population not included.

[c] Run size has declined to ≤ 500, but now stable.

[d] Catastrophes occuring within the last 10 years.

[e] Decline $< 90\%$ but biologically significant.

[f] See Figure 1 for assessing hatchery impacts.

ulations may persist above migration barriers even if spawning habitat is inaccessible to anadromous fish, so migration barriers can not be taken as evidence of extinction for *O. mykiss*. In some cases, dams create suitable habitat in downstream reaches (typically through regulated discharges of cold water), and may support a population. We assess the status of such populations with the criteria described below, but note that the identity of tailwater populations may differ from populations historically found above the barrier.

Populations entirely dependent on artificial production (i.e., found only in a captive broodstock program or hatchery) would be considered extinct in the wild.

Risk categories from "high" to "low" are defined by various quantitative criteria, and correspond to specific risks of extinction within specific time horizons (Table 1). We extend Allendorf et al.'s (1997) criteria categories and risk levels in two ways (Table 1). First, we define criteria for the "low" risk category, which are implicit in Allendorf et al. (1997) Table 1. To simplify analysis, we collapse Allendorf et al. (1997) "very high" and "high" risk categories into a single "high" risk category. We add a set of criteria to deal with fish produced by hatcheries that spawn in the wild. Allendorf et al. (1997) deal with hatchery fish in their assessment of conservation value, but for our purposes of defining recovery criteria, the influence of hatchery fish must be included in the viability criteria.

Populations are classified as "data deficient" when there are not enough data to classify them otherwise. It is possible to classify a population as "high" risk with incomplete data (e.g., if it is known that $N_e < 50$, but trend data and hatchery straying are lacking), but a low risk classification must be met with all criteria.

Risk Criteria

Following Allendorf et al. (1997), the first set of criteria deal with direct estimates of extinction risk from population viability models. If such analyses exist and are deemed reasonable, such assessments may be sufficient for assessing risk; indeed, Allendorf et al. (1997) intended that their other criteria be used when

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such analyses were not available. The simplest useful population viability assessments are based on the random-walk-with-drift model (Dennis et al. 1991), and can be extended to account for observation error (Lindley 2003); we use this model where possible in this paper. We note that trying to predict absolute extinction risk is subject to many pitfalls and is viewed with skepticism by many conservation biologists and ecologists (Beissinger and Westphal (1998) provides a review of the various issues). We therefore recommend that population viability analysis (PVA) results be compared to the results of applying the simpler criteria, described below.

The effective population size criteria in the second row of Table 1 relate to loss of genetic diversity. The effective population size, N_e, is smaller than the population census size N due to variation in reproductive success among individuals. For Chinook salmon, N_e/N ranges from 0.06 to 0.29 (Waples et al. 2004). N_e can be estimated from detailed demographic or genetic data (e.g., see Ardren and Kapuscinski 2003). Very small populations, for example with $N_e < 50$, suffer severe inbreeding depression (Franklin 1980; Soulé 1980), and normally outbred populations with such low Ne have a high risk of extinction from this inbreeding.

Somewhat larger, but still small, populations can be expected to lose variation in quantitative traits through genetic drift faster than it can be replaced by mutation. Franklin (1980) and Soulé (1980) used population genetics models to show that such drift is significant when $N_e < 500$. The assumptions behind the $N_e > 500$ rule are problematical in two ways. On one hand, the original models used to derive the 500 rule (Franklin 1980; Soulé 1980) assumed that all mutations were mildly deleterious, but later research showed that only 10% of mutations are mildly deleterious (Lande 1995). This means that mutation effectively introduces new genetic variation at only 10% of the rate previously assumed, so N_e should therefore be > 5000 to attenuate the loss of genetic diversity due to drift. On the other hand, the models of Franklin and Sóule also assume that populations are closed to immigration. Very low levels of immigration, on the order of one individual per generation, can prevent the loss of alleles through drift (Wright 1931). We note that salmonid populations within ESUs are expected to have immigration at such low rates. Given the countervailing effects of the violations of the assumptions underlying the $N_e > 500$ rule, we apply the Allendorf et al. (1997) criteria as they stand, but note that with future research, it may be possible to define population size targets that conserve genetic variation and account for migration and genetic structuring within ESUs (e.g., Whitlock and Barton 1997).

The population decline criteria are intended to capture demographic risks. The rationale behind the population decline criteria are fairly straightforward– severe and prolonged declines to small run sizes are strong evidence that a population is at risk of extinction. The criteria have two components– a downward trend in abundance and a critical run size (< 500 spawners). Note that spawning run size is distinct from N_e. Although it is not clear how Allendorf et al. (1997) chose 500 as the threshold spawning run size, we adopt this threshold to maximize consistency with their criteria. We also note that typical salmonid populations near a carrying capacity of 500 spawners require only modest intrinsic growth rates to have low probability of extinction, given typical levels of variation in population growth (D. Boughton, NOAA Fisheries, Santa Cruz, CA; in preparation).

The catastrophe criteria trace back to Mace and Lande (1991), and the underlying theory is further developed by Lande (1993). The overall goal of the catastrophe criteria is to capture a sudden shift from a low risk state to a higher one. Catastrophes are defined as instantaneous declines in population size due to events that occur randomly in time, in contrast to regular environmental variation, which occurs constantly and can have both positive and negative effects on the population. Catastrophes have a qualitatively different effect on the distribution of mean time to extinction than does environmental variation. Because of this, it is sensible to treat catastrophes separately from population declines. We view catastrophes as singular events with an identifiable cause and only negative immediate consequences, as opposed to normal environmental variation which can produce very good as well as very bad conditions. Some examples of catastrophes include disease outbreaks, toxic spills, or vol-

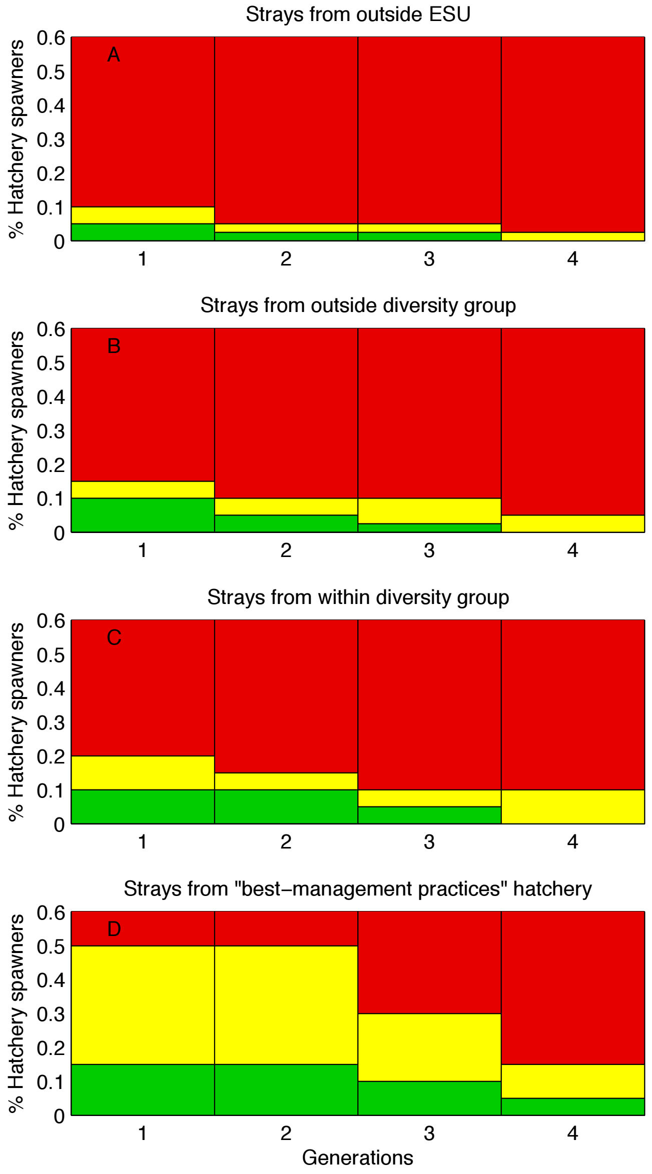

Figure 1. Extinction risk levels corresponding to different amount, duration and source of hatchery strays. Green bars indicate the range of low risk, yellow bars moderate risk, and red areas indicate high risk. Which chart to use depends on the relationship between the source and recipient populations. A: hatchery strays are from a different ESU than the wild population. B: Hatchery strays are from the same ESU but from a different diversity group within the ESU. C: Hatchery strays are from the same ESU and diversity group, but the hatchery does not employ "best management practices." D: Hatchery strays are from the same ESU and diversity group, and the hatchery employs "best management practices." Redrawn from Interior Columbia Basin Technical Recovery Team (2005).

canic eruptions. A high risk situation is created by a 90% decline in population size over one generation. A moderate risk event is one that is smaller but biologically significant, such as a year-class failure.

We view the spawning of hatchery fish in the wild as a potentially serious threat to the viability of natural populations. Population genetics theory predicts that fish hatcheries can negatively impact wild populations when hatchery fish spawn in the wild (e.g., Emlen 1991; Lynch and O'Hely 2001; Ford 2002; Goodman 2005). These predictions are supported by mounting empirical evidence (e.g., Reisenbichler and McIntyre 1977; Chilcote et al. 1986; Reisenbichler and Rubin 1999; McLean et al. 2003; Kostow 2004). In assessing the genetic impact of immigration on a population, one must consider the source of the immigrants, how long the impact goes on, the number of immigrants relative to the size of the recipient population, and how divergent the immigrants are from the recipient population. We adopt the approach of the Interior Columbia Basin Technical Recovery Team (TRT) (2005) to define how different scenarios relate to extinction risk for natural populations, summarized in Figure 1. We made one significant change to the Interior Columbia Basin Technical Recovery Team (2005) hatchery introgression criteria, allowing up to 5% of naturally spawning fish to be of hatchery origin while maintaining a low risk, if the hatchery fish are from a hatchery using "best management practices" (see Flagg et al. 2004; Olson et al. 2004; Mobrand et al. 2005, for a description of these practices) using broodstock derived from the wild population. This is consistent with the ICBTRT scheme, which can result in a low-risk classification even with moderate amounts of straying from best-practices hatcheries, so long as other risk measures are acceptable. We note that the risk levels depicted in Figure 1 are based on expert opinion, and that the empirical basis for relating hatchery impacts to extinction risk is currently limited (Bilby et al. 2003).

Allendorf et al. (1997) did not specify how to calculate estimates for the various viability criteria. Table 2 provides estimators that we have used in this paper. The average run size is computed as the mean of up to the three most recent generations, if that much data are available. Mean population size is estimated as the

Table 2. Estimation methods and data requirements for population metrics. St denotes the number of spawners in year t; *g* is mean generation time, which we take as three years for California salmon.

Metric	Estimator	Data	Criterion
$\hat{S}_t$	$\sum_{i=t-g+1}^{t} S_i/g$	$\geq$ 3 years spawning run estimates	Population decline
N_e	$N \times 0.2$ or other	varies	Population size
N	$\hat{S}_t \times g$	$\geq$ 3 years spawning run estimates	Population size
Population growth rate (% per year)	slope of $\log(S_t)$ v. time $\times 100$	10 years S_t	Population decline
c	$100 \times (1 - \min(N_{t+g}/N_t))$	time series of N	Catastrophe
h	average fraction of natural spawners of hatchery origin	mean of 1-4 generations	Hatchery influence

product of the mean run size and the average generation time. Population growth (or decline) rate is estimated from the slope of the natural logarithm of spawners versus time for the most recent 10 years of spawner count data. The fraction of naturally spawning fish of hatchery origin is the mean fraction over one to four generations.

ESU Viability

ESU viability depends on the number of populations within the ESU, their individual status, their spatial arrangement with respect to each other and sources of catastrophic disturbance, and diversity of the populations and their habitats. In the most general terms, ESU viability increases with the number of populations, the viability of these populations, the diversity of the populations, and the diversity of habitats that they occupy. Under natural conditions, most salmonid ESUs have persisted for at least many centuries, and perhaps much longer, given the observed level of genetic differentiation within and among them. How much can an ESU be altered before it is considered at risk of extinction? While we will not assess ESU viability in absolute terms, we assume that recovery planners will want ESUs to be likely to persist in the face of environmental variation of the sort we know has occurred over the last 500-1000 years. Such variation has included natural catastrophes such as prolonged drought, volcanic eruptions, large wildfires, and anthropogenic impacts such as the 1991 Cantara metam sodium spill. Such catastrophes could occur at any time in the foreseeable future. Therefore, for ESUs to be considered viable, they should at a minimum be able to persist if challenged by any one of these types of catastrophes.

Viability by Representation

We assess ESU viability with two different approaches. The goal of both approaches is to spread risk and maximize future potential for adaptation. The Puget Sound, Willamette/Lower Columbia and Interior Columbia TRTs have used variations on the idea of dividing ESUs into subunits (Myers et al. 2003; Ruckelshaus et al. 2002; Interior Columbia Basin Technical Recovery Team 2003), and requiring representation of all subunits and redundancy within the subunits (which we call the “representation and redundancy” rule). The ESU subunits are intended to capture important components of habitat, life history or genetic diversity that contribute to the viability of salmonid ESUs (Hilborn et al. 2003; Bottom et al. 2005). If extinction risks are not strongly correlated between populations, two populations, each with low risk of extinction, would be extremely unlikely to go extinct simultaneously (McElhany et al. 2003). Should one go extinct, the other could serve as a source of colonists to re-establish the extirpated population. Therefore, at

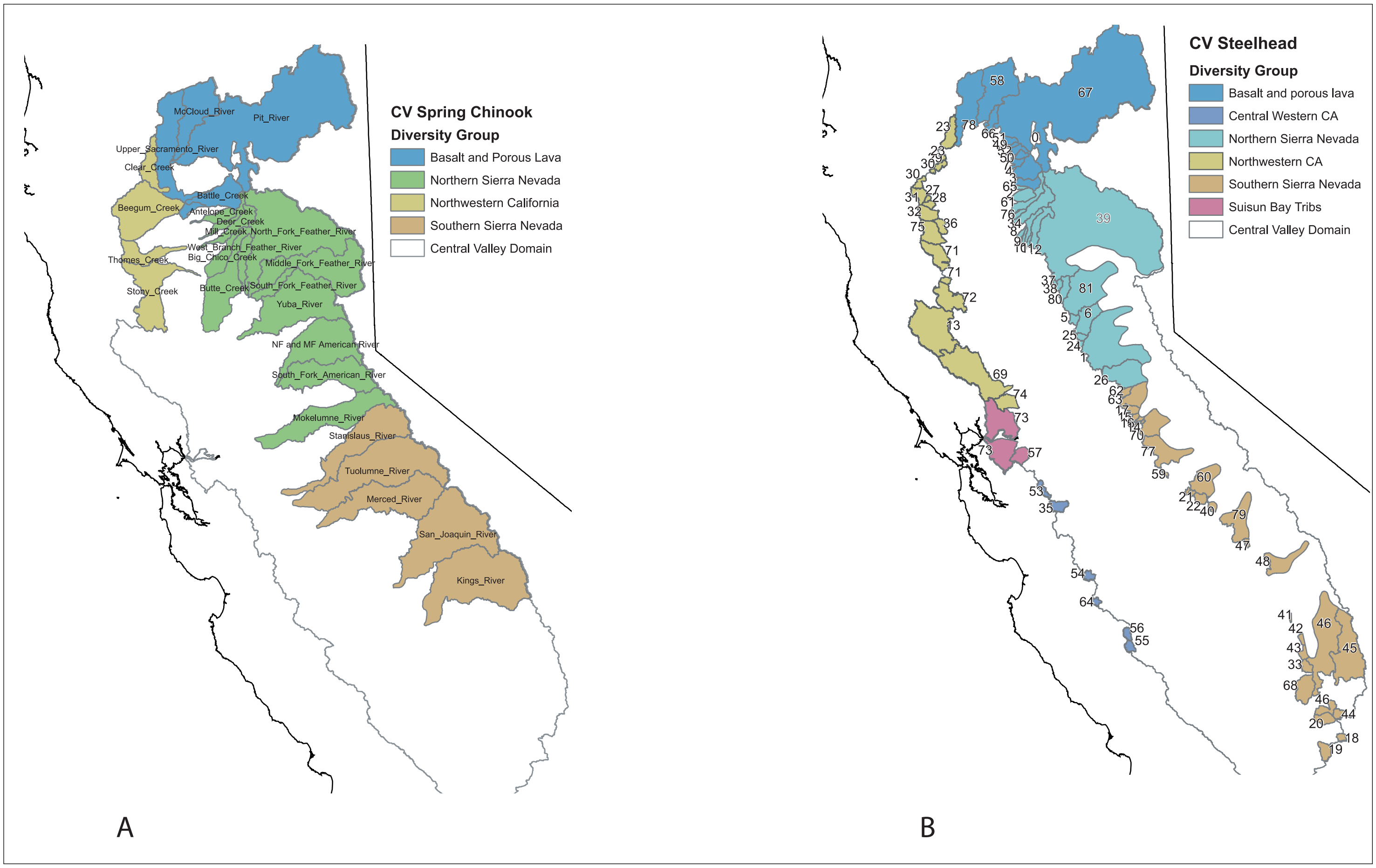

Figure 2. Salmonid ecoregions within the Central Valley. Map A: Central Valley spring-run Chinook salmon. Map B: Central Valley steelhead. Sacramento River Winter-run Chinook salmon not shown because this ESU has only one region (Basalt and porous lava). The numbers identifying steelhead populations correspond to Table 1 in Lindley et al. (2006).

least two viable populations within each ESU subunit are required to ensure viability of the subunit, and hence the ESU. In the cases of large subunits, more than two viable populations may be required to maintain connectivity among populations.

As discussed in Lindley et al. (2004), drainages in the Central Valley basin are characterized by a wide variety of climatological, hydrological, and geological conditions. To a first approximation, floristic ecoregions, such as the Jepson ecoregions defined by Hickman (1993), provide an integrative view of these differences. We use the Jepson ecoregions as a starting point for salmonid ecoregions, but modify them to account for the effect of springs, which are very influential on salmonids, but less influential to upland plants (Figure 2). Instead of the Cascade Ranges region, we define a "basalt and porous lava" region that comprises the streams that historically supported winter-run Chinook salmon. All of these streams receive large inflows of cold water from springs through the summer, upon which winter-run Chinook salmon depended. This region excludes streams south of Battle Creek, but would include the part of the Upper Sacramento drainage used by winter-run, and part of the Modoc Plateau region. The southern part of the Cascades region (i.e., the drainages of Mill, Deer, and Butte creeks) is added to the Sierra Nevada region, but the Sierra Nevada region is divided into northern and southern parts (split somewhat arbitrarily south of the Mokelumne River). This split reflects the greater importance of snowmelt runoff in the southern part, and distinguishes tributaries to the Sacramento and

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San Joaquin rivers. The Central Valley steelhead ESU has two additional salmonid ecoregions: the Suisun Bay region which consists of tributaries to or near Suisun Bay, where summer temperatures are moderated by the marine influence of nearby San Francisco Bay and the Pacific Ocean, and the Central Western California ecoregion, which contains west-side San Joaquin Valley tributaries.

Viability by Assessment of Specific Threats

An alternative to the representation and redundancy rule is to assess the relationship between ESU structure and specific sources of catastrophic risk. For example, one can assess whether a spill of toxic material at a certain point could extirpate all populations of an ESU. The advantage of this approach is that it is explicit: benefits or shortcomings of a particular ESU structure can be seen. The disadvantage is that we are unlikely to foresee all possible catastrophes, and more generally, this approach does not fully consider the value that biocomplexity has for ESUs. With this caution in mind, we assess the present structure of ESUs in relation to volcanic eruptions, wildfire, and drought[1].

Volcanos may seem like an unlikely threat, but the Mt. St. Helens eruptions of 1980 extirpated salmon in the Toutle River (Jones and Salo, 1986). The Cascades Range, of which Mt. St. Helens is a member, forms the northeastern boundary of the Sacramento River basin and is volcanically active. To assess the risk from volcanic eruptions, we obtained data on impact for lava flow, volcanic blast, pyroclastic flows, and debris-lahar flows from Hoblitt et al. (1987). For each volcano and impact type, we computed the percentage of habitat that would be impacted for each population.

While probably less devastating than a major volcanic eruption, fires can cause large injections of fine particles into streams, and fires have been implicated in the extinction of trout populations (e.g., Rinne 1996; Brown et al. 2001). In addition, fire-fighting chemicals are toxic to juvenile salmon (Buhl and Hamilton 1998). Assessing whether two populations might be vulnerable to a single large fire is in part a question of how frequently fires of such size arise. Moritz (1997) provides a way of estimating the relationship between fire size and return frequency from fire size data. We acquired data on fire sizes within the Central Valley domain from the California Department of Forestry, and created a time series of the largest fire in each year for the period 1908–2003. We then found the maximum diameter of the polygon describing each fire. The probability of the largest fire in a year having a maximum diameter less than than some specific size x, P(Xmax ≤ x), was estimated empirically following Moritz (1997).

Prolonged droughts have been implicated in the extinction of riverine fish species in the southwestern US (Douglas et al. 2003; Matthews and Marsh-Matthews, 2003), and a short drought had severe impacts on Sacramento River winter-run Chinook salmon broods in 1976 and 1977 (National Marine Fisheries Service, 1997). We estimated the correlation scale for drought by computing the correlation among the Palmer drought severity index scores among the grid points within CA presented by Cook et al. (2004) using a spline correlogram, which estimates a non-parametric covariance function (Bjornstad et al. 1999). Of particular interest is whether this characteristic scale is larger or smaller than the scale of ESUs—if it is larger, then drought risk can not be mitigated by maintaining widely-separated populations (although it would reduce the risk of simultaneous drought).

APPLICATION TO CENTRAL VALLEY SALMONIDS

Central Valley Spring-run Chinook Salmon

Perhaps 15 of the 18 or 19 historical populations of Central Valley spring-run Chinook salmon are extinct, with their entire historical spawning habitats behind various impassable dams (Figure 3 and Table 3). Butte Creek and Deer Creek spring-run Chinook salmon are at low risk of extinction, satisfying both the PVA (Figure 4) and other viability criteria (Table 3). Mill Creek is at moderate extinction risk according to the PVA, but appear to satisfy the other viability criteria for low-risk status. Lindley et al. (2004) were uncertain whether Mill and Deer creek populations were each independent or two parts of a single larger population. If viewed as a single population, Mill and Deer Creek spring-run Chinook salmon are at low extinction risk. Early-returning Chinook salmon persist within the

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Feather River Hatchery population and spawn in the Feather River below Oroville Dam and the Yuba River below Englebright Dam. The current status of these fish is impossible to assess due to insufficient data.

With demonstrably viable populations in only one of at least three diversity groups that historically con-

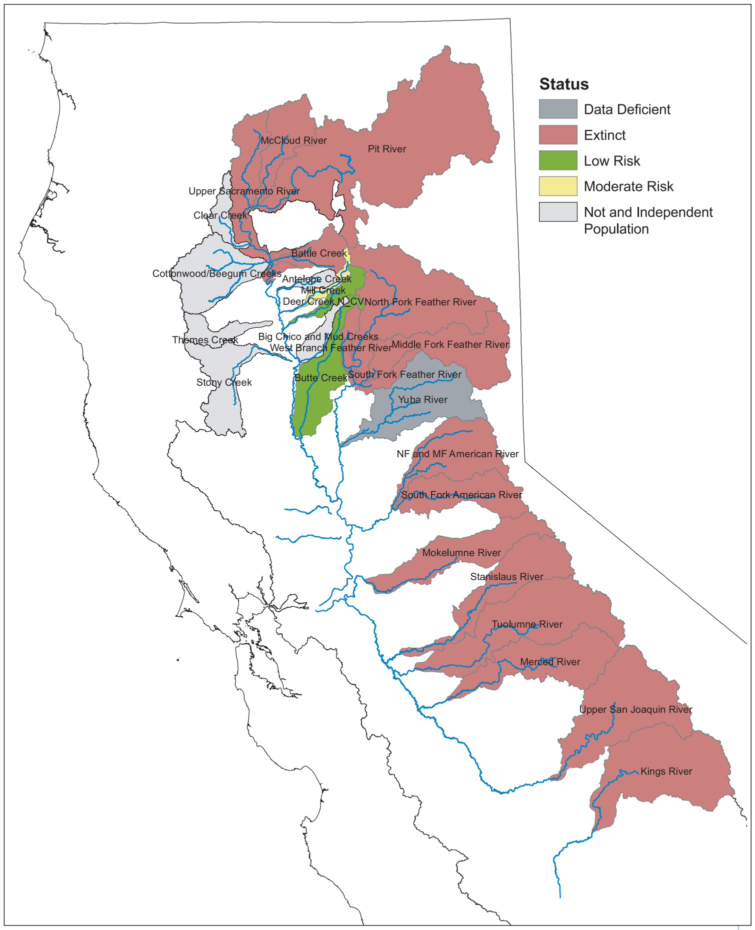

Figure 3. Status of historical Central Valley spring-run Chinook salmon populations.

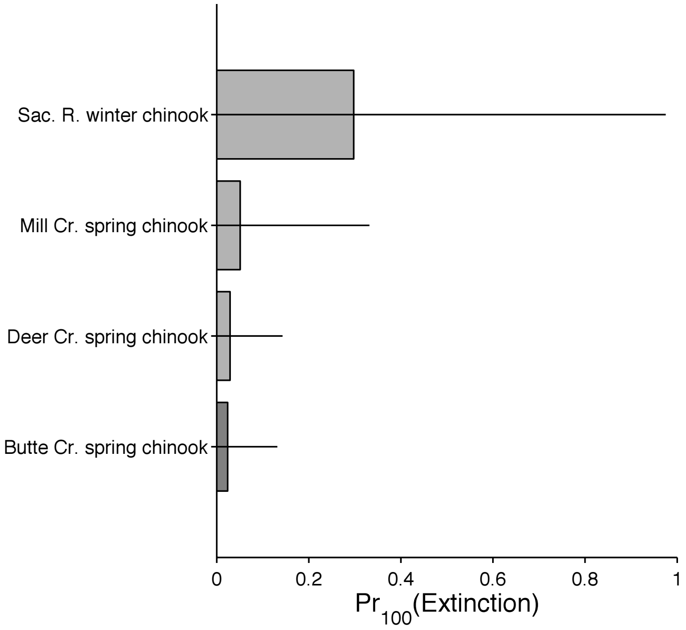

Figure 4. Probability of population extinction as estimated by the random-walk-with-drift model. Bars indicate the expected probability of extinction; lines indicate the 90% central interval for the estimate of the mean.

Table 3. Viability of populations. Steelhead populations that are not listed are data deficient. Chinook populations that are not listed are presumed extinct, due to impassable dams blocking access to spawning habitat. WRC = winter-run Chinook salmon; SRC = spring-run Chinook salmon. Catastrophes not included in this table because none were observed in the last decade. See Table 2 for definition of metrics. Spawning escapement data was obtained from California Department of Fish and Game's 2005 GrandTab database, available from the Native Anadromous Fish & Watershed Branch, 830 S Street, Sacramento, CA 95814. Steelhead data for American River from McCracken et al. (2005).

ESU	Population Name	PVA result	N	std	Pop. growth (% per year)	std	$\hat{S}$	std	h	Risk Category
Sac. R. WRC	mainstem	Moderate	26,870	2280	27.7	6.3	8140	691	Low	Low
C. V. SRC	Butte Cr	Low	22,630	7400	11.4	12.6	6860	2240	Very Low	Low
C. V. SRC	Mill Cr	Moderate	3360	1300	17.9	5.95	1020	394	Very Low	Low
C. V. SRC	Deer Cr	Low	6320	1920	7.63	7.58	1920	1010	Very Low	Low
C. V. SRC	Yuba									Data Deficient
C. V. SRC	Feather									Data Deficient
C. V. Steelhead	Feather								High	High
C. V. Steelhead	Battle Cr								High	High
C. V. Steelhead	American						< 500		High	High
C. V. Steelhead	Mokelumne								High	High

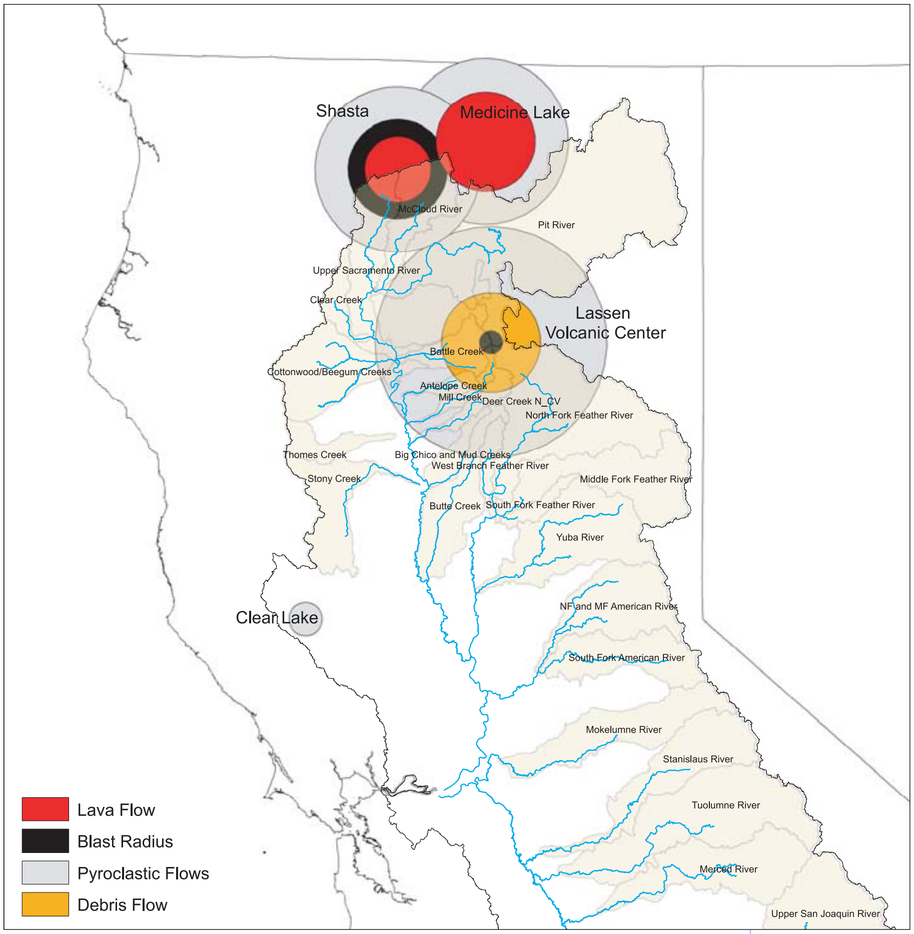

Figure 5. Volcanic hazards affecting the Central Valley recovery domain. Circles indicate the possible spatial extent of various kinds of volcanic effects that could devastate salmonid stream habitat, including lava flow, blast, pyroclastic flow, and debris. Data from Hobblitt et al. (1987)

tained them, Central Valley spring-run Chinook salmon fail the representation and redundancy rule for ESU viability. Historically, the Central Valley spring-run Chinook salmon ESU spanned four ecoregions: the region used by winter-run Chinook salmon plus the northern and southern Sierra Nevada and the northwestern California region. There are two or three viable populations in the northern Sierra Nevada (Mill, Deer and Butte creeks), although these populations were once probably relatively small compared to populations such as the Feather River. A few ephemeral or dependent populations are found in the Northwestern California region (e.g., Beegum and perhaps Clear creeks). Spring-run Chinook salmon have been entirely extirpated from both the basalt and porous lava region and the southern Sierra Nevada region.

The current distribution of viable populations makes the Central Valley spring-run Chinook salmon ESU vulnerable to catastrophic disturbance. All three extant independent populations are in basins whose headwaters lie within the debris and pyroclastic flow radii of Mt. Lassen (Figure 5), an active volcano that the USGS views as highly dangerous[2] (Hoblitt et al. 1987). The historical ESU was of such a large scale that neither Mt. Lassen, Mt. Shasta, or Medicine Lake could have extirpated even an entire diversity group, let alone the entire ESU. The current ESU structure is, not surprisingly, vulnerable to drought, which has a correlation scale of approximately 640 km (Figure 6), on order of the length of the historical ESU. Even wildfires, which are of much smaller scale than droughts or large volcanic eruptions, pose a significant threat to the ESU in its current configuration. A fire with a maximum diameter of 30 km, big enough to burn the headwaters of Mill, Deer and Butte creeks simultaneously, has roughly a 10% chance of occurring somewhere in the Central Valley each year (Figure 7).

We note that the historical Central Valley spring-run Chinook salmon ESU was widespread enough to be invulnerable to all of these catastrophes, except perhaps prolonged drought. The correlation scale of drought is roughly 640 km, and the Central Valley spring-run Chinook salmon ESU is about 500 km from the Pit River to the Kings River. It is possible that Central Valley spring-run Chinook salmon were less vulnerable to drought than might be expected because they once occupied diverse types of watersheds, including those with very high influence from springs. In fact, annual mean stream flow in Southern Cascade streams is less well correlated with annual mean precipitation than in other regions (see Appendix A in Lindley et al. (2006)).

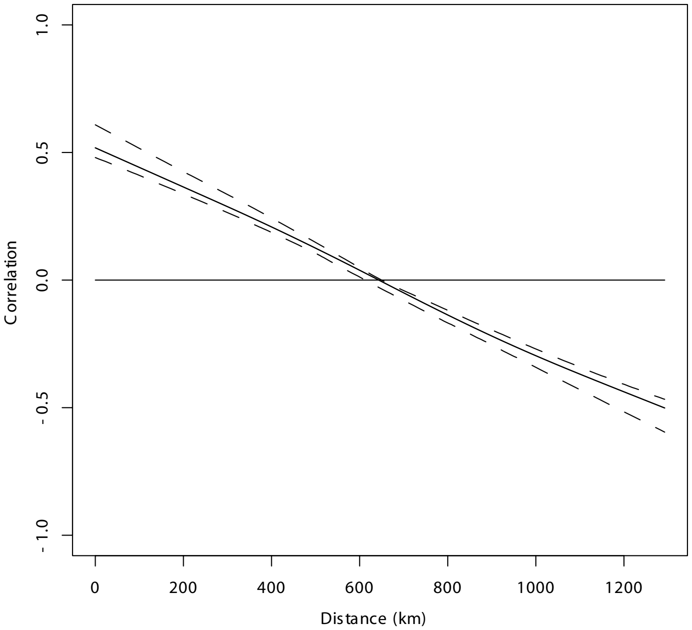

Figure 6. Spline correlogram fit to the gridded Palmer drought severity index data for California of Cook et al. (2004). Solid line indicates the estimated correlation function; dashed lines are the 95% confidence interval. Note that the correlation of drought indices declines with distance between locations, with no correlation evident at a distance 640 km.

Sacramento River Winter-run Chinook Salmon

All four historical populations of Sacramento River winter-run Chinook salmon are extinct in their historical spawning range (Table 3). The upper Sacramento, McCloud and Pit River populations had spawning and rearing habitat far upstream of impassable Keswick and Shasta dams, although these populations were apparently in poor condition even before the construction of Shasta dam in the 1940s (Moffett 1949). Winter-run Chinook salmon no longer inhabit Battle Creek as a self-sustaining population, probably because hydropower operations make conditions for eggs and fry unsuitable (National Marine Fisheries Service 1997). Also, until recently access to much of the basin was blocked by the Coleman National Fish Hatchery barrier weir.

The population of Sacramento River winter-run Chinook salmon that now spawns below Keswick dam is at moderate extinction risk according to the PVA (Figure 4), and at low risk according to the other criteria. Since roughly the mid-1990s, this population has been growing, although its previous precipitous decline to a few hundred spawners per year would have qualified it as high risk at that time, and prior to that, the 1976-77 drought would have qualified as a high-risk catastrophe. At present, the population easily satisfies the low-risk criteria for population size, population decline, and catastrophe, but hatchery influence is a looming concern. Since 2001, hatchery-origin winter-run Chinook salmon from Livingston Stone National Fish Hatchery (LSNFH, perhaps one of the best examples of a "best-management practices" Chinook salmon hatchery) have made up more than 5% of the natural spawning run, and in 2005 it exceeded >18% (K. Niemela, USFWS, Red Bluff CA, unpublished data). If the contribution of LSNFH to natural spawning exceeds 15% in 2006-07, the winter-run Chinook salmon population would be reclassified as moderate risk, and even the lower observed rates will become problematic if they continue for the next decade.

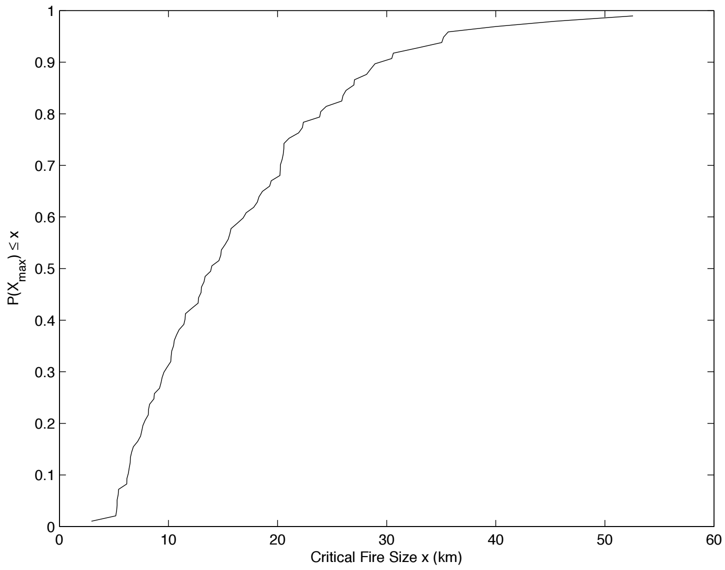

Figure 7. The probability that the largest fire in a year (Xmax) will be smaller than the critical size x. Based on observed fire sizes for the Central Valley recovery domain during the 1908–2003 period.

The Sacramento River winter-run Chinook salmon ESU does not currently satisfy the representation and redundancy rule because it has only one population, and that population spawns outside of the ecoregion where it evolved. For the Sacramento River winter-run Chinook salmon ESU to satisfy the representation and redundancy rule, at least two populations would need to be re-established in the basalt-and-porous-lava region. This may require passage past Shasta and Keswick dams.

Obviously, an ESU represented by a single population at moderate risk of extinction is at high risk of extinction over the long run. A single catastrophe could extirpate the entire Sacramento River winter-run Chinook salmon ESU, if its effects persisted for four or more years. The entire stretch of the Sacramento River used by winter-run Chinook salmon is within the zone of influence of Mt. Lassen. Some other possible catastrophes include a prolonged drought that depletes the cold water storage of Lake Shasta or some related failure to manage cold water storage, a spill of toxic materials with effects that persist for four years, or a disease outbreak.

Central Valley Steelhead

There are almost no data with which to assess the status of any of the 81 Central Valley steelhead populations described by Lindley et al. (2006). With few exceptions, therefore, Central Valley steelhead populations are classified as data deficient. The exceptions are restricted to streams with long-running hatchery programs: Battle Creek and the Feather, American and Mokelumne rivers. In all cases, hatchery-origin fish likely comprise the majority of the natural spawning run, placing the natural populations at high risk of extinction. In the American River, the natural spawning run appears to be comprised mostly of hatchery-origin spawners (McCracken et al. 2005). The broodstock used by Feather River Hatchery is derived from native fish from the Feather River, but hatchery-origin fish probably play a large role in maintaining the Feather River population (Kindopp et al. 2003). The Coleman National Fish Hatchery steelhead program uses many “best management practices,” but hatchery fish make up substantially more than 15% of the natural spawners in Battle Creek (Campton et al. 2004).

There is no evidence to suggest that the Central Valley steelhead ESU is at low risk of extinction, or that there are viable populations of steelhead anywhere in the ESU. Conversely, there is evidence to suggest that the Central Valley steelhead ESU is at moderate or high risk of extinction (McEwan 2001; Good et al. 2005). Clearly, most of the historical habitat once available to steelhead has been lost (Yoshiyama et al. 1996; McEwan 2001; Lindley et al. 2006). Furthermore, the observation that anadromous *O. mykiss* are becoming rare in areas where they were probably once abundant (California Department of Fish and Game, unpublished data; McEwan (2001)) indicates that an important component of life history diversity is being suppressed or lost. It should be noted, however, that habitat fragmentation, degradation, and loss are likely having a strong negative impact on many resident as well as anadromous *O. mykiss* populations (Hopelain 2003).

Discussion

Population Viability

In this section, we applied viability criteria, and PVA where possible, to assess the status of Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, and Central Valley steelhead populations identified by Lindley et al. (2004) and Lindley et al. (2006). For Central Valley steelhead, we were only able to assess the status of populations with a strong hatchery influence, even though the criteria-based approach that we employed has low data requirements compared to some PVA approaches. For extant, independent Chinook salmon populations, we were able to apply a PVA model as well as the simpler criteria (because relatively long time series of spawning run size are available for these populations). In two cases, the PVA gave the same result (Butte Creek and Deer Creek both classified as low risk), and in the other two cases, risk assignments differed by one category (winter-run Chinook salmon and Mill Creek spring-run Chinook salmon classified by the PVA as moderate risk, while the criteria indicate low risk). That populations can satisfy the criteria for low risk while just failing a PVA suggests that the criteria for low risk really are criteria for minimal viability. Recovery planners may want to aim somewhat higher for at least some populations as a precautionary measure.

There have been three population-level risk assessments for winter-run Chinook salmon, by Botsford and Brittnacher (1998), Lindley and Mohr (2003), and Good et al. (2005). The analysis of Botsford and Brittnacher (1998) was conducted at a time when it was much less clear that winter-run Chinook salmon were on an upward trend, and not surprisingly, Botsford and Brittnacher (1998) found that winter-run Chinook salmon were certain to go extinct if the trends seen up to the time of their analysis were to continue. Lindley and Mohr (2003) used a model that allowed for a change in population growth rate following initiation of conservation measures in 1989 and density-dependent reproduction. Allowing for the possibility that winter-run Chinook salmon population growth rate increased after 1989 led to a much more optimistic prediction for extinction risk of 24% in 100 years. The analysis in Good et al. (2005), like Lindley and Mohr (2003), allowed for a change in population growth in 1989, but included more recent data and ignored density dependence. Good et al. (2005) found that if the 1989-present growth rate holds into the future, the winter-run Chinook salmon population has essentially no risk of extinction. The varying conclusions of these studies illustrates the sensitivity of PVA results to both data and model assumptions, especially those about future conditions and the effect of density on population growth rate.

ESU Viability

Our assessment of the viability of Central Valley Chinook salmon ESUs is broadly consistent with other recent assessments. Good et al. (2005), based on the combined opinion of an expert panel, considered the Sacramento River winter-run Chinook salmon ESU to be in danger of extinction, and the Central Valley spring-run Chinook salmon ESU to be likely to become endangered in the foreseeable future. These findings were essentially unchanged from the earlier review of Myers et al. (1998). United States Fish and Wildlife Service (1994) suggested that Central Valley spring-run Chinook salmon could be considered “restored” when Mill and Deer creeks both have >500 spawners, and the average total number of spawners in Sacramento tributaries exceeds 8,000, with a minimum of 5,000 spawners, over a 15 year period that includes at least three critically dry years. Central Valley spring-run Chinook salmon have achieved these abundance levels since about 1998, but are not yet “restored” as defined by United States Fish and Wildlife Service (1994). The restoration goals of United States Fish and Wildlife Service (1994) are based on estimates of what could be attained in Sacramento River tributaries that are still accessible to spring-run Chinook salmon, and do not address issues of viability.

National Marine Fisheries Service (1997) proposed that for Sacramento River winter-run Chinook salmon to be recovered, there would need to be on average 10,000 females spawning naturally in the mainstem Sacramento River, and recommended creation of a second winter-run Chinook salmon population in Battle Creek. Should Sacramento River winter-run Chinook salmon achieve these draft goals, their status would be much improved, but they would still be excluded from much of the apparently unique areas in the upper Sacramento, McCloud, and Pit River tributaries that gave rise to their unique life-history strategy.

Good et al. (2005) found Central Valley steelhead to be in danger of extinction in the foreseeable future, in agreement with an earlier assessment (Busby et al. 1996). We were unable to assess the status of the Central Valley steelhead ESU with the more quantitative approach developed in this paper, because of data limitations. This should not be viewed as a contradictory finding—what little information is available for Central Valley steelhead is not positive (Busby et al. 1996; McEwan, 2001; Good et al. 2005).

Even if there were adequate data on the distribution and abundance of steelhead in the Central Valley, our approaches for assessing population and ESU viability might be problematical because the effect of resident *O. mykiss* on the viability of populations and ESUs is unknown. From one perspective, resident fish may reduce the extinction risk of the ESU through the production of anadromous individuals that can bolster or rescue weak steelhead populations. Such life history diversity also confers risk spreading, in that members of the ESU are spread among habitats that are subject to independent sources of disturbance. For instance, fish in the ocean are unaffected by flooding, while fish in rivers

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are immune to poor feeding conditions in the ocean. At the margins of a species' range, where conditions may be more frequently unfavorable, such life history diversity could be an adaptation to the unpredictable environment (Jonsson and Jonsson 1993.)

On the other hand, the apparent dominance of the resident form is a recent and unnatural phenomenon. It is likely that the apparent shift towards the resident life history strategy is partly a response to hypolimnetic releases from reservoirs, which alter trophic, temperature and flow conditions for some distance below the dam (McEwan, 2001). *O. mykiss* may take up residency in these altered areas due to their phenotypic plasticity, or the fitness of *O. mykiss* using these areas may exceed the fitness of anadromous fish, which would drive an evolutionary (i.e., genetic) change if life history strategy is heritable. Another component of the shift is likely the decline of steelhead due to loss of suitable steelhead habitat. Even if the shift in life history strategy is a plastic response, the fitness of steelhead may decline due to relaxed selection pressure. At longer time scales, this is likely to be a problem, because storage reservoirs have finite lifetimes, and when they are filled with sediments, the rivers downstream will be much less suitable for year-round residency.

Both the United States Fish and Wildlife Service (1994) goals for Central Valley spring-run Chinook salmon and the National Marine Fisheries Service (1997) goals for Sacramento River winter-run Chinook salmon are primarily focused on abundance and productivity, a traditional fisheries and natural resource perspective. In light of the mounting failures of that traditional perspective, ecologists are increasingly recognizing the importance of diversity in sustaining ecological processes (e.g., Daily 1999; Pauly et al. 2002; Elmqvist et al. 2003; Fischer et al. 2006). Recent thinking on salmonids (e.g., McElhany et al. 2000; Hilborn et al. 2003; Bottom et al. 2005) highlights the importance of habitat, life history, and genetic diversity as the foundation for productivity (and hence abundance). Our approach to assessing and specifying ESU viability broaden the focus from abundance and trends to include the numbers, diversity, and spatial distribution of populations across the landscape. Restoring and sustaining diverse populations of salmonids will require restoring and sustaining the habitats and ecological processes upon which they depend.

Summary

In this paper, we have developed a framework for evaluating the viability of salmonid populations and ESUs, based on simple criteria and rules that have modest data requirements. When applied to Chinook salmon ESUs, the framework makes clear that the risk facing these ESUs is not so much the low viability of extant populations, but rather that much of the diversity historically present in these ESUs has been lost. While the criteria and rules that comprise our framework are based in no small part on expert judgment and are subject to considerable uncertainty, our conclusions are not particularly sensitive to the exact values of the criteria.

The utility of our framework can be judged in several ways. It provides quantitative criteria that allow that status of salmonid ESUs to be assessed in an objective way, and it points out areas where things need to improve for ESUs to be removed from the endangered species list. The framework is, however, rather simplistic, and significant improvements, especially at the ESU level, could be made as our understanding of salmonid population biology improves. Perhaps the most significant shortcoming of our framework is the implicit assumption that future will be like the past. In the next section, we evaluate this critical assumption.

CLIMATE VARIABILITY AND CHANGE

Introduction

Viability assessments, including ours, typically attempt to answer the question of whether the population will persist into the future if it continues to experience conditions like it has in the recent past. Future conditions, however, are not likely to be like the recent past. In this section, we briefly review descriptions of natural climate variability, and regional-scale predictions of how climate might change over the next century in response to rising atmospheric greenhouse gas concentrations. Natural climate variation will make it difficult to properly assess whether ESUs are recovering in response to management actions. Anthropogenic climate change may preclude some otherwise attractive recovery strategies, depending on future greenhouse gas emissions and the response of regional climate.

Natural Climate Variability

Fisheries scientists have shown that ocean climate varies strongly at decadal scales (e.g., Beamish 1993; Beamish and Bouillon 1993; Graham, 1994; Miller et al. 1994; Hare and Francis 1995; Mantua et al. 1997; Mueter et al. 2002). In particular, the identification of the Pacific Decadal Oscillation (Mantua et al. 1997) seems to have led to the belief that decadal-scale variation may be cyclical, and thus predictable. As pointed out by Rudnick and Davis (2003) and Hsieh et al. (2005), apparent regime shifts need not be cyclical or predictable, but rather may be the expression of a stochastic process with red noise. If this interpretation is correct, then we should expect future ocean climate conditions to be different than those we have observed in the past few decades.

Terrestrial climate, like ocean climate, appears more variable the longer that it is observed. For example, Ingram et al. (1996) showed that freshwater inputs to San Francisco Bay varied with a period of 200 years, and several extreme and prolonged wet and dry periods occurred over the last 2,000 years. A 7,000-year river-flow reconstruction by Goman and Wells (2000) for the same area shows even longer-lasting periods of extreme conditions. Analysis of tree-ring data show that prolonged and intense droughts were more common during the period 750-1100 before present than in more recent centuries (Cook et al. 2004).

Natural climate variability poses several potential challenges for recovery planners. First, the population viability criteria that we have proposed may not offer sufficient protection in the case of a prolonged period of unfavorable climatic conditions. Second, a prolonged period of unusually favorable climatic conditions could cause populations to grow enough that they satisfy our biological viability criteria even though serious problems with habitat quality remain. In other words, the ESU may temporarily appear to be recovered, but its status would decline as soon as conditions become more typical. Conversely, the effects of substantial improvements to habitat quality could be masked by poor climatic conditions, possibly eroding society's enthusiasm for doing the hard work of salmon recovery. The key to overcoming these challenges is to consider climate variation in future assessments, hopefully with the benefit of improved understanding of the links between specific populations and regional climate conditions. Research is needed in this area.

Presumably, Central Valley salmonid ESUs are capable of surviving the kinds of climate extremes observed over the past few thousand years if they have functional habitats, because these lineages are on order of a thousand years old or older[3]. There is rising concern, however, that the future climate will be unlike that seen since perhaps the Pliocene, due to global warming in response to anthropogenic greenhouse gas emissions.

Climate Warming

The consensus of climate scientists is that the Earth's climate is warming, and that the warming is caused in part by the accumulation of greenhouse gases in the atmosphere (McCarthy et al. 2001; Oreskes, 2004). While there is a scientific consensus about global climate change, the effects of global warming at regional scales are generally less certain. Here, we briefly review available regional-scale forecasts relevant to the Central Valley domain, and then speculate on possible impacts on Central Valley salmonids.

Climate forecasts for the Central Valley

Making regional-scale climate forecasts involves choosing an "emissions pathway" and running one of a number of global climate models with an embedded regional-scale model that can capture features, such as mountain ranges, that can significantly modify the global pattern. As in any modeling exercise, there are a number of sources of uncertainty, but particularly important ones in this case are the assumption about future emissions and the choice of climate model. The uncertainties are addressed by examining a number of emissions pathways and by using several models.

The recent paper by Hayhoe et al. (2004) examines multiple emissions pathways using two global models to make regional forecasts for California. Their results are alarming. The more sensitive Hadley Center Climate Model (HadCM3) predicts that under the high emissions scenario (where CO_2 rises to 970 ppm by 2100, also known as the "business as usual" scenario), average summer temperature would rise 8.3°C and snowpack would be reduced by 89%. The HadCM3 also predicts that the climate will get drier, with possibly a 43% reduction of inflows to southern Sierra reservoirs. At the other extreme, the low-sensitivity Parallel Climate Model (PCM) predicts that average summer temperature would rise slightly more than 2°C if emissions were curtailed such that CO_2 rises to 550 ppm by 2100. The PCM predicts that total precipitation could rise slightly, but snowpack would still be reduced by 28% in this scenario.

Dettinger (2005) analyzed six different climate models under three emissions scenarios to produce distributions of future temperature and precipitation. This analysis showed that uncertainty due to the models was about equal to that due to emission scenario. There was general agreement among the models that temperatures will rise significantly (between 2 and 7 °C by 2100), while total precipitation is expected to decline slightly. Temperature and precipitation predictions were negatively correlated (i.e., warming is associated with drying).

Dettinger et al. (2004) and VanRheenen et al. (2004) used the PCM to investigate in detail how climate change may influence the hydrology of Central Valley rivers. These analyses find that average precipitation will decline over time, while the variation in precipitation is expected to increase substantially. Extreme discharge events are predicted to become more common, as are critically dry water years. Peak monthly mean flows will generally occur earlier in the season due to a decline in the proportion of precipitation falling as snow, and earlier melting of the (reduced) snowpack. By the end of the century, it may be difficult to achieve current operations targets for fish conservation even with substantial decreases in other demands for water. Knowles and Cayan (2002) show that in summer, saline water will intrude farther into the Bay and Delta than it does now. Within some limits, water storage reservoirs might be operated to mitigate changes to the hydrograph caused by climate change, although water project operations are likely to become even more contentious as temperature rises, snowmelt falls, and population rises.

Possible Effects on Salmon and Steelhead

Regional-scale climate models for California are in broad agreement that temperatures in the future will warm significantly, total precipitation may decline, and snowfall will decline significantly. What are the likely consequences for salmon and steelhead in the Central Valley? Melack et al. (1997) states that predicting the response of salmon to climate warming "requires examination of the responses of all life history stages to the cumulative effects of likely environmental changes in the lakes, rivers and oceans inhabited by the fish." Such an endeavor is beyond the scope of this paper, and the question of climate change effects on Pacific salmonids has received surprisingly little attention to date. In this subsection, we briefly review the literature and conduct a simple assessment of the effects of warmer summer temperature on the availability of freshwater habitat.

Focusing on freshwater life history phases, Neitzel (1991) reviewed the likely responses of salmonids in the Columbia River basin to climate warming, which he anticipated would affect salmonids through alterations to the timing of discharge and changes in sedimentation rate, temperature, and flow. Effects are predicted to depend on the river and on the species or run. As in the case of many salmonid populations in the Columbia River basin, spring-run Chinook salmon are likely to be negatively impacted by the shift in peak discharge (needed for smolt migration), and juvenile steelhead are likely to be negatively impacted by reduced summer flows. All Central Valley salmonids are likely to be negatively affected by warmer temperatures, especially those that are in freshwater during the summer.

Recent summer mortality of adult spring-run Chinook salmon in Butte Creek offers a case in point. Mean July water temperature in the middle of the spawning reach of Butte Creek is often around 18-20°C in July. In 2002 and 2003, mean water temperature in Butte Creek exceeded 21°C for 10 or more days in July, and 20-30% of adults in 2002 and 65% of adults in 2003 died (reviewed by Williams 2006), primarily from columnaris.

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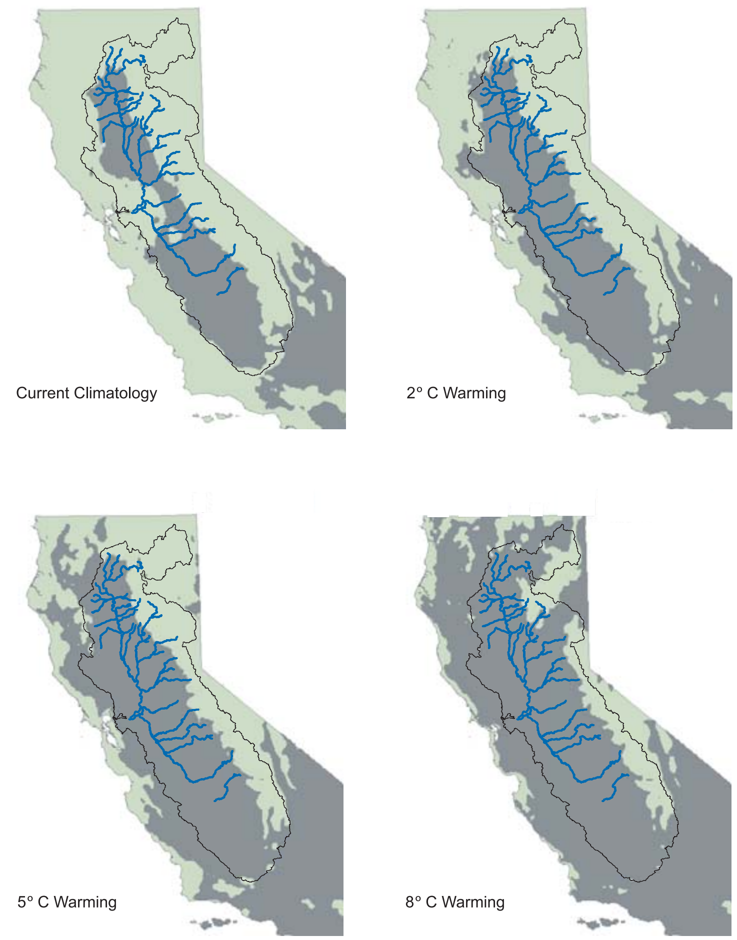

Figure 8. Effects of climate warming on availability of over-summer habitat. Mean August air temperatures exceeding 25°C are shown in gray; blue lines indicate the historical distribution of spring-run Chinook salmon.

Less obvious effects, such as reduced viability of gametes, may also have occurred. These data suggest that existing conditions in Butte Creek are close to the thermal tolerance limit for Chinook salmon.

Myrick and Cech (2004) state that juvenile Chinook salmon are unlikely to be capable of rearing for extended periods in temperatures exceeding 24°C, and juvenile steelhead may be able to withstand slightly higher temperatures. Maximum in-stream temperatures of many streams frequently exceed 24°C at lower elevations, which may determine the lower distributional limit of salmonids (Yoshiyama et al. 1996; Lindley et al. 2006). Distributions at higher elevations were once largely restricted by natural barriers to movement, but are now limited by dams in many streams (Lindley et al. 2006). If these artificial migration barriers are not removed, climate warming is expected to reduce the amount of habitat available to Central Valley salmonids that reside in freshwater during summer months, as the lower distributional limit rises, and the upper limit remains constrained by physical barriers.

A rough view of the consequences for Central Valley spring-run Chinook salmon and Central Valley steelhead can be obtained by adding the regional warming forecasts of Dettinger (2005) to PRISM temperature fields, and overlaying this with the distributional data presented in Lindley et al. (2004). Figure 8 shows how the area with high summer temperatures (mean August air temperature > 25°C) may expand under three warming scenarios. Under current conditions, streams that had major independent populations of spring-run Chinook salmon all have significant amounts of habitat above the 25°C isotherm, although dependent populations generally had little or no habitat above the 25°C isotherm (Figure 8, upper left). By 2100, mean summer air temperatures are expected to rise by at least 2°C. Under this scenario, the amount of habitat above the 25°C isotherm is reduced, but in general, most streams that historically contained habitat above this isotherm would not lose all such habitat. The exceptions are the Tuolumne, Merced, and upper San Joaquin rivers, and Butte Creek, where the 25°C isotherm might just rise to the upper limit of the historical distribution of spring-run Chinook salmon (Figure 8, upper right). Under the expected warming of around 5°C, substantial habitat would be lost, with significant amounts of habitat remaining primarily in the Feather and Yuba rivers, and remnants of habitat in the upper Sacramento, McCloud, and Pit rivers, Battle and Mill creeks, and the Stanislaus River (Figure 8, lower left). Under the less likely but still possible scenario of an 8°C warming, spring-run Chinook salmon habitat would be found only in the upper-most reaches of the north fork Feather River, Battle Creek, and Mill Creek. This simple analysis suggests that Central

Valley salmonids are vulnerable to warming, but more research is needed to evaluate the details of how warming would influence individual populations and subbasins.

The hydrologic effects of climate change are harder to evaluate. Increased frequency of scouring floods might be expected to reduce the productivity of populations, as egg scour becomes a more common occurrence. The timing of various life history events is presumably an adaption to past climate conditions (temperature and discharge timing), and populations may not be well-adapted to future hydrographs. One concern is that warmer summers will delay spawning, and earlier and more frequent floods will impact eggs and alevins before they emerge from the gravel, a phenomenon thought to limit the productivity of some Chinook salmon stocks (Beer and Anderson 2001), and one that might be impossible for salmonids to adapt to, given fundamental constraints on development.

The flip side of frequent flooding is the possibility of more frequent and severe droughts. Long-term climate records show that warm periods have been associated with droughts in California (Davis 1999; Cook et al. 2004), and the regional climate change models reviewed above hint at the possibility of increasing frequency of droughts. In the Central Valley, low flows during juvenile rearing and outmigration are associated with poor survival (Kjelson and Brandes 1989; Baker and Morhardt 2001; Newman and Rice 2002) and poor returns in subsequent years (Speed 1993).

Climate change may also impact Central Valley salmonids through community effects. For example, warming may increase the activity and metabolic demand of predators, reducing the survival of juvenile salmonids (Vigg and Burley, 1991). Peterson and Kitchell (2001) showed that on the Columbia River, pikeminnow predation on juvenile salmon during the warmest year was 96% higher than during the coldest.

To summarize, climate change may pose new threats to Central Valley salmonids by reducing the quantity and quality of freshwater habitat. Under the worst-case scenario, spring-run Chinook salmon may be driven extinct by warming in this century, while the best-case scenario may allow them to persist in some streams. Uncertainties abound at all levels, however. First, the composition of Earth's atmosphere is partly under human control, and we cannot predict how it might be managed in the future. Even if the emissions pathway was known, different climate models offer significantly different climate forecasts (although we note that the differences are quantitative, and the models are in qualitative agreement). Finally, we have only the crudest understanding of how salmonid habitats will change and how salmonid populations will respond to those changes, given a certain climate scenario. This is another area where research is needed.

SUMMARY AND RECOMMENDATIONS

For Central Valley steelhead, there are insufficient data to assess the risk of any but a few populations, and therefore, we cannot assess the viability of this ESU using the quantitative approach described in this paper. However, qualitative information does suggest that the Central Valley steelhead ESU is at a moderate or high risk of extinction. Most of the historical habitat once available to steelhead is largely inaccessible and the observation that the anadromous forms of *O. mykiss* are becoming less abundant or rare in areas where they were probably once abundant indicates that an important component of life history diversity is being suppressed or lost. Even in populations that exhibit life-history polymorphism, steelhead are important to viability and long-term persistence and are critical to the conservation of the population (Travis et al. 2004; Bilby et al. 2005).

For the Chinook salmon ESUs, we found that extant populations are now at low or moderate risk of extinction, but the extensive extirpation of historical populations has placed these ESUs in jeopardy of extinction. The proximate problem afflicting these ESUs and the Central Valley steelhead ESU is that their historical spawning and rearing areas are largely inaccessible, due to the direct or indirect effects of dams.

Recovering even a few populations may therefore be a challenging and slow process, although we stress that there appear to be some opportunities that, if successful, would greatly increase the viability of all three ESUs. Some possibilities that are being considered include restoring flows and habitat in the San Joaquin River below Friant Dam and in Battle Creek, and restoring access to the Yuba River above Englebright Dam. All of these actions, in our view, have the potential to significantly improve the status of affected ESUs, but achieving recovery may require access to additional historically-utilized spawning areas that are currently blocked by dams.

As we pursue the more ambitious and long-term habitat restoration solutions, there are some easier but very important things that should be done as soon as possible. These include the following, in no particular order:

1. Secure all extant populations. All three ESUs are far short of being viable, and extant populations, even if not presently viable, may be needed for recovery. An important lesson to draw from Hilborn et al. (2003) is that tomorrow's most important populations might come from populations that are relatively unimpressive today. We recommend that every extant population be viewed as necessary for the recovery of the ESU. Wherever possible, the status of extant populations should be improved.

2. Begin collecting distribution and abundance data for *O. mykiss* in habitats accessible to anadromous fish. This is fundamental to designing effective recovery actions and eventual delisting. Of equal importance is assessing the relationship of resident and anadromous forms of *O. mykiss*. Any quantitative assessment of population or ESU viability could be inadequate unless we know the role resident fish play in population maintenance and persistence. It has been well-documented that Chinook salmon has been the major focus of anadromous fish monitoring, assessment, and research in the Central Valley (McEwan 2001) and there needs to be a more equitable partitioning of research funds and effort.

3. Minimize straying from hatcheries to natural spawning areas. Even low levels of straying from hatchery populations to wild ones works against the goal of maximizing diversity within ESUs and populations. Current mark and recovery regimes do not generally allow reliable estimation of contributions of hatchery fish to natural spawning, so we recommend that all hatchery fish be marked in some way. A number of actions could reduce straying from hatcheries to natural areas, including replacing off-site releases with volitional releases from the hatchery, allowing all fish that attempt to return to the hatchery to do so, and reducing the amount of fish released (see CDFG and NMFS 2001, for a review of hatchery issues).

4. Begin conducting critical research on fish passage, reintroductions, and climate change[4]. To recover Central Valley salmon and steelhead ESUs, some populations will need to be established in areas now blocked by dams or insufficient flows. Assuming that most of these dams will remain in place for the foreseeable future, it will be necessary to move fish around the dams. We are unaware of such projects involving dams of the scale typical in the Central Valley. Assuming that a feasible solution to that problem is found, it is necessary to reintroduce fish to the newly available habitat. Should this be allowed to occur naturally, or should a more active approach be taken? If so, which fish should be used as the donors? Finally, in a warmer future, some basins might cease to be suitable for salmon or steelhead. It would be a costly mistake to invest heavily in restoring habitat that will become too warm to support salmonids.

5. Accept the notion that listed salmonid ESUs are likely to be conservation-reliant (Scott et al. 2005). It seems highly unlikely that enough habitat can be restored in the foreseeable future such that Central Valley salmonid ESUs could be expected to persist without continued conservation management. Rather, it may be possible to restore enough habitat such that ESUs can persist with appropriate management, which should focus on maintaining ecological processes at the landscape level. NOAA regulators should begin considering how to implement conservation agreements among agencies and stakeholders that will be acceptable to all parties and ensure the persistence of populations and ESUs.

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ENDNOTES

[1] We also examined the potential of toxic spills, earthquakes, and landslides to extirpate ESUs, but concluded that these risk sources were generally not a threat to ESUs with more than one population.

[2] We note that any particular debris flow would cover only a portion of the circle depicted in Figure 5, and that a single flow might not necessarily devastate all three spring-run Chinook salmon streams.

[3] Using data in Lindley et al. (2004) and relationships in Waples et al. (2004), the Fst observed between Sacramento River winter-run Chinook salmon and fall-run Chinook salmon (based on neutral markers) could have arisen in around 780 years if these ESUs were completely isolated from one another.

[4] The CVTRT is preparing a comprehensive list of research recommendations.

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California Department of Fish and Game San Joaquin River Fall-run Chinook Salmon Population Model Peer Review: Response to Peer Review Comments

Initial Response

San Joaquin River Fall-run Chinook Salmon Population Model
August 22, 2008

Mr. Dean Marston (CDFG)
Mr. Tim Heyne (CDFG)
Dr. Alan Hubbard (UC Berkeley)
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Executive Summary

In late 2005, the California CDFG of Fish and Game (CDFG) submitted to the State Water Resources Control Board (SWRCB) a report documenting a quantitative analysis (based on what we now refer to as Version 1.0, V1.0, or the original model). The purpose of model 1.0 was to develop a preliminary planning and evaluation tool to assess of the possible effects upon juvenile and adult fall run Chinook salmon production stemming from a decade of water flow management in the San Joaquin River (SJR) system, based on the objectives set in 1995 in the Vernalis Adaptive Management Program (VAMP). Five formal reviews and five supplemental reviews of Model 1.0 (and documentation) were received in 2006. This document provides an initial response to these reviews; but, more importantly, it also provides a revised analysis in response to many valid and constructive points raised by reviewers, using a modified version of the original model (Version 1.5, V1.5). Also provided is a detailed description of a new model that will be used to carry out analyses needed to address all salient criticisms raised by reviewers, and is a tool for the design of management regimes implemented at the resolution of weekly flow rates (Version 2.0, V2.0). This is a finer temporal scale than suggested by reviewers but in our view is much needed for the VAMP.

At this time, the central finding of CDFG's 2005 report still stands: the spring outflow in the SJR system is the primary factor controlling the production of juvenile thence adult fall-run Chinook salmon. It is clear that an analysis that can account for this effect at the resolution of weekly flow rates (as envisioned in model V2.0) is a key tool for helping evaluate the adequacy of meeting VAMP objectives (e.g., developing long term water quality objectives to adequately protect fall-run Chinook salmon in the SJR basin) and other management issues of interest to management of SJR fall-run chinook salmon. It is also clear that a better accounting, as in V2.0, of the variable annual impacts of the marine fishery may be needed to confirm accuracy of constructed escapements in the model. Further, the influence of fall flows on the spawning success of escapement populations and of late spring flows, exports, and the delta environment (water quality and predators) on smolt survival must undergo robust statistical evaluation for a more reliable implementation of the VAMP. These additional refinements are underway as elements of CDFG's Model V.2.0 now under development. In the interim, development of Model V1.5 has been implemented by replacing linear regression analysis with more appropriate generalized linear methods (e.g., logistic and log-transformed regressions). This change in V.1.5 addresses criticisms relating to the need to account for nonlinearities in the data and the fact that probabilities can only take on values between zero and one. Therefore, model Versions 1.5 and eventually 2.0 represent two different modeling tools to help assess and partially answer the same question: how much spring flow, over what duration, and over what frequency is sufficient to adequately protect fall-run Chinook salmon in the SJR basin. Model Version 1.5 continues the empirical emphasis originating from model Version 1.0, whereby

the data, irrespective of biological theory, drives outcomes. Model Version 2.0 will allow biological theory to drive outcomes. It remains to be seen whether including more parameters in V.2.0, which will introduce more potential variability, will improve the predictive power of the model.

The analysis undertaken to develop the 2005 CDFG model and documentation, the subjection of the 2005 CDFG model and report to open critical review, the response to peer review as summarized herein, and the ensuing analysis and model building in response to the review (V.1.5 & 2.0) should be seen as part of on ongoing adaptive planning tool (e.g. model) development process that is needed to help identify water management practices needed to adequately protect fall run Chinook salmon in the SJR basin. This document summarizes the current status of our understanding, and articulates our efforts going forward to refining that understanding.

Introduction

The CDFG is the only Trustee Agency responsible for management of fall-run Chinook salmon in the San Joaquin River basin pursuant to Section 1802 of the California Fish and Game Code. As a result of this statutory authority and responsibility, the CDFG is charged with actively participating all planning and use of resources that have the ability to affect salmon.

In early 2005 it became necessary for the CDFG to provide comments to the State Water Resources Control Board (SWRCB) regarding the adequacy of the SWRCB's Spring SJR at Vernalis flow objectives as identified in the SWRCB's Periodic Review of the 1995 San Francisco Bay/Sacramento-San Joaquin Delta Estuary Water Quality Control Plan (1995 WQCP). In responding to the SWRCB's request for comments on the 1995 WQCP, the CDFG evaluated the 1995 WQCP by asking four key questions: 1) What is the current status of the SJR fall-run Chinook salmon population?; 2) What level of protection is being afforded salmon smolts out-migrating from the SJR into the South Delta?; 3) What is the status of the Vernalis Adaptive Management Plan (VAMP) experiment?; and 4) What influence does spring flow have on fall-run Chinook salmon production in the SJR?

In March 2005, the CDFG provided comments to the SWRCB that in summary stated that the 1995 WQCP SJR spring Vernalis flow objectives, as identified in the Vernalis Adaptive Management Program (VAMP), were not adequate for the long-term protection of fall-run Chinook salmon beneficial uses in the SJR because: 1) the SJR salmon population trend continues to decline (e.g., below the 1967-1991 historic average upon which the SWRCB's narrative Doubling Goal was established, Figure 1); 2) salmon smolts are not afforded the level of protection as envisioned by the 1995 WQCP (e.g., smolt window of protection is only about 50% instead of the 66-75% predicted window of protection, Figure 2); 3) the VAMP experiment is not working because it has not been implemented as designed (e.g., no 7,000 cfs test flows have occurred and flows have been allowed to flow through the Head of Old River Barrier); and 4) spring outflow remained the primary factor controlling fall-run Chinook salmon populations in the SJR.

The mechanism for the reason for the 1995 WQCP Vernalis flow objective inadequacy is in large part due to: 1) the lack of substantive VAMP spring flow improvement (by water year type) as compared to that which historically occurred (pre-year 2000) (Figure 3); 2) the narrowness of the pulse flow protection window (e.g. 31 days is too short a duration); 3) the infrequent occurrence of elevated flow objective levels (e.g., no 7,000 cfs flow levels have occurred in the first 9 years of VAMP, Table 1); and 4) the frequent occurrence of reduced flow objective levels (e.g., in the first 9 years of VAMP the 3200 and 4450 flow levels have occurred in 6 out of the 7 official VAMP study years, Table 1). As a result of these concerns, in 2005 the CDFG asked the SWRCB to conduct a peer review process of VAMP. During workshop proceedings the SWRCB Chair asked the CDFG to submit to the SWRCB its Vernalis flow recommendations.

The CDFG then used information and analyses amenable at that juncture (2005) to evaluate various parameters that had been, and continue to be, identified as influencing the long term abundance of fall-run Chinook salmon into the SJR. These parameters included ocean harvest, Delta exports and smolt survival, abundance of spawners, and spring flow magnitude, duration and frequency (Marston 2005). The CDFG found at that time that the non-flow parameters had little, or no, relationship to the long term population abundance of fall-run Chinook salmon in the SJR basin. Instead, spring flow (e.g., magnitude, duration, and frequency) appeared to have a significant influence upon SJR fall-run Chinook salmon abundance returning to the SJR basin.

The CDFG used the significant relationship between Vernalis spring flow volume, duration, frequency, and SJR fall-run Chinook salmon abundance to construct a simple regression-based SJR fall-run Chinook salmon population abundance prediction spreadsheet model (model V1.0). To quickly address the SWRCB Chair’s question, the CDFG then used this model to determine the Vernalis spring flow objectives that could potentially: 1) accomplish the 1995 WQCP Narrative Doubling Goal for fall-run Chinook salmon in the SJR; 2) improve the escaping salmon replacement ratio; and 3) accomplish objectives 1) and 2) (preferenced by restoring an increasing population trend) at the lowest water demand.

In Late 2005 the CDFG submitted its draft model and model documentation to the SWRCB. In 2006 the CDFG received three types of reviews of its model: a) formal reviews; b) informal reviews; and c) unsolicited reviews. Formal peer reviews consisted of comments from five reviewers and were received from a Cal-Fed (i.e., public) funded, single, blind, independent peer review. It is noted that Cal-Fed (actually UC Davis) independently selected the reviewers and the CDFG identified the review questions.

Informal reviews were received from Ms. Pat Brandes (USFWS), Dr. Ken Newman (USFWS), and Dr. Henrietta Jager (ORNL).

Unsolicited peer reviews were received from the San Joaquin River Group Authority and from Mr. John Bartholow (USGS-Retired).

In June 2007 the CDFG, in partial recognition of the various comments received and in recognition that it wanted to make model refinements, including those of pertinence from independent peer comments received, executed a grant agreement with the California State University at Fresno Foundation (CSUF) to help refine its SJR salmon population model. The model refinement team assembled under the auspices of the CSUF-CDFG grant includes: Dr. Alan Hubbard (UC Berkeley), Dr. Wayne Getz (UC Berkeley), Dr. Lara Rachowicz, Dr. Matthew Daugherty (UC Berkeley), Mr. Avry Dotan, Mr. Ivan Mlaker, and Mr. Richard Starfield. These individuals, along with Mr. Dean Marston (CDFG) and Mr. Tim Heyne (CDFG) comprise the Model Refinement Team. Other non-grant individuals who have provided information and/or significant assistance include Dr. Carl Mesick (USFWS), Dr. Ken Newman (USWFS), Pat Brandes, Dr. Bruce McFarlane (NOAA), Dr. Brian Wells (NOAA), Dr. Henrietta Jager (Oak Ridge National Laboratory), Mr. John Bartholow (USGS-Retired), Dr. Dave Hankin (Humboldt State University), Ms. Sheila Greene (DWR), Ms. Erin Chappell (DWR), Mr. Allen Grover (CDFG) and Mr. Marty Gingras (CDFG). It is noted that mention of one's name <u>does not</u> imply they endorse either the model or its use. Further, it indicates that the Model Refinement Team has contacted a wide variety of individuals with expertise in the three ecological elements included in its SJR Salmon Model: Inland (e.g., factors influencing juvenile production, abundance, and out-migration survival), Delta (e.g., factors influencing juvenile/adult migration and survival), and Ocean (e.g., factors influencing adult salmon abundance such as harvest and ocean conditions).

The Model Refinement Team considered the comments from all ten of the peer reviews, including those from the formal, informal, and unsolicited reviews. It is noted that the San Joaquin River Group Authority (SJRGA) had the opportunity over several months to prepare their review whereas Cal-Fed reviewers had only a narrow window within which to complete their review process. Thus, we were especially careful to consider all comments from the SJRGA. It is also noted that the independently conducted, single, blind peer reviews provided the CDFG with both positive and negative (i.e., critical) comments. Readers should recognize that only critical comments are provided and addressed here. A list of positive/affirmative comments from the Cal-Fed peer review is provided in Appendix 2.

Responses to peer review criticisms are segregated in the following order: 1) General; 2) Data Analysis; 3) Model Structure; 4) Model Validation; 5) Model Results; and 6) Presentation. The "Comment Number" is the number used to reference the comment; there are 51 comments in total.

There are three model versions referred to in this document: Model Version 1.0 (V.1.0) (original model); Model Version 1.5 (V.1.5) (present model); and Model Version 2.0 (V.2.0) (future model). Model Version 1.5 and Version 2.0 (future) are two separate models that the Model Refinement Team created to address the peer review comments. They are described in Appendices 2 and 3, respectively. Model Version 1.5 (2008…Appendix 2) is a revised version of Model Version 1.0 (2005) with additional statistical methods utilized, whereas Version 2.0 (Appendix 3) will be an original mechanistic, population model that will include more biological theory than Versions 1.0 or 1.5.

Peer Reviews are enumerated as follows. These ten peer review documents are readily available upon request:

A. Formal Solicited Reviews
    (1) CDFG SJR Model CALFED Review #1.pdf
    (2) CDFG SJR Model CALFED Review #2.pdf
    (3) CDFG SJR Model CALFED Review #3.pdf
    (4) CDFG SJR Model CALFED Review #4.pdf
    (5) CDFG SJR Model CALFED Review #5.pdf
B. Informal Solicited Reviews
    (6) Henrietta Jager Review.pdf
    (8) Pat Brandes Review.pdf
    (9) KenNewmanSJRModelReview.pdf
C. Unsolicited Reviews
    (7) John Bartholow Model Notes.pdf
    (10) SanJoaquinRiverGroupAuthorityReview.pdf

Comments and Responses

Below, we provide the 51 comments drawn from the ten peer reviews listed above and provide detailed comments and responses to each of them. Note that we frequently quote directly from the SJRGA review (text from this report in italics).

Comment Category 1: General Comments

Comment #1: Model is too simplistic. A more rigorous modeling approach (e.g. life-cycle model) is recommended.

Response: The original model (Version 1.0) was simplistic because it what purposely designed to be an empirically based model given the relatively short response period within the SWRCB's Periodic Review. The empirical data available to date indicates that use of additional empirically defined parameters other than spring flow does explain a substantial amount of variability inherent in the long-term SJR fall-run Chinook salmon population model trend. Model Version 1.0 is a type of life-cycle model which tracks salmon abundance in three ecosystems: inland, delta, and ocean. Admittedly, the inland and ocean model components in Version 1.0 are "black box" in nature due to the apparent lack of empirically defined inland or ocean parameters that could improve the model's predictive power. Model Version 1.5 primarily addresses statistical criticisms and continues to allow the empirically defined data relationships to drive model outcomes. Model Version 2.0 will introduce biological theory and will ultimately provide the option to allow theory to over-ride empirical relationships in determining model outcomes. Model Version 2.0 will also include more parameters, the details of which are in Appendix 3.

Comment #2: Time Series: Analysis of inter-annual correlation (autocorrelation) of flow is needed. Sensitivity analysis of effects of flow sequences will be useful. Inter-annual variability may be under represented. Testing for stationarity of data (hydrological and biological) is needed.

Response: Once the statistical models that comprise version 1.5 are decided upon, we will account for the possibility of autocorrelation of the residuals of these models in calculating the inference for the regression coefficient estimates. However, given the relatively small sample size available for determining the autocorrelation structure, the resulting statistical inference at this stage cannot be considered robust, as the inference will depend on an explicit model of the correlation structure.

Comment #3: Model relies too heavily on statistical correlations. Complementary model relying more on biological consideration would be useful. Model must be built differently to avoid inter-dependence between variables.

Response: The comment, "Model must be built differently to avoid inter-dependence between variables" is not specific enough to address. However, the first point, that the model V1.0 is too empirical, is a valid consideration. Our solution is to take too approaches on the spectrum of purely empirical to purely biological, which will be addressed by V1.5 (more empirically motivated) and V2.0 (more biologically motivated). We think it is important to have both approaches, as one relies more directly on the data alone (V1.5) whereas the other uses more information outside the data (information about the biology/life cycle of fall-run in this system). The first approach has the advantage that it does not depend as heavily on assumptions of the underlying models and can provide inferences that are more directly tied to the data available. The limitations of V1.5 is that some questions of how changes in environmental factors are related to changes in the numbers of salmon over time can not be addressed, mainly because the resolution of V1.5 needs to be commensurate with the current resolution of the data (e.g., at this point, the model V.1.5 is not a natural way to address different scenarios of flow that result in the same mean flow over the breeding season). V2.0 will have the advantage of being able to compare the relative magnitude of effects of different environmental variables (e.g., oceanic conditions versus changes in the flow patterns) and measure at resolutions (e.g. time-steps etc) convenient for management decisions on the ultimate abundance of salmon. The downside, of course, is that interpreting these sorts of models is much more dependent on assumptions regarding the models used for different components. In addition, they will typically involve many more parameters, which given the limited data available, means model V. 2.0 predictions will be much more variable than the smaller empirical model.

This brings up the major statistical issue all models face regarding the choice of models to use to evaluate management decisions, and is the statistical version of “no free lunch”. This is colloquially known as the variance-bias trade-off. The more detail a model has (V2.0), the more variable (less precise) its predictions will be; and the less detail the more biased (V1.5). Thus, we believe it is important to adopt both approaches. In the end, if both versions suggest common themes, that becomes even stronger evidence for the factors that influence the health of the population.

Comment: *"While flow conditions undoubtedly contributed to this variation, the first step in the modeling process should be to establish a reasonable relationship between parental spawners and juvenile production. Clearly, the model value of 15 smolts per spawner is not reasonable."* Page 7 from SJRGA report.

Response: Given the new form of the model, there is no longer a simple proportional relationship (the model is log-log linear in escapement). Now, it implies a 1.5 increase in the mean number of smolts at Mossdale for a 10-fold increase in escapement. Empirically (though admittedly dependent on the structure of the model), the association with the size of escapement and number of smolts appears weaker than the earlier association with flow.

Comment: “*The second problem is that all of the benefits of flow accrue during the migration period from March 15 through June 15. Thus, there are at least three implicit hypotheses underlying the smolt-production relationship:*
(1) several million pre-smolts are produced each year regardless of spawner abundance;
(2) environmental conditions (including flow) prior to migration do not appreciably affect the survival or production of pre-smolts; and thus, (3) spring flow in the San Joaquin River (and relevant tributaries) is the single key determinant of the survival rate, and hence abundance, of smolts that migrate to Mossdale.

To our knowledge, there is no solid empirical evidence to support any of these hypotheses. A larger role must certainly be placed on spawner abundance; otherwise, adult abundance goals for future escapement would seem largely irrelevant. Moreover, because the model relates Mossdale smolt production to the average daily flow from March 15 through June 15, the flow pattern over this spring period is also of little consequence in the model. For example, the same predicted smolt production can result from either a scenario where steady, moderate flows occur over the whole period, or a scenario where generally low flows occur through May followed by a strong peak in early June. Given that relatively few smolts pass Mossdale during June, the first scenario would be expected to provide much more suitable conditions for survival." Page 7 from SJRGA report.

<u>Response</u>: In short, this argues for the influence of earlier flows and a stronger association of the association of spawner abundance and production of smolts. Version 2.0 with weekly time increments will be able to examine differences in the influence of flow during different parts of the season. However, it is spurious to say that there is "no solid empirical evidence" to support any of these hypotheses. For instance, depending on how the number of spawners is entered, the simple empirical associations suggest a *relatively* weak association of smolt production and numbers of spawners.

Comment #4: Encompass a broader range of potentially important parameters like ocean survival, delta conditions, temperature, habitat, and winter and spring flow.

<u>Response</u>: Various topics and specific comments are addressed in this section.

<u>Ocean Conditions</u>
Marston 2007 shows that SJR adult salmon reduction began in 2000 well before the downturn in ocean conditions in 2005. The salmon reduction also occurred concurrent with a reduction in spring flow, and elevated water temperatures, during the years between 1999 and 2004 (e.g. when for each successive year from 1999 to 2004 spring flows were reduced in magnitude). It is theorized that what is driving adult escapement abundance trends is the amount of smolts leaving the delta and entering the ocean on an annual basis (e.g. more smolts entering the bay equates to more adults in the ocean which equates to more adults escaping inland to spawn). For smolts to leave the bay they must survive in the nursery tributaries <u>and</u> through the Delta.

Analysis of coded wire tag recoveries to determine jack rates and age maturation rates, in addition to evaluating all smolt survival vs. flow studies that have been conduced in the SJR tributaries and South Delta, will shed light whether this theory is true. This analysis is on-going and the results will be reported as part of

V. 2.0 documentation. The results of this analysis will be incorporated into model V 2.0.

Ocean Harvest

It is acknowledged that harvest of salmon by sport and commercial ocean fisheries is a source of mortality of SJR salmon as evidenced by recovery of coded wire tagged salmon released from the Merced River Hatchery (http://www.rmpc.org). After all sport and commercial harvest is legal in California, is a beneficial use of salmon that pre-dates Statehood, and is partially equivalent to the harvest of agricultural crops, one difference being that fish harvest rates are designed for sustainable populations.

The question is: Is ocean harvest a significant source of mortality that governs the historical inland escapement abundance trend? The Central Valley Harvest Index, when compared to SJR escapement trends, suggests that it is not (Marston 2005). A recent analysis of the relative relationship of Chipps smolt abundance, ocean conditions, and ocean harvest upon age 2 inland escapement indicates that neither ocean conditions nor ocean harvest (both sport and troll) substantially influence age 2 inland escapement (see Appendix 2). See note for ocean conditions above.

Delta Conditions (e.g. Exports and Predator Abundance)

Three separate evaluations have been performed to evaluate the significance of exports upon adult SJR salmon abundance or juvenile smolt out-migration survival trends. Marston & Mesick (2006) compared adult cohort abundance trends against export levels directly and found that spring flow explains 60% of the variability whereas exports explain only 8%. When spring export influence upon adult production (escapement 2.5 years later) from an export to inflow ratio is compared, at first glance there appears to be a relationship with exports and adult production. The 2006 VAMP Annual Report shows a regression correlation that indicates that the E:I ratio explains about 56% of the variability in adult escapement abundance trends. However, when exports and spring flow are segregated and viewed independently from one another in comparison to spring flow, and are transformed by log10, exports explain only 16% of the variation whereas spring flow explains 38% (Marston & Mesick 2006). The Escapement 2.5 years earlier metric assumes that annual escapement estimates are primarily comprised of age 3 salmon. This metric is confounded by presence of age 2 thru 5 salmon, and the age group percentages can vary widely over time (Mesick & Marston 2007). Brood year production cohorts are a more informative evaluation metric because multi-year confounding is removed. It may be that spring flow has first order production effects whereas spring exports only have second order production effects.

Newman (2008) conducted a fairly thorough evaluation of South Delta (e.g. VAMP) juvenile salmon smolt survival tests and concluded that exports had little to no influence upon smolt survival in the river reaches tested. However it is noted that Dr. Newman has recommended that a more thorough model selection process be employed and that this will be conducted in the future (Pat Brandes personal communication). A different modeling approach may produce different results.

Recently, studies of coded wire tagged (cwt) juvenile salmon produced by the Merced River Hatchery and released at various location throughout the SJR basin, and recovered by the exports facilities (e.g. 1994 through 2006) provide insight (documentation in preparation). Figure 4 shows that recovery of MRH cwt's is extremely low. With either the Head of Old River Barrier installed or not, the median recovery is less than 1%. It is noted that if only a small percentage of smolts are reaching the Delta, say for example 2%, than a 1% loss at the export facilities would be a large loss. However, looking at export facility recoveries from Mossdale coded wire tag releases only (Figure 5), a similar trend is evident (e.g. only a small percentage of smolts is being entrained by the pumps) thus indicating that entrainment of smolts by export facilities during spring operations is not resulting in a long-term population impacting source of mortality.

In summary, three lines of independent analysis point to the conclusion: exports are not demonstrating a substantial influence upon long term SJR salmon abundance and survival. This does not mean that export facilities are not having a substantive effect, but it does show that studies conducted to date are inferring that spring export operations are not having a substantive effect upon long-term adult fall-run production trends in the SJR basin.

It is thought that predation of out-migrating juvenile salmon is a substantial source of mortality that is having long term population abundance level impacts upon SJR salmon abundance trends. Recently, annual striped bass abundance trends for the Delta and S.F.-San Pablo Bay were obtained (CDFG-Marty Gingras). Annual striped bass abundance indices are plotted against annual juvenile survival (Figure 6) and age 2 inland escapement abundance (Figure 7). There is a lot of scatter between annual striped bass abundance trends and both smolt survival and age 2 inland escapement abundance, indicating that striped bass predation may not be a significant source of mortality (e.g. population level controlling). Additional analysis could help to confirm, or reject, this finding.

Water Temperature
See response to comment #29.

Spawning Habitat Restoration (from Mesick et al. 2008*)*
Preliminary analyses (Mesick et al. 2007) suggest that although the degraded condition of the spawning habitat in the Tuolumne River, at all but very low spawner abundance levels, limits the production of fry, more fry are currently being produced than can be supported by the rearing habitat. If true, then gravel augmentation and restoring sediment transport will not substantially increase adult recruitment.

The preliminary analysis is based on rotary screw trap captures in the Tuolumne River. At least 7,300,000 and 3,500,000 juveniles were produced in the Tuolumne River in 1999 and 2000, respectively. The estimates are based on rotary screw trap catches at the 7/11 site (RM 38.6), which is downstream of the majority of the spawning habitat in the Tuolumne River (Turlock Irrigation District and Modesto Irrigation District 2005); only a portion of the migratory period was sampled during both years and so the true estimates are probably higher. It is likely that these numbers far exceeded the capacity of the rearing habitat, because only 0.4% of these fish in 1999 and 1.4% of these fish in 2000 survived to a smolt-size as measured by passage estimates at the downstream Tuolumne River trap at Grayson (RM 5.2).

Smolt production also appears to be controlled by the quality of the rearing habitat and not the production of fry in the Stanislaus River. After implementing a spawning habitat restoration project in the Stanislaus River that added spawning-sized gravel to 18 sites between Goodwin Dam and Oakdale in summer 1999 (Carl Mesick Consultants 2002), juvenile production, which was measured with a rotary screw trap at Oakdale (RM 40), increased by 32% in spring 2000 compared to spring 1999 (Figure 8). However, there was no increase in the number of smolt-sized fish that migrated from the river in spring 2000 compared to spring 1999 as measured with rotary screw traps at Caswell Park (RM 5) even though the mean flow from March 1 to June 15 at Goodwin Dam was nearly identical (1,497 cfs) in 1999 and 2000.

It is apparent that parent stock size, within the stock sizes that have been historically observed to date, may not be the primary parameter influencing production, rather instream flow (specifically prolonged floodplain inundation flow) has a strong effect on production, and that existing physical habitat (e.g. habitat limitations) may have no substantial effect on production in comparison to flow. It is noted that no adults (spawners) would produce no juvenile recruits and that no physical habitat (e.g. complex spawning and rearing habitat preferred by juvenile and adult salmon) would severely curtail juvenile thence adult production.

Density Dependence
Comment: *"The neglect of stock size has serious management implications. The only way smolt production could fail to be directly proportional to parent stock size is if there were severe habitat constraints between escapement and smolt outmigration, such that the relevant habitat was fully saturated even in years of poor escapement. But this would imply a severe form of density dependence, which CDFG does not consider. The assumption that parent stock size has little effect on production explicitly contradicts statements regarding the absence of habitat limitations, and raised fundamental questions about the point of trying to increase cohort production in the first place."* Page 11 from SJRGA report.

Response: Two things remain true for all animal production models, reproductive adults (spawners) are needed to produce new cohorts, and environments have finite capacities to support stocks. This necessarily implies that full-spectrum stock-recruitment relationships pass through zero and have a maximum value or upper bound. Despite this, one can still fit a line to stock-recruitment data with bounded stock levels provided one recognizes that extrapolation beyond the bounds is problematic. Second, although stock-recruitment that is spread extensively across the stock axis will always have a density-dependent signal embedded in it, this signal may well be swamped by noise and only become statistically detectable at sample sizes that are much larger than found in real data sets. Thus, in practice, density dependence is a subtle statistical issue and in the case here it seems that it is not possible to tease apart from an explicit model that implies how the number of spawners in the fall impacts the number of smolts per spawner migrating past Mossdale. We have looked at this issue several ways, from first verifying a simple association of the number of spawners and number of smolts (exact permutation test of this bivariate association shows no association) to fitting a model based on the Ricker formulation of density dependence, and other versions in between these two. There is no simple bottom-line to report at this point. Unexpectedly, there is no convincing statistical association between the numbers of spawners and number of smolts, so without adjusting for other factors, one can not say definitely that they are not independent random variables. However, if flow is accounted for (adjusted for), there now appears a statistical relationship of the two. However, depending on how one adds the Spawners in the model, the evidence points to some density dependence (untransformed, the results imply more spawners = lower rate of smolts/spawner) to no evidence (log(spawners) the results imply the more spawners, the higher the rate of smolts/spawner); note that in some of the replies below we discuss how one can trivially introduce the statistical appearance of density dependence. Hopefully, with the more refined data from the rotary screw traps that we are in the process of formatting for analysis, we will have a more definitive answer. However, one thing is common among all these approaches – flow as currently measured has a relatively large association with numbers of smolts. So, though one can quibble with the form of the density dependence, and it is important that future data can be used to refine it, the important point we make, particularly in our attached appendices, is that flow appears to have a strong empirical relationship regardless.

Comment: *"Finally, it is abundantly clear from the data we analyzed that much of the variability in survival rates appears to be related to annual conditions other than flow. In some years survival rates appear high despite low flows, while in other years survival rates are low when flow conditions are high, such as in 2005 (VAMP 2005). This indicates that other factors might be just as or even more important than flow. Careful review of other environmental conditions associated with the individual smolt survival estimates may indicate other factors that affect smolt survival. For example, incorporating other variables such as temperature* *and exports (e.g., Newman 2003) could help to refine estimates of the underlying flow-survival relationship."* Page 13 from SJRGA report.

Response: This is a good point, and we are examining other factors more closely in our V. 2.0 model to determine whether there is evidence that other factors included in the model might result in better prediction (less variability around the predicted survival). Again, failing to include other factors related to survival does not necessarily bias the association between flow and survival (see Comment #17 for further discussion).

Comment: *"In terms of checking model consistency, a useful question to ask is: "how consistent are the data in Figure 8 with the assumed value for marine survival of 5%?" To address this question, we computed the implied marine survival for each year as follows: Marine survival = 100% *(Observed cohort production)/(Chipp's smolt estimate). These values are shown in Figure 9. It is important to recognize that these values of implied marine survival are derived from the CDFG model predictions of Chipp's smolt abundance. Therefore, the degree to which these implied marine survivals differ from the value assumed in the model (e.g., 5%) is an indication of model consistency. As shown in Figure 9, there is strong lack of consistency between the implied estimates of marine survival and the assumed value (5%). The implied values range from 1% to 63%, with a median or average value across years of 28%. In fact, the implied marine survival is greater than 20% in nine of the 14 years. It is also clear that implied marine survival tended to be much greater on average for years in which Vernalis spring flow was low (e.g., < 5,000 cfs)."* Page 15 from SJRGA report.

Response: A good point and a possible short-coming of the original model. Included in the attached Version 1.5 (Appendix 2) is a recent analysis of Ocean survival versus environmental factors. In our model V. 2.0 (Appendix 3) we will incorporate more detail on both spatial distribution of fish, harvest effort by age, etc. to derive a model that will explain hopefully more of the variability from Chipps to Escapement. Again, this shortcoming of the current model certainly results in greater variation around the prediction (as described above), but again does not necessarily bias the effect of flow on salmon abundance.

Comment #5: Sampling error and between year variation: Must be somehow accounted for in the analysis.

Response: As subsequent forms of our models are developed, we will consider extensions of the underlying data-generating model that will include measurement error and other forms of variability currently not included. The most important impact of this will be on the inference.

Comment #6: HORB: Scenarios for HORB in and out must be corrected (many comments related to this).

Comment: *"…model scenarios use the with HORB relationship between smolt survival through the Delta and flow, when flows are in excess of 7000 cfs. This needs to be changed in the model. For instance in figure 34 and 35, flows of 14,000 cfs without the barrier would equal the survival obtained at 6000 cfs with the barrier. This aspect of the two relationships are not incorporated into the model results. Also in hindcasting escapement the model should incorporate the HORB relationship for only part of the year when it was in – the rest of the season should not include it."* From Review Document #8 (see list in Introduction).

Response: Because the HORB was rarely installed in the historical baseline timeframe (e.g. 1967-2000) including the HORB-in would have minimal, if any, influence upon long-term adult abundance trends. It is noted that the HORB-out and HORB-in have different smolt survival values. Recent analysis by Newman (2008) provides a thorough analysis of South Delta smolt survival studies conducted to date. Model Version 1.0 allows the user to include the HORB installation and operation both for dates within years and which years it will be operational. Model Version 1.0 also allows the user to identify the maximum flow value that the HORB is operational. This same flexibility to identify when, and under what flow levels, the HORB is operable will be included in model versions 1.5 and 2.0. Model results including HORB-in or HORB-out will be clearly defined in future model runs.

Comment: *"…the with HORB data with smolt survival indicates that during the experiments flow and export levels are significantly correlated. You cannot determine which variable is important when they vary together without further experimentation when the two variables do not vary together. The without HORB data was gathered at exports of less than 3700 cfs (the with barrier at exports of less than 2300 cfs)– thus you cannot conclude that exports aren't affecting survival at all export levels, with or without a barrier"* From Review Document #8 (see list in Introduction).

Response: Newman (2008) concluded associations between water export levels and survival probabilities were weak to negligible. Also, this comment suggests a recognized design flaw of the VAMP experiment. In recent analyses reported to date (various authors) where the effects of flow are separated from the effects of exports, flows always show a much stronger association or provide a better explanation, for the variability both in juvenile survival and in adult production. This does not mean that exports do not have adverse effect it just means that exports have yet to be identified as a population level controlling source of mortality for SJR salmon. As stated earlier, spring flow may have first order production effects whereas exports may only have second order production effects.

Comment: *"The historical model run operates all years without a barrier, but yet most of your scenarios operate with the barrier in place, even at high flows where* *the barrier wouldn't be installed. I would rerun your scenarios without the barrier relationship and see how that would change your recommendations."* From Review Document #8 (see list in Introduction).

Response: See response comment above for HORB base-line. Model Version 1.0 allows the user to set the max flow for HORB. In all model scenarios, when the HORB-in condition was set, the HORB was operated at approximately 6,100 cfs max as constrained by the empirical measurements conducted to date (e.g. only flows up to about 6,100 cfs have been evaluated with the HORB-in). If the HORB-in is set and flows are in excess of 6,100 cfs then the HORB-out survival relationship is used.

Comment: *"Table 21: Only scenario 2 has the HORB identified but scenarios 3-11 say they also have the barrier in. This should be made clearer in the table and using the with barrier relationship with the flows identified probably is not justified. What is additional predicted escapement ? From what ? the baseline? What is the baseline?"* From Review Document #8 (see list in Introduction).

Response: Comment noted.

Comment #7: Programming language: Excel modeling could be prone to errors.

Response: The inference here is that model results are wrong or errant due to Excel programming glitches. We are not aware of any software bugs that imply that Excel has computation errors. Perhaps the reviewer's comment is regarding the adequacy of using Microsoft Excel as a platform for developing models with this level of complexity. In that regard, it should be noted that Excel has a number of portals that allow one to invoke very sophisticated computation capabilities, such as, Macros, User Defined Functions, VB Code, and interface with third party software. In fact, an experienced programmer can launch almost any software through Excel in a manner that is transparent to the end user. In addition, even when using Excel in the classical way (i.e., built in standard equations and function) it is sometime more valuable than a compiled code, as the end user can trace the computation process more easily. However, we concur with the reviewer's comment that Excel is sometimes not the preferred software for modeling, especially when running intense statistical calculations. This is one of the reasons that we decided to consider building the new generation model (Version 2.0) using a more statistically oriented, readily available, software package such as "R".

Comment #8: External data: Modeling results on other rivers should be used and included.

Response: Other models may exist that could be modified for use to evaluate the relationship of flow and non-flow factors upon juvenile and adult production and long term abundance trends. The model refinement team encourages others to bring forth other model applications that have received at least the same level of peer review rigor this model has to see if substantial differences in the Vernalis flow magnitude, duration, and frequency occur as compared to that predicted by the CDFG's Model Version 1.5 (Refined Original Model; Appendix 2) or later Model Version 2.0 (New Model, Appendix 3).

A detailed life-history model of the San Joaquin river fall run Chinook salmon that has a tributary level spatial resolution was developed by Ecological Analysts (EA 1991) in the early 1990s. Its implementation was in STELLA, which is far too cumbersome to be embedded (through appropriate call routines) in software designed to explore management questions, and would thus have to be translated into other code. Further, all parameters in the EA model would have to be re-estimated using data obtained over the past 15 years, and the EA model itself is not easily extended to include a more refined spatial structure, such as dividing each tributary into 2 or more reaches. The EA model also assumes all cohorts are initiated in the same week each year and that the development rate of each cohort from one life stage to the next (i.e., egg to alevin, alevin to fry, and fry to smolt) is fixed. These are assumptions that are not reasonable if temperature regimes are affected by flow and development rates are temperature dependent, as is the case for SJR salmon (Myrick & Cech 2001, Marston 2007; Rich 2007). In "modernizing" the EA model, CDFG's model V2.0 allows egg production to be spread out over the spawning season, and both development times and survival rates to be dependent on flow and temperature. In addition, unlike the fixed migration rates, in the EA model, CDFG's V2.0 allows migration to depend on flow (or at least detect if it is dependent on flow). See Appendix 3 for more details.

Comment Category 2: Data Analysis

Comment #9: General: Data points are excluded without proper justification (outlier).

Comment: *"A third potential problem is that CDFG omitted the 1989 data from the regression analysis because that year was an outlier (see Figure 4). They state (page 18): '… [the 1989] Mossdale smolt estimate was not consistent with other years. Why the 1989 smolt estimate is high relative to other years is currently unknown.' However, outliers can often provide valuable insight, and it is generally recommended that outliers not be discarded unless there is good reason to believe that the data are unreliable. Instead, the effects of outliers on the analysis should be thoroughly examined. In this case, the data point may indeed provide valuable insight. The Mossdale smolt estimate was roughly 4.2 million even though Vernalis flow was only 1,900 cfs, yet the preceding escapement estimate was comparatively high at 20,583 (Table 1). Thus, a reasonable explanation for the large smolt estimate is that it resulted from a large escapement. The fact that CDFG excludes this smolt estimate because it is* *inconsistent with the expected relationship with flow suggests a strong preconceived bias toward a largely unsupported hypothesis (i.e., that spring flow is the only important determinant of smolt production)."* Page 8 from SJRGA report.

<u>Response</u>: It is good to have justification outside the data to remove an outlier, which is conceded above. We will do a more detailed analysis of the effect of removing the outliers. In addition, because we will examine the effect of flow within more refined increments in our new model (see Appendix 3), this point (1989) may no longer be a statistical outlier.

This comment pertains to the removal of the 1989 Mossdale Smolt Production data point value of 4.2 million smolts. The criticisms provided include: i) outliers should not be discarded unless there is good reason to believe the data are unreliable, ii) even though Vernalis spring flow was relatively low and since escapement was relatively high, one explanation for the high number smolts is a high level of escapement, and iii) a bias exists towards a largely unsupported hypothesis that spring flow is the only important determinant of smolt production.

Each of these three criticisms warrant consideration. First, is there evidence that provides good reason to believe the data are unreliable. Using the rationale provided by the reviewers that high escapement could explain a high number of smolts, a comparison of relatively like years of fall escapement, Vernalis spring outflow, and Mossdale Smolt Production is provided in Table 2. From Table 2 we see that four years exist between the years 1988 and 2004 where escapement was greater than 20,000 spawners and flow was below 3,000 cfs. From Table 2 we see that three of the four years compared all had relatively similar smolt production estimates. However, 1989 really stands out as an aberrant value being over 500% of the minimum value in comparison to the other values which ranged from 115% to 159% of the minimum value. This is evidence that something different happened in 1989 that was not present in other years but that neither flow level nor fall spawner abundance appears to explain the difference. This type of comparison is precisely why the 1989 data value is considered an outlier. The comment regarding bias is not supported.

We note the question that should be asked is: “what is the difference in the Mossdale Smolt Production relationship with and without the 1989 data point?” Figure 9 compares the regression correlation between the data sets (e.g. using spring flow and smolt production) with, and without, the 1989 data point value. Per Figure 8, there is not a substantial difference in either slope or y-intercept indicating that the removal of the 1989 data point does not materially influence (e.g. bias) the model estimates. It is noted that while the regression lines are not different, the confidence band widths surrounding the with, and without, 1989 data point value do differ (Figure 10).

Comment: *"Finally, from a statistical perspective, the regression analysis and results used to derive the smolt-production relationship are highly questionable. First, the form of the linear function is not a conventional approach. Typically, the effects of escapement and flow would be examined using stock-recruitment models (Quinn and Deriso 1999). We revisit this topic in more detail below when discussing evidence of density dependence. Second, standard diagnostics of the regression (i.e., statistical methods for assessing the validity of model assumptions and the influence of individual data points) reveal that the relationship is primarily determined by two data points (1995 and 1998)."* Page 8 from SJRGA report.

Response: This comment appears to contradict the above comment about removing outliers (or highly leveraged points). The estimation procedure used for the current statistical models (V.1.5 and V.2.0 in progress) no longer are as sensitive to outliers, as would be the case for the original linear model. However, we will do a detailed leverage analysis for our current statistical models.

Comment #10: General: Liner models developed are unbounded. Selection of type of equations fitted is not sufficiently elaborated. More sophisticated methods than regression methods must be applied.

Comment: *"The mathematical formulation of the model results in highly questionable relationship between flow and cohort production. This relationship is not consistent with available data."* Comment 1 (Page 1) from SJRGA report.

Response: This is an assertion at this point, without specific evidence (later in report). However, we comment that the statistical models that make up the original model (Version 1.0) have been re-evaluated and in some cases re-done to address some of the general criticisms in Model Version 1.5. One of the major criticisms is that the sub-models in the original model were not proper models, or that the forms of the regression model did not guarantee that the mean outcome was predicted to be in its natural range. For instance, if the outcome was binary (e.g., smolt survival yes=1/no=0) then the mean of this outcome will be between 0 and 1 (and will estimate a probability of survival). In this case, a logistic model would be a proper model as it would insure that 0<predicted mean < 1. In this case, a linear model would not guarantee an estimated probability. The link function is what controls the range of predictions on the original scale (e.g., the logit link in the case of the logistic model), and we have re-fit the models so that proper models are used. However, we note that there is nothing inherently wrong about fitting improper models. If both models are non-parametric there is no difference in the fit to the data. For instance, if the probabilities to be estimated are not near 0 or 1, then use of an improper linear model could be an adequate fit (and indistinguishable from the proper model). Thus, one advantage of proper models is that they can provide safer extrapolations to situations outside the data used to estimate the parameters of the model (i.e., situations with greater than the test flows used or fish populations larger than the data used to estimate the model). However, they are no panacea and as will be emphasized, extrapolations are always statistically dubious. Thus, test conditions with higher flow rates would be beneficial in several respects.

Comment: *"The statistical methods used to derive two key relationships in the model are overly simplistic and unconventional. These two relationships determine (1) the number of smolts that migrate to Mossdale, and (2) the survival rate of smolts between Mossdale and Chipps Island."* Comment 4 (Page 2) from SJRGA report.

Response: This is another assertion. Again in V.1.5 and V.2.0 (in progress), we have changed the forms of the regression models, though the use of regression models to estimate survival relationships in general should not be considered unconventional.

Comment: *"The relationship determining smolt survival is assumed to be a linear function of flow. However, it appears to be equally plausible that the relationship is nonlinear. This survival relationship is critical to the evaluation of alternative VAMP flows and a more rigorous statistical analysis should be conducted."* Comment 6 (Page 2) from SJRGA report.

Response: We have re-analyzed these relationships to improve V.1.5 (see Appendix 2).

Comment: *"Linear regressions were used to derive the relationships for Mossdale smolt production (equation 1), Mossdale-to-Chipp's survival rate (equation 2), and SJR Escaping Adults (equation 3). In all cases, the Y-intercepts of these regressions were set to zero when used in the model. However, the following problems arise with one or more of the relationships as a result of the statistical approach:*

(1) The data violate the assumption of normality and should be transformed.
(2) The method used is not a conventional approach to analyzing such data and likely results in a misleading and biased relationship.
(3) The relationship is driven by a few data points that have high "leverage." This results in highly significant relationships that appear convincing or well defined when in fact they should be treated with greater uncertainty and skepticism.
(4) The relationship does not appear to be linear.
(5) An influential data point is arbitrarily excluded from the analysis."
Page 6 from SJRGA report.

Response: As a blanket way of addressing these points, we have re-fit the statistical models using exploratory procedures and using types of regression that result in proper models. The specific responses are as follows:

1. Though not explicit, we will assume that (1) refers to the normality of the residuals of the regression (the conditional distribution of the outcome is normally distributed). This is a legitimate criticism if the inference on the coefficient estimates is sensitive to the normality assumption or one wishes to have forecast confidence intervals for future predictions. At this point of the modeling stage, we are concentrating on estimating the means of the various stages within certain time intervals and any inference provided refers to estimates of this mean. Thus, the 2nd point does not apply. The first one is more relevant; however, the central limit theorem is often invoked in the construction of the confidence intervals, short of assuming normality of the outcome data. However, in this case, since we are no longer using linear models, there is no exact theory for constructing confidence intervals on the coefficient estimates and this criticism is no longer relevant.
2. (2) is an assertion without being specific enough to address. We assume they are relating to the use of linear models in the context of outcomes more commonly modeled by logistic or log-linear regression and so we will assume that this has been addressed.
3. The new link functions used have the effect of reducing the influence of outliers with regard to the explanatory variables and so this no longer applies. However, if specific examples can be presented, more robust fitting procedures (non-MLE) can be used that reduce the impact of influential points.
4. See (1) above.
5. Seems to contradict (3). Excluding a data point because one believes it is biasing the regression estimates should not be based solely on the data (that is, not by simply the appearance of an outlier); there should be other information available that suggests the point is not representative of the data-generating distribution of interest, either due to some sort of severe measurement or unusual event. See our response to Comment #9 for a discussion of this specific data point.

Comment: *"There would seem to be several serious problems with this relationship. First, escapement in the model has very little influence on smolt production. The coefficients used in the model correspond to roughly 15 smolts per spawner and 150 smolts per cfs of flow. Thus, a single cfs of spring flow produces 10 times as many smolts at Mossdale than does a single spawner. Consequently, omitting spawners from the model by setting the escapement coefficient to zero has almost no effect on the results. That is, the model produces numerous smolts even when there are no parental spawners. This is highly irregular from a modeling perspective, and from a biological perspective it is, of course, impossible."* Page 7 from SJRGA report.

Response: We have changed the form of this relationship (a log-linear relationship) and so the relative effect of flow and escapement is now different.

We do however still see a relatively large impact from flow. This is an empirically derived relationship, using a standard model fitting procedure (MLE) and so should be considered conventional. Note, that the criticism that the model would predict the possibility of having smolts even if there was 0 escapement is gratuitous, and is just a function of not having the estimated intercept be EXACTLY 0, it is certainly not “highly irregular”. Note, there was also a criticism of setting the intercept to 0, which would get rid of this problem, and this was also criticized – a sort of can’t win for losing. There is a conundrum in the comments.

Comment: *"We contend that the approach used by CDFG is overly simplistic, and as a result, little consideration is given to alternative forms of the flow-survival relationship. Specifically, using linear regression and forcing the Y-intercept to equal zero can easily result in a biased depiction of the flow-survival relationship. Admittedly, it is difficult to obtain reliable statistical descriptions of these relationships because data are limited and highly variable. It appears that CDFG used just seven data points to estimate the HORB-out regression and nine data points for the HORB-in regression (see Figure 34 in CDFG 2005).*

A more conventional approach to analyzing smolt survival data is to use regression analysis based upon the logistic model described above or some related form of generalized linear model (McCullagh and Nelder 1989; Newman and Rice 2002; Newman 2003; Pyper and Smith 2005). To illustrate the importance of considering alternative flow-survival relationships, we fit logistic regression models to survival-rate data found in VAMP (2004, 2005). These data are for 38 CWT experimental groups released between 1989 and 2005 at Dos Reis, Mossdale, and Durham Ferry (Table 2). Survival-rate estimates were derived using differential recovery rates (DRR or CDRR) computed using paired releases at Jersey Point and CWT recoveries at Chipp’s Island and Antioch (see VAMP 2005 for details)." Page 12 from SJRGA report.

Response: This is a good point, and we have re-fit this relationship both with a different functional form and with a new method for estimating survival at Chipps (see Appendix 2). We examine the empirical proportion surviving versus flow (and with the HORB both in and out) using generalized additive models (GAM) approach to examine the relationship without assuming a particular logit-linear functional form. It results in the relationship seen in Figure 11.

Comment: *"In summary, we recommend that CDFG thoroughly examine the consistency between observed data and model predictions for each of the key life-stage components of their model. Modeling and examining relationships in terms of survival rates will help to avoid the pitfalls encountered in the current analysis."* Page 16 from SJRGA report.

Response: We agree and have re-analyzed the models. In addition, the new model being developed will be able to address flow in a more flexible ways, given the weekly time step and also have a more detailed ocean component, in order to examine how changes in flow at various life stages influence cohort production, relative to other factors like harvest effort, ocean conditions, etc.

Comment #11: General: Predictors in regression analysis are not independent.

<u>Response</u>: Predictors in a regression model do not need to be independent to interpret the results of the model, so this shows a general misunderstanding of regression or the reviewers just do not provide enough detail to make sense of this criticism. The extreme form of dependence, colinearity, is certainly an issue but thus far our models have not encountered this. We can address this and incorporate their concerns if they simply provide more information about their concerns.

Comment #12: Delta Smolt survival: Use logistic model instead of power analysis for survival.

<u>Response</u>: A new functional form has been fit.

Comment #13: General: Results of regression analysis biased by few data points.

<u>Response</u>: At this point, the data available is somewhat limited and given the relatively small sample size (number of years with useable data), individual points have more influence on the regression estimates than one would prefer. In addition, this small sample size makes robust inference somewhat problematic, as there is very limited data to estimate the residual error structure of the data (e.g., autocorrelation). The more detailed data that will become available, predominantly the rotary screw trap (RST) data, could alleviate this issue somewhat.

Comment #14: Escapement: Escapement reconstruction should be based on better analysis.

<u>Response</u>: Escapement deconvolution has been updated and methods used to deconvolve escapement estimates into brood year production cohorts is described in detail in Mesick et al. (2007). Mesick et al. (2007) used all available empirical data to develop the age segregations used to identify brood year production cohorts. If a more statistically reliable method of reconstructing cohorts becomes available they could be compared to those in Mesick et al. (2007) and analyses conducted to see if substantially different results occur.

Comment #15: Exports: Eliminating possible effects of Exports is not convincingly Elaborated.

Response: See response to comment #4 (exports section). For more supporting information assessing the relative importance of flow and exports upon smolt survival in the Delta the reader is referred to Newman (2008).

Comment #16: HORB: Evaluation of HORB effects is limited to too few data points to be conclusive.

Response: Comment Noted. Newman (2008) conducted a Bayesian Hierarchical modeling process to assess the relative influence of the HORB upon smolt survival. Newman concluded that: (a) The expected probability of surviving to Jersey Point was consistently larger for fish staying in the San Joaquin River (say passing to Dos Reis) than fish entering Old River, but the magnitude of the difference varied between models somewhat; (b) thus if the HORB effectively keeps fish from entering Old River, survival of out-migrants should increase; (c) there was a positive association between flow at Dos Reis and subsequent survival from Dos Reis and Jersey Point, and if data from 2003 and later were eliminated from analysis the strength of the association increased and a positive association between flow in Old River and survival in Old River appeared; (d) associations between water export levels and survival probabilities were weak to negligible. Given complexity and number of potential models for the VAMP data, however, a more thorough model selection procedure using Reversible Jump MCMC is recommended.

Comment #17: Ocean harvest: Better ocean survival analysis needed. Ocean harvest cannot be constant.

Comment: *"The model does not account for harvests when computing estimates of cohort production or annual escapement. Given that the large fluctuations in harvest rates occurred over the time period used in the model, comparisons between observed and predicted values of cohort production (or worse, between observed and predicted annual escapement) that do not account for harvests are likely to be poor indicators of model performance."* Comment 9 (Page 2) from SJRGA report.

Response: Different components of the model (e.g., parameters relating to Inland Production) use different sets of data to estimate parameters. For example, survivorship of smolts per spawner as a function of environmental conditions, such as flow, does not need to involve the ocean part of the model if smolt data at Mossdale is used rather than escapement data. This approach allows us to directly assess the relevance of flow conditions on the health of the salmon population, though it does fail to indicate the relative magnitude of this effect on ultimate escapement of these fish to the effects of ocean conditions and harvest. However, it still could estimate the effects of flow, if there is not confounding by ocean factors (e.g., if for instance harvest effort goes up when the stock is larger). This is a general theme of some of the criticisms that the original model fails to account for important factors influencing the variability of for instance cohort production. However, this is only a valid criticism if 1) the model was used to make accurate predictions of future cohort production and/or 2) these other factors confound the relationship of flow to salmon survival. However, if these left-out variables do not confound (that is are related BOTH to flow and the outcome salmon variable, Figure 12), then one can estimate a valid association of flow and salmon even if these factors are not part of the regression model including flow.

Comment: *"… in order for model predictions to be meaningful, they should incorporate variability in harvests over time."* Page 19 from SJRGA report.

Response: We plan to take precisely this advice in our new model, by using more refined data on both Ocean conditions and fishing intensity.

Comment #18: Central Valley Harvest Index (CVHI) should be included as a Model Parameter.

Response: It is acknowledged that ocean harvest is a source of mortality for SJR salmon (e.g. recovery of MRH released coded-wire-tag salmon in ocean fisheries). The reviewer rightly acknowledges that Sacramento River fall-run production dwarfs SJR fall-run production. It is assumed that SJR and Sacramento fall-run stocks are equally targeted in ocean fisheries. While perhaps a valid assumption, it is an assumption that remains to be tested. If true, then the CVHI indicates that SJR and Sacramento fall-run are being caught in the same proportion in ocean fisheries. So even though more Sacramento fall-run are being produced and harvested they may be harvested at rate proportional to SJR fall-run. The CVHI is an indicator of harvest relative to Central Valley escapement. Thus when the CVHI is relatively high it means that a proportionately larger amount of salmon were harvested relative to escapement, whereas, a low CVHI means that a proportionately lower amount of salmon were harvested relative to escapement. By plotting the SJR escapement vs. CVHI we are trying to discern whether relative harvest abundance is correlated with lowered escapement abundance to confirm or reject the hypothesis that ocean harvest is “controlling” SJR salmon escapement. While other analyses might be developed in the future (e.g., SJR specific harvest index from recovery of MRH cwt releases, etc.) to better assess the relative population level mortality pressure that ocean harvest is having upon SJR fall-run escapement abundance, the CVHI, as it exists today, indicates that ocean harvest is not strongly correlated with SJR escapement abundance. Thus the empirical evidence at the time model Version 1.0 was developed indicated that ocean harvest really did not explain a substantial amount of variability in the long term SJR salmon abundance trends.

Recently a preliminary SJR harvest index was developed (unreported analysis of recovery of coded wire tagged MRH origin fish in ocean fisheries and inland escapement). Figure 13 compares the SJR harvest index to the CVHI. Preliminary data and results indicate that the Central Valley Harvest Index is higher than the SJR harvest index suggesting that Sacramento fall-run are being harvested at a higher rate than SJR salmon, indicating that adult production is lower than that which is reported by the CVPIA-AFRP. The significance of this is that SJR adult production may be lower than what is currently being estimated. Figure 14 shows the SJR harvest index and SJR escapement for the years 1980 to 2003. Preliminary data analysis indicates that the SJR harvest index explains only 10% percent of the variability in SJR escapement trends for the years 1980 to 2003. It is likely that the paucity of data at the upper end of the SJR harvest index is creating the appearance that there is a correlation between the SJR harvest index and SJR escapement.

Model (version 1.5), which is life-stage based and predicts escapement, could include harvest as a source of mortality in the ocean. This model predicts a certain number of smolts will enter the ocean on an annual basis. It is recognized that harvest is a real source of mortality for these fish as they grow and that there is no way of estimating the actual rate of natural mortality (predation by killer whales and seals, etc.) at present, so incorporating the rate of harvest based on the CVI explains only partially the source of ocean mortality.

To address the issue of whether or not to included ocean harvest as a specific parameter in the model, model V2.0 will have ocean harvest included as an ocean module parameter (see Appendix 3). Consideration will be given to incorporating the following equation (developed by Mesick et al. 2007) in model V1.5:

Recruitment = Age 2(i+1)/((1-SCVI*1.122)+(TCVI*0.118))) +
Age3(i+2)/(1-((SCVI*1.122)+(TCVI*1.118))) +
Age4(i+3)/(1-((SCVI*1.122*0.54)+(TCVI*1.118))) +
Age5(i+4)/(1-((SCVI*1.122*0.54)+(TCVI*1.118)))

The Central Valley Indices of sport harvest (SCVI) and troll harvest (TCVI) from 1980 to 2005 are contained in Mesick et al. 2007.

Comment #19: Escape: Effect of October flow conditions on adult returns are not Addressed.

Response: Agree. Fall flows were left out because fall flow did not show a strong correlation to either juvenile or adult production. Evidence has emerged (Jackson 2008) regarding the relationship of adult abundance to fry abundance and fry abundance to smolt abundance. At a certain spawner abundance level, sufficient egg abundance exists to fully seed available fry habitat and that winter flow volume dictates fry abundance and, fry abundance combined with spring flow magnitude, duration, and frequency determine smolt out-migration survival and abundance which is linked to Delta out-migration survival and abundance. Juvenile migration into the ocean appears to be driving adult inland escapement abundance (Appendix 2). Model Version 2.0 will allow the influence of fall flow timing and magnitude upon juvenile and adult abundance to be more fully assessed.

Comment Category 3. Model Structure

Comment #20: Exports: Effect of Exports must be included.

Response: Comment noted. Please see response to comment #4. Exports, to the extent that a meaningful empirical relationship can be developed to include in the model, will be included as a parameter in model version 2.0. It must be noted that from an empirically defined perspective, it does not make sense to include a parameter simply to include it for sake of convenience knowing that the parameter (as it has been defined and has been assessed thus far) has very little, or no, influence upon SJR salmon production trends.

Comment #21: Fry Production: Contribution to escapement neglected.

Response: Fry contribution to escapement was not neglected it was purposely left out because no empirical evidence exists to include it as a production influencing parameter. Therefore is it reasonable and prudent to focus management actions on factors contributing to smolt production in SJR tributaries and South Delta and, to develop a predictive simulation model tool that allows parameters that strongly influence smolt production, such as spring flow volume magnitude, duration, and frequency, to be assessed as changes in state variables are considered**.**

Comment #22: Habitat: Needs to include evaluation of habitat improvement measures (i.e., gravel restoration).

Response: See Response to Comment #4 (e.g. Habitat Improvement).

Comment #23: Hatchery: Smolt production should not be effected by flow.

Response: Depends upon how you define “smolt production”. It is true that in a hatchery, development of eggs to the smolt stage is not typically dependent upon instream flow (e.g. barring inadequate flow volume to the hatchery and/or insufficient water quality for water supplied to the hatchery etc.). However, at point of release into the river, smolt production is most definitely influenced by flow as demonstrated by numerous smolt survival vs. instream flow level tests that have been conducted throughout the SJR basin. Smolt production, defined either as the number of smolts leaving either the Stanislaus, Tuolumne, or Merced Rivers, and the Delta, is most definitely affected by instream flow level.

Comment #24: Outmigration Window: Spawner outmigration flow window determination. Meaning of flow/days ratio not clear.

<u>Comment</u>: *"The inclusion of 'duration' as a variable in the model is based on an unclear treatment of the ratio of days and flow that is not described in the document. From the data presented wet years showed both the longest (67 days) and the shortest duration (24 days) and critical years were almost as variable (34-57 days). The author seems to assume that the duration of the outmigrant period is the factor controlling subsequent return of the cohort. It is much more likely that years of low smolt abundance may appear to have a short emigration window because the sampling program can only detect fish at higher abundances – in years of high abundance the fish appear in the nets more regularly than in years when smolt are less abundant. It is not clear how the author developed their recommendations for number of days in the window of protection, but inspection of the data presented in Table 3 shows no relationship."* From Review Document #3 (see list in Introduction).

<u>Response</u>: The terms "spawner" and "out-migration" should not be linked together as the term spawner refers to adults migrating into the river to spawn and the term out-migration refers to juveniles leaving the river. The term flow/days ratio refers to the metric identified in Model Documentation (Marston 2005…Table 3) where the column labeled "Ratio (Flow/Days)" refers to the average daily flow during the spring pulse flow period (e.g. defined as cubic feet per second per day) divided by the number of days in the pulse flow period. For instance using data from row number one in Table 3, in 1988 the pulse flow at Vernalis averaged 1,936 cfs over a 57 day period (e.g. Apr.6 to June 2) returning at Flow:Duration ratio of 34 (e.g. 1,936 divided by 57 = 34). This metric was developed in an attempt to capture the concept, <u>and importance</u>, of both i) the amount of flow and ii) the duration of the smolt out-migration window of protection as SJR salmon smolts are migrating through the South Delta. Model Version 1.0 results presented at the 2006 Cal-Fed Environmental Water Account (EWA) Peer Review Conference indicated i) that the window of flow duration had greater smolt production improvement potential than flow magnitude, and ii) raising flow magnitude and increasing flow duration had more production potential than simply raising flow magnitude. This is to be expected (e.g. importance of flow duration) given that the current 31-day window of protection protects only about 50% of out-migrating smolts on average. Therefore providing a longer window of protection protects a greater fraction of smolts. A higher flow magnitude and providing a longer window of duration window would increase the number of smolts migrating into the South Delta and increase smolt survival through the Delta.

<u>Comment</u>: *"The author refers to a ratio of flows/days in support of their argument for including the number of days of outmigration as a regression variable. Such a ratio suggests that increasing number of days should lower the* *value of flow for outmigrants, but since the scale of flows is so much larger than the scale of days (1086 to 21808 cfs vs. 24 to 67 days) the resultant ratio is simply a restatement of the relationship with flow."* From Review Document #3 (see list in Introduction).

Response: Comment noted. Since the flow parameter is comprised of both flow magnitude and duration, including another time term would cause auto-correlation. In summary the combination of higher flow over longer duration, which provides increased window of protection for smolts out-migrating and increases smolt survival of smolts out-migrating, produces a greater number of smolt migrating through the Delta (e.g. a necessary pre-cursor for producing more adult escaping from the ocean…more juveniles into the ocean results in more adults coming out of the ocean).

Comment: *"Table 3: How was the flow window determined? What is the ratio (flow/days) intended to represent? Where did you get the estimate of juveniles out migrating? How can 1995 only have 24 days? Is this biased by when you started and stopped sampling?"* From Review Document #8 (see list in Introduction).

Response: Comment noted, see response above.

Comment: *"It seems like scenarios 5 and 8 (Figure 53) do appear to change significantly with the increase in length of the protection window, but that doesn't seem to be reflected in the text."* From Review Document #8 (see list in Introduction).

Response: Comment noted.

Comment #25: Salinity: Include effect of salinity to survival

Response: Comment Noted. Model version 2.0 will assess many parameter linkages to juvenile and adult production, salinity is one of the parameters that will be assessed. It is noted that Rich and Loudermilk (1991), in their preliminary evaluation of Chinook salmon smolt quality in the San Joaquin Drainage, found that gill ATPase levels (e.g. indicator of smoltification readiness) peaked in Merced River Hatchery smolts in late May to early June. This indicates that May would be the preferred time to make hatchery releases; however, May is typically when spring pulse flow shut down thereby resulting in substantially diminished flow velocities (e.g., longer travel times and exposure periods) and increased water temperatures that can kill smolts directly or even reverse the physiological process of smoltification. If naturally produced fish show the same gill ATPase peak levels in May as do hatchery produced fish, which is what Rich and Loudermilk found (e.g. ATPase levels peaked in late May-early June in naturally produced fish), then this could explain why poor adult production is highly correlated with years that have no or poor spring pulse flow in the mid to later part of May. It is noted that Rich and Loudermilk (1991) recommended that a more comprehensive study program be implemented to more fully assess smolt health and the causes for low smolt survival in the San Joaquin Drainage. More studies regarding the on-set and duration of gill ATPase are needed to determine if the late May-early June peak in gill ATPase is consistent across years.

Comment #26: Spawner abundance: Missing analysis of spawner abundance and 2 1/2 years earlier spring flow.

Response: Various VAMP annual reports have documented the strong relationship between spawner abundance and Vernalis spring flow magnitude 2.5 years earlier. As stated earlier this metric (escapement 2.5 years earlier) is a metric that is confounded by multiple age groups that have the capacity to vary widely over time. The appropriate metric to use in evaluating adult production against environmental variables present during the brood production year is "brood year production cohort" not "escapement 2.5 years earlier." Model Versions 1.0 and 1.5 have used the "brood year production cohort" metric.

Comment #27: Spawner Density: Apply Ricker equation to spawner density analysis. Density dependence must be included. Collinearity between spawner density and flow should be addressed. Use non-linear model for density.

Comment: *"The relationship determining smolt production (i.e., the number of smolts at Mossdale) appears highly unrealistic because (1) it does not adequately account for the role of parental spawners, and (2) it assumes that smolt production is determined almost exclusively be spring flow."* Comment 5 (Page 2) from SJRGA report.

Response: As pointed out by reviewers, when spawner numbers are very low then cohort production will be concomitantly low. Essentially at very low spawner densities we expect a linear, albeit highly variable stock recruitment relationship that passes through the origin (zero spawners implies zero recruits). The variability is driven by environmental factors, particularly flow and temperature. At higher spawner densities the relationship between spawners and recruits may become completely submerged in variability driven by environmental factors. This could be why there appears to be very little evidence of density dependence in the existing data – in fact, the number of smolts appears to be statistically independent of the number of spawners (see analysis in Appendix 2). We note that one reviewer spuriously demonstrates the existence of density dependence relationship in a regression analysis of the form log(Y/X) vs. X: such an analysis produces a significant relationship even when Y and X (numbers of smolts and spawners) are statistically independent because the dependent variable log(Y/X) incorporates the independent variable (X). Thus we argue that it is not necessarily problematic to fit a density-independent relationship provided the relationship is constrained to hold above a critical density at which the linear decline to 0 is expected to occur. This constraint threshold can also be estimated or a two-parameter saturating (i.e., Beverton and Holt) stock-recruitment function can be fitted. We will make more explicit this constraint issue in an analysis of model Version 1.5, but this problem is automatically taken care of in model Version 2.0.

Comment: *"The underlying population dynamics of the model can be described by a single equation in which adult cohort production is directly proportional to the square of spring flow: Adult Cohort Production α (Spring Flow)^2 ."* Page 4 from SJRGA report.

Response: Given the latest versions of the statistical models, this is no longer true. In addition, the way flow is entered, there is no reason to expect that the prediction is systematically biased in any way unless there are unmeasured aspects of the ocean model that confound the relationship of flow-smolt survivorship and the relationship of the number of smolts making it out of the delta and the probability of escapement (that is probability of surviving to spawn and not being harvested). The statistical models were chosen empirically based on regression smooths fit to the data (note, this does make inference regarding these models as somewhat problematic as the data is used in the model fitting procedure).

Note that a Ricker density dependent model with flow as a modifier of the density-dependent relationship can be written in the form:

$$S_t = F^{\alpha} E_{t-1} e^{-\beta E_{t-1}}$$

where S_t is the expected number of smolts at Mossdale, E_{t-1} is the total escapement the previous Fall and F is Vernalis Flow (modified from Speed, 1993, page 280); α and β are the parameters. Note, we can also represent this model on the log scale as:

$$\log(S_t) = \alpha * \log(F) + \log(E_{t-1}) - \beta * E_{t-1} \qquad (1).$$

This is a convenient form, because one can fit this using generalized linear models with a log-link (and for now, we assume Poisson errors) and $\log(E_{t-1})$ as an offset, E_{t-1} and $\log(F)$ as covariates. Or, more generally, as a log-linear model:

$$\log(S_t) = g(E_{t-1}, F; \theta) \qquad (2)$$

where g is an arbitrary function and θ is a vector of unknown parameters. For now, we have taken this last approach, assuming an additive model in F and E_{t-1}

and using generalized additive models to examine the form of *g*. Note, that this general model (2) includes as sub-model (1). The results suggest a model of the form:

$$\log(S_t) = \alpha * F + \beta * \log(E_{t-1}), \qquad (3)$$

which results in the following fit. This actually supports the contention opposite of what the reviewers imply (though they are discussing cohort production versus flow). That is, the effect of increasing flow by a fixed amount appears to have greater impact as the starting flow increases, and this impact is also greater the greater the starting number of spawners, a simple consequence of the log-linear nature of model (3).

Comment: *"Stock-recruitment curves, which depict particular forms of density-dependent relationships, are usually an integral part of any salmon population dynamics model (Quinn and Deriso 1999). To demonstrate that the SJR data exhibit clear evidence of density dependence, we fit stock-recruitment curves to three data sets provided in CDFG (2005). In the report, two of these data sets were cited as providing little evidence of any relationship between escapement and adult production (density dependent or not), but strong evidence that flow primarily determined adult production. These conclusions were again based on linear regressions of the form described above for Mossdale smolt estimates (equation 5)."* Page 9 from the SJRGA report.

Response: Again, we addressed this in our reply to a comment on page 4 and reply to comment 3 (page 2) from the SJRGA report. The estimation procedures described in the SJRGA Review will result in a dependence of the ratio of smolts/escapement versus escapement even if smolts and escapement are statistically independent (that is, there is no statistical evidence there is any relationship). We provide in Appendix 2 a simple, exact permutation test used to test the independence of smolts at Mossdale and total Escapement, and find no evidence of a statistical relationship. We do no believe of course that there is no relationship, but it could be given the weakness of it (i.e., survival of smolts dominated by environmental variables and the proportion surviving being universally very small) in addition to measurement error in both flow and smolts, and the limited sample size, there is little empirical evidence of a strong relationship. Our new model (V.2.0), using more refined estimates of the production of smolts from RST data, as well as the ability to include data on egg survival, and number of redds produced during a season, might indicate a more compelling density-dependence relationship. In the interim, we do agree that density dependence should be a priori a possibility in a model predicting the number of smolts, and as mentioned above, we have examined it empirically and fit statistical models that can naturally incorporate it.

Comment: *"In summary, there is strong evidence of density dependence in SJR production data. Further, the use of stock-recruitment analysis to estimate the* *relative contributions of escapement and flow to juvenile or adult production should provide more reliable and defensible results than those obtained by CDFG. We therefore strongly recommend that CDFG investigate alternative stock-recruitment relationships, and incorporate an appropriate form into their model as a basis for relating escapement to juvenile production."* Page 11 from SJRGA report.

Response: We addressed this above. If one cannot first demonstrate a significant association of smolts and escapement, it's hard to argue there is strong statistical evidence of density-dependence. However, as described above, we do not preclude the possibility of density dependence in our estimating statistical relationships of smolts to flow and escapement.

Comment #28: Stock/recruitment analysis missing.

Response: Please refer to our discussion and reply for Comment #27.

Comment #29: Temperature: Model needs to include results of SJR temperature Modeling.

Response: Agree. Water temperature will be included as a model parameter in model version 2.0. Spring water temperature decreases with flow increases in the Stanislaus (Figure 15), Tuolumne (Figure 16), and Merced Rivers (Figure 17) and as a result of increased tributary flow, and at Vernalis (Figure 18). It is interesting to note that water temperature at Vernalis cannot be cooled with increases in tributary flow when Friant is making substantial flood control releases (Figure 17). However, when Friant is in flood control release mode the SJR east-side tributaries are typically also in flood control release mode the combination of which is that water temperatures at Vernalis average about 68°F (20°C). Water temperature modeling indicates that water temperatures can be cooled to about 64°F (18°C)[1] at Vernalis when flows are approximately 8,000 cfs (e.g. when combined increased releases from east-side tributaries occurs when Friant is not in major flood control operations). Figure 19 (from Newman 2008) shows increased smolt mortality as water temperatures increase in the SJR approaching the South Delta. We also point out that travel times for smolt migration accelerate under these higher flows, thus reducing exposure time.

It is interesting to note that all three east-side tributaries provide substantially cool water temperatures at their respective confluences at flow levels approximating 3,000 cfs. Instream flow levels at the 3,000 cfs level provide substantial juvenile fish production benefits: i) greatly increased smolt survival (Marston 2005, Deas 2004, TID 2006, Marston 2007, Newman 2008), ii)

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[1] The California CDFG of Fish and Game recently identified that water temperatures for spring juvenile salmonid out-migration at Vernalis were impaired and submitted a listing proposal to the Central Valley Regional Water Quality Control Board to list spring water temperatures at Vernalis as impaired under the Federal Clean Water Act Section 303(d).

increased flood plain inundation which provides improved habitat quantity and quality (Jackson 2008, Gard 2008), and iii) reduced predation upon juvenile salmonids (Myrick and Cech 2001), and iv) SJR cooling capability at Vernalis, and increased smolt survival to and through the South Delta, when Friant is not in flood control operations.

Note also that, as requested by reviewers, we have begun to compile salmon coded wire tag (cwt) releases in the SJR system to facilitate survivorship analyses as was done for the Tuolumne river (Stillwater Ecosystems, Watershed & Riverine Sciences 2005). These analyses will eventually be used to refine estimates of reach specific juvenile Chinook salmon for the inland module of new model (See Appendix 3). These data should allow independent estimates of the effects of both flow and temperature on smolt survival in different reaches of the SJR system.

<u>Comment</u>: *"The strong correlation between spring flow and cohort production is certainly suggestive, but this correlation should not be interpreted as proof of a causal mechanism. It is well known that correlations between measures of fish productivity and environmental variables are often misleading and regularly breakdown as new data are collected (Walters and Collie 1988; Myers 1998). Furthermore, spring flows are likely to be highly correlated with flow conditions during other periods, as well as with other variables (e.g., temperature) that might be important determinants of juvenile growth or survival. Such "collinearity" limits the potential to distinguish between important and unimportant variables (e.g., Smith et al. 2003)."* Page 16 from SJRGA report.

<u>Response</u>: Our comments regarding confounding are relevant to this point. It is certainly true that correlation does not always equal causation, and one should always be cautious in interpreting associations derived from observational (non-experimental) data. However, the above discussion mixes up 2 different sorts of phenomenon. The first is that spring flow can be associated with flow during other periods and so these flow periods can confound the apparent association of spring flow and fish abundance (these other flow periods could represent the *W* in Figure 12). The second point is subtly different, in that things like temperature are on the causal pathway of temperature to survival. In this case, it is not a confounder of the relationship of flow and fish, but represents one of the pathways of how flow affects fish (temperature could represent a node in between A and Y in Figure 12). Depending on one's goal in the analysis, one might or might not adjust for temperature in an analysis examining flow and fish. For instance, if one wants to estimate the <u>total</u> causal association of spring flow and fish abundance, then one biases the estimate of this association (equivalent in some circumstances to a coefficient in a regression equation) by including temperature in the model. On the other hand, if one wants to estimate the causal association of spring flow and fish apart from the pathway relating to temperature, then in some circumstances simple adjustment works. For the purposes of the overall model, it is not clear that adjusting for temperature is

appropriate (particularly if there is no way to adjust flow and temperature separately). However, for the first issue, the absence of control of potential confounders, our new model by including more refined time steps will be better able to assess the relative contribution of flow at different critical periods to future cohort production.

Comment #30: Vernalis flow: Spring flow can be augmented with measures that will not improve flow in spawning areas. Vernalis flow is not good a surrogate for other habitat measures (upstream habitat, temperature, transport and all other impacts).

Response: It is recognized that many things influence adult and juvenile production. The question is what specific factors within the production process are controlling (e.g. limiting) population abundance. It is becoming increasingly clear (for reasons stated above) that spring flow both in the SJR tributaries and at Vernalis is critical to achieving more substantial and more stable juvenile, thence adult, salmon production in the SJR basin.

Comment: *"Nevertheless, there were some notable differences across years in April/May and February/March flow that may relate to cohort production. In particular, there were four brood years (1983, 1996, 1998, and 1999) for which average April/May flows at Vernalis were less than 6,000 cfs while February/March flows were 9,000 cfs or more (Table 3). The ratio of February/March to April/May flows in these years ranged from 1.6 to 4.9 (Table 3). Furthermore, the cohort production in these years was roughly 60% greater on average than the predicted values based on April/May flow. To test for possible effects of February/March flow in addition to April/May flow, we added the natural logarithm of the February/March to April/May flow ratio to the regression. The effect of the flow ratio was statistically significant (P = 0.041) and indicated an important contribution of February/March flow to cohort production. For example, predictions of cohort production increased by 70% when February/March flow was double that of April/May flow, and decreased by 43% when February/March flow was half that of April/May flow."* Page 18 from SJRGA report.

Response: Again, it is a good point that other periods of flow could contribute to cohort production, and our new model will have the resolution to include different effects for different critical periods. For the current model (V.1.5), the April/May flow is chosen as a proxy for flow conditions that could affect survival of offspring. Note, that the sample size is relatively small for regression models with many variables, thus the variability of the prediction goes up quickly relative to the reduction of the bias as one adds covariates to the model. The reviewers make a good point that leaving out Feb/March flow could bias the predictions, but they do not address whether adding them reduces the bias enough to compensate for the estimation variance that could very well be increased. One goal of model selection is this trade-off of variance and bias. Various methods (cross-validation) and statistics (AIC, BIC, etc.) have been used to try to optimize this balance for finite sample problems. In this case, the April/May flow was used not because it was thought to be the only period influencing ultimate cohort production, but was the best proxy for flows measured over the relevant periods.

We do of course recognize there is value to juvenile fish when flows occur in February and March, and are sustained (daily) at levels inundating nursery floodplain areas in the tributaries and along the SJR. Sustained high flows accelerating this habitat benefit from February through early June are even better.

Also the April/May period is used because this period, rather than Feb/March or other period, is the period that is coincides with smolt out-migration, and smolt out-migration abundance is strongly correlated with adult salmon production (Mesick et al. 2007, Jackson et al. 2008).

See Comment #29 for additional discussion.

Comment #31: Vernalis flow: Spring flow importance is not result of (confirmed by) model runs, but the model is built under this assumption.

Response: The apparent inference in this criticism is that the model was developed to support the hypothesis that spring flows are important, rather than being built upon the premise that the scientific data collected to date strongly support the finding that spring flow in the SJR tributaries, and at Vernalis, is the primary factor influencing both juvenile and adult production in the SJR basin. This inference is incorrect, as indicated in earlier responses. The relationship between spring flow and juvenile, thence adult, fall-run Chinook salmon production exists in the SJR basin. Model version 2.0 will add additional parameters that have been identified as having production influencing potential (e.g. delta exports, ocean conditions etc). It remains to be seen whether adding additional parameters will increase substantially the model's predictive power.

Comment: *"The model is basically comprised of three linear relationships that relate escapement (spawner abundance) and springtime Vernalis flow to future adult production.*
*(1) Mossdale Smolts = B1 * Escapement + B2 * Vernalis Flow*
*(2) Mossdale-to-Chipp's Smolt Survival = B3 * Vernalis Flow*
*(3) SJR Escaping Adults = B4 * Smolts surviving to Chipp's Island*
*= B4 * (Mossdale Smolts * Mossdale-to-Chipp's Survival)."*
Page 4 (Comment 1) from SJRGA report.

Response: This is not an accurate description of the model, because *SJR Escaping Adults* is not simply all spawners, but the portion that are from the specific cohort. So, this relationship applies across all ages of spawners, so the last equation could be written more accurately as:

SJR Escaping Adults(t+δ) = $\alpha(\delta)$*B4 * Smolts surviving to Chipp's Island(t) where $\alpha(\delta)$ is a parameter which is a function of the particular cohort. So, the model does not ignore the fact that Escapement is a function of several cohorts.

Comment: *"It is often the case that a simple model is preferable to a more complex one, especially when data are limited. However, at the same time, it is critical to understand why higher spring flows are associated with higher cohort production. In the absence of a clear mechanistic relationship, or even a plausible guess, the exercise of translating an empirical correlation into reasonable management recommendations is highly speculative and suspect. For example, there is no obvious reason to expect that increasing flow for a single week would affect smolt survival in that week in the same way that the season- wide average flow is related to season-wide smolt survival. However, that is exactly what the above model formulation assumes."* Page 5 from SJRGA report.

Response: The new model, with the weekly time step and use of more refined flow and smolt data (from RST) will address this point. For now, one must acknowledge the model cannot distinguish flow differences as smaller time scales than the summary measures of flow used (see Appendix 3).

See Comments #3, #27, and #40 for additional discussions.

Comment #32: Winter flows: Effect on fry and smolt rearing not analyzed.

Response: Agreed. See earlier discussion regarding role of winter flow upon fry, thence smolt production. See discussion in Comment #4.

Comment: *"The only environmental variable affecting salmon production that is included in the model is Vernalis spring flow. As a result, the effects of spring flow are likely overstated. Other potentially important determinants of juvenile growth and survival are not included. In particular, the potential beneficial effects on fry of high flows during January to March should be considered."* Comment 8 (Page 2) from SJRGA report.

Response: The inference behind this comment is that winter flow and/or fry production are materially influencing adult production trends in salmon bearing SJR east-side tributaries. It is becoming increasingly clear that spring flow is the primary driver of juvenile and adult production in the SJR east-side tributaries (e.g. spring flow is the production bottleneck). Therefore, it is not unreasonable to a have a model that includes only the primary factor influencing salmon production (e.g. spring flow). However, model version 2.0 will have winter flow and both fry production and fry out-migration as model parameters and the outcome of that inclusion will become clear.

The issue of whether or not Vernalis spring flow effects upon salmon production are overstated depends on whether or not Vernalis winter flow is materially influencing long-term adult salmon production trends in the east-side SJR tributaries. Model Version 1.0 documentation (Marston 2005) showed that Vernalis flow, at levels less than about 10,000 cfs, primarily consists of flow from the east-side tributaries (e.g. Stanislaus, Tuolumne, and Merced Rivers). At measured spring flows greater than 10,000 cfs Friant flood control releases contribute to Vernalis flow levels. For winter flows, this same relationship (e.g. east-side tributary flow comprises the majority of Vernalis flow) is true as well (Figure 20).

It is known that in years when winter freshet flows (e.g. pulse flow concurrent with rainfall events) occur fry can out-migrate from the Stanislaus, Tuolumne, and Merced Rivers in large numbers (various sources). Thus far, it does not appear that out-migrating fry, and the winter flows they depend upon for out-migration, are materially contributing to adult production. However elevated late winter flows to appear to improve smolt rearing habitat and also lead to improved smolt production (Jackson et al. 2008).

Analyses comparing fry production from the Stanislaus River to adult brood year cohort production, show that fry out-migration abundance is poorly correlated to adult production as compared to smolt out-migration abundance (Carl Mesick personal communication). Jackson (et. al 2008; provided in its entirety as Appendix 4) showed that spring Vernalis flow explained the vast majority of variability in Tuolumne River adult recruits. This is not surprising given that Tuolumne River flow contributes substantially to Vernalis spring flows. Jackson showed that Tuolumne River spring flow explains most of the variation in the number of smolts leaving the Tuolumne River.

Jackson showed that juvenile production in the Stanislaus River was higher in years when elevated winter flows occurred and hypothesized the reason for this was that winter flows forced fry into the downstream reaches where they could rear during spring pulse flow periods. A recent Tuolumne River instream flow assessment by Gard (2008) showed that floodplain inundation increases dramatically as flows enter the 1,000 to 3,000 cfs range.

The data suggest that the influence of spring flow is considerably more important (e.g. first order effects) than flows at other times of the year (e.g. second order effects) for determining productivity of the SJR Chinook fall run population. From a modeling perspective, if the effect of one factor can be demonstrated to have an order of magnitude less effect on production than another factor, then the lesser factor can be omitted whenever the effects of noise in the model are at least as large as this lesser factor thereby masking its contribution to the variables concerned (e.g., contribution of a cohort to future escapement or annual escapement).

To quantitatively describe first and second order effects, a multivariate general linear model would have to be fitted to the data that had flows at different times of the year as independent variables and see which of these flow windows is best correlated with the observed variable (e.g. cohort contribution to catch plus escapement).

It appears elevated spring flow has a three-fold benefit i) it produces more juvenile rearing habitat, ii) it produces more smolts leaving natal tributaries, and iii) it produces more adults (e.g. presumably by increased smolt production and out-migration from the tributaries, increased smolt survival through the Delta which, results in more juveniles leaving the Delta and entering the ocean which results in more adults returning inland to spawn).

Comment Category 4. Model Validation

Comment #33: Hatchery: Sensitivity analysis needed for hatchery assumptions.

Response: Hatchery supplementation assumes the well documented (e.g. supported) production trends which have occurred at the Merced River Hatchery (MRH) over the last 30+ years. Regarding smolt survival vs. flow relationships, because most of the SJR smolt survival flow vs. survival tests have been conducted using MRH production, it is both reasonable and prudent to assume that future hatchery production would behave (e.g. survive) at the same rates

Mesick 2008 found that hatchery fish comprise the majority of escaping spawners in at least one of the SJR tributaries (e.g. Tuolumne River). Mesick concluded a two-fold reason for this: i) large amount of strays entering the Tuolumne from hatcheries occurring in both the SJR and Sacramento River basins; and ii) lack of sufficient spring instream flows for smolt production and out-migration survival. While not strictly a “sensitivity test” it is another line of empirically derived evidence supporting the hatchery relationships provided in, and results stemming from, the model.

Future model development efforts will include a classical sensitivity analysis to discern which model parameters are having the most influence upon salmon production.

Comment #34: No model validation.

Response: Agree within the classical sense of model validation. Because salmon have such a unique life cycle where age classes from various brood years overlap it is impossible to validate a full life history model in the classical sense where a calibrated data set is compared to a validation data set.

Comment #35: Validation data should not be included in analysis.

Comment: *"Improving Predictive Reliability. The predictive reliability of the model can be assessed by holding out data to test against for validation purposes. Alternatively, the variation associated with redictions can be assessed by removing a handful of data and refitting the model's equations using a bootstrap approach to quantify how different the model's predictions are using parameters fitted to different subsets of years."* From Review Document #1 (see list in Introduction).

Response: Comment noted.

Comment: *"I have not fully digested the argument made in the SJRGA review about calibrating juvenile outmigrants rather than escapement, but it could only be more informative to check fit at different points in the life cycle. My concern would be the relative quality of the types of data used for comparison. Validation reflects on the data as well as the model. Using high quality, independent data that has not already been used in the model should be a priority."* From Review Document #1 (see list in Introduction).

Response: Comment noted.

Comment: *"1) The ability to hold out data for validation purposes is important. Here, the same data are used to develop the empirical relationships and to predict for validation. To present validation results it would be a good idea to wait until you have a few more years to predict that were not included in the model. Alternatively, you might consider a bootstrap method, but that would require re-fitting the empirical models. If you want to submit the paper now, just refer to what you are presenting as calibration, rather than validation (which it is not)."* From Review Document #6 (see list in Introduction).

Response: Comment noted. Validation is a process that pertains to fitting model parameters to part of the data and then to using another part of the data to assess the "goodness-of-fit". A more modern and, in our opinion, better concept is to use Bayesian methods to find the distributions of model parameter values (rather than point values) that are most likely in the context of producing the observed data. This approach then allows prediction of most likely outcomes, but with confidence intervals determined using the estimated distributions. This approach also allows us to compare the performance of various models relating to different assumptions, particularly simplifying assumptions that replace functional dependence with constant rates.

Comment #36: Validation should be based on cohort production rather than escapement.

<u>Comment</u>: *"As a result (reference to comment #10), the model is a poor predictor of cohort production. The poor performance of the model is not immediately obvious because the model currently compares predicted and observed annual escapement rather than cohort production. Cohort production should be used as the primary measure for evaluating model performance."* Comment 2 (Page 1) from SJRGA report.

<u>Response</u>: In our view, the variables used to evaluate the performance of the model depend on the purpose of the model. We agree that the current model is far too crude in not following the fate of cohorts in any detail, particularly their fate in the ocean fishery. This is remedied by formulating an age structured cohort fisheries model (model V2.0). However, in this new model, it may still be appropriate to find the best fitting parameters in terms of minimizing differences between model estimates and empirical data on escapement.

EA Engineering (1991) used escapement to validate their model in two ways: i) used an earlier time period than what the model was built upon and ii) conducted a variety of statistical tests comparing historical estimates of escapement to modeled estimates of escapement. These procedures could be considered for model validation in future model versions.

See response to Comment #10 for additional explanation.

Comment #37: Escapement: Not a significant predictor for smolt abundance calculation.

<u>Response</u>: See response to Comment #27.

Comment Category 5. Model Results

Comment #38: Hatchery: Questionable statement that hatchery will increase smolt production and subsequent escapement. Conclusions regarding hatchery augmentation seem dubious.

<u>Response</u>: If smolt production is in fact driving adult abundance, and empirical data collected to date strongly supports that it is, then in instances where hatchery production is focused on producing and releasing smolts it would not be unreasonable to assume that substantial adult production could accrue from smolt-sized hatchery releases. However, it is noted that the same environmental conditions that cause smolt mortality in SJR tributaries and in the South Delta would also cause mortality upon hatchery produced smolts. The main point to be gleaned here is that larger numbers of smolts must be produced to enable a

larger quantity of smolts to migrate through the “environmental gauntlet” presented to smolts during years when insufficient spring flows exist.

An Aside Regarding Hatchery Augmentation: The issue of hatchery production and supplementation as mitigation and/or restoration tool for salmon production loss is a broad and complex one. To some, the “hatchery” word invokes a strong emotional response and is a topic that is seems to be highly divisive given the strong emotional response it elicits. Many have extolled the benefits or impacts of hatcheries (Williams 2006 as one example) so an exhaustive treatment will not be provided here. It would be helpful if a forum, or some type of unbiased peer review panel process, were convened to identify the constraints within which a hatchery could operate to assist in restoration and management of fall-run Chinook salmon in the SJR basin. Perhaps the CDFG, as the State’s Trustee Agency for protection and management of fall-run Chinook salmon in the SJR basin, could take the lead in sponsoring such an investigative forum such that a preferred type of hatchery (Lichatowich): i) mitigation, ii) harvest augmentation, iii) supplementation, iv) restoration, or v) conservation, if any, might be a viable management tool coupled with appropriate juvenile and adult evaluation metrics to assess successful could be considered. How to achieve a balance between artificial and natural production and maintain genetic integrity of both will be the challenge.

Recently the FWS conducted a threat of extinction analysis for the Tuolumne River (Mesick 2008). Mesick applied the threat of extinction methodology assessment as identified in Lindley et al. (2007). Lindley et al. characterized the risk of extinction for Chinook salmon populations in the Sacramento-San Joaquin Basin relative to population size, rates of population decline, catastrophes, and hatchery influence. Per Mesick (2008) populations with a high risk of extinction (greater than 20 percent chance of extinction within 20 years) have a total escapement that is less than 250 spawners in three consecutive years (mean of 83 fish per year), a precipitous decline in escapement, a catastrophe defined as an order of magnitude decline within one generation occurring within the last 10 years, and a high hatchery influence. Populations with a low risk of extinction (less than 5 percent chance of extinction in 100 years) have a minimum total escapement of 2,500 spawners in three consecutive years (mean of 833 fish per year), no apparent decline in escapement, no catastrophic declines occurring within the last 10 years, and a low hatchery influence. Populations with a moderate risk of extinction are those at intermediate levels to the low and high risk criteria (e.g., total escapement in three consecutive years between 250 and 2,500 spawners.

Mesick concluded that the Tuolumne River fall-run Chinook salmon population is at a moderate to high risk of extinction based on the criteria by Lindley and others (2007) because the total escapement of naturally produced fish was about 755 spawners from 2005 to 2007 (i.e., moderate risk), there was a precipitous decline in escapement (i.e., high risk), and there was a catastrophic decline in escapement over a generation between 2000-2002 and 2003-2005 (i.e., high risk). Regarding hatchery influence, Mesick stated that there are no data to directly assess the genetic impacts of adult hatchery fish on the naturally produced Chinook salmon population in the Tuolumne River. If there are impacts from the Feather River, Nimbus, and Mokelumne River hatchery releases, then the average annual escapement needed to maintain a low risk of extinction would be substantially greater than 833 fish.

To maintain an average escapement of 833 fish Mesick estimated that adult brood year production would have to be 1,388 fish. Mesick estimated that a spring pulse flow level of 1,100 cfs over a 45-day period in April and May would be needed to provide suitable conditions for migrating juvenile salmon to reduce the threat of extinction. From information provided in response to Comment #32 and from smolt survival information contained in Marston 2005 (and elsewhere) an increase in pulse flow from less than 500 cfs, which is common in drier water year types, to over 1,000 cfs would have some improvement for reducing water temperatures thru reducing thermal impacts to out-migrating juvenile salmon and by increasing smolt survival (e.g. resulting in an increase in smolt abundance migrating into the South Delta which is a necessary precursor for improving adult escapement).

Recent analysis suggests that the MRH, which was constructed as a small supplementation hatchery, and more recently is financed in part with funds to partially offset State export facility losses (B. Loudermilk personal communication), is having a population conservation influence upon Merced River escapement abundance in that MRH production and release into the Merced River appears to have delayed the recent population crash as compared to the Tuolumne.

Figure 21 shows SJR tributary flow hydrographs in 2002, which is representative of dry year flow schedules in the Stanislaus, Tuolumne, and Merced Rivers. The Stanislaus has highest instream flow levels, followed by the Tuolumne then the Merced Rivers. It is interesting to note that the Stanislaus had the higher instream flow in late May-early June which we know from water temperature, smolt physiology, and smolt out-migration studies provides an increased smolt out-migration protection window that affords increase smolt survival (by higher flow) and increased smoltification readiness (by reduced water temperatures). Figure 22 shows the SJR escapement trend from 2000 thru 2007 and shows all three rivers salmon population crashed by 2007. However, the Tuolumne salmon population was the first to crash in 2005 while the Stanislaus and Merced population lagged two years behind before crashing. The Stanislaus had the highest instream flow schedule in the drier years during the brood production years contributing to the 2002 thru 2007 escapements. The Merced, with the lowest instream flow schedule for the drier years contributing to the 2002 thru 2007 escapements augmented natural smolt production with artificial (e.g. hatchery) smolt production. The Tuolumne River with an in-between instream flow schedule and no hatchery augmentation showed the worst population resiliency and was the first to crash. It appears that hatchery augmentation, which infuses smolts into the juvenile production pipeline, can dampen population abundance stressors.

However, even excessive and prolonged environmental pressures (e.g. insufficient instream flows etc) can cause the adult population to crash even if hatchery augmentation occurs (e.g. hatchery fish susceptible to same environmental stressors as naturally produced fish). Additionally, MRH smolt production rises and falls based upon MRH escapement abundance. MRH escapement abundance experiences the same peaks and crashes as does the Stanislaus, Tuolumne, and Merced in-river escapements. This suggests that hatchery production alone cannot produce population resiliency alone and that improvement in instream flows during the smolt out-migration season needs to occur concurrently. Similarly, its impacts assumed by many are variable at best. Improved environmental conditions in the spring would help maintain an adequate hatchery escapement to provide a sufficient number of smolts that could augment natural production and reduce instream flow needs. Today, hatchery augmentation would occur within some well defined hatchery genetic planning guidelines to help maintain genetic integrity. Monitoring of both hatchery juvenile production and contribution to adult escapement should occur to be able to assess the relative influence hatchery production is having upon naturally produced fish genetics.

Comment #39: Model uncertainty: Maximum likelihood or Bayesian estimation must be used. Monte Carlo. Ad-hoc tuning the model parameters.

Response: For model V2.0, we will use a Bayesian estimation technique (using a MCMC algorithm to derive a random sample from the posterior distribution) to derive the parameter estimates and confidence ranges.

Comment #40: VAMP: Evaluation of VAMP effects is weak. Not enough data for any serious conclusion (dry years observed only).

Comment: *"Because the relationship between flow and adult production is not reasonable, current version of the model should not be used to evaluate the possible effects of alternative VAMP flows on adult production."* Comment 3 (Page 2) from SJRGA report.

Response: This is being addressed both by alterations to the original model (e.g. V.1.5) as well as the development of a new model (V2.0) that contains more refined time steps in the inland portion and more detail in the ocean section of the model. This will allow for estimation of the impacts of more detailed scenarios of VAMP flows as well as a better evaluation of the relative importance of ocean harvest and conditions on the impact of returning spawners relative to the changes in flow regimes and their impact both on returning spawners and outmigrating smolts. However, an important point to keep in mind is that this more refined model will be more highly parameterized, and that will likely lead to greater variability in the prediction of state variables relative to the existing simpler model, given the classic variance-bias trade-off. In the current model, flow is entered as a summary statistic over large blocks of time and associated likewise with summaries of fish abundance as measured over a season. The pitfall of such an approach is that one can not distinguish how perturbations to flow on shorter time scales lead to changes in survival. The virtue is that the data are most reliably measured at these larger scales, particular with regard to fish abundance, since it is now averaged over a larger time scale which reduces inherent day to day basis or week to week basis variability, some of which is real and some of which is measurement error. Thus, the estimated associations, though not able to inform decisions about flow on a finer time scale, will be more reliable (less variable) than those measured on a weekly time step. So, there is in essence no free lunch, as the variability of the overall model with regards to prediction will go up as the model contains more parameters. Thus, both the cruder model and the more refined model will each be useful for assessing the impact of flow. Other empirical data and models will no doubt be useful as well.

For additional information regarding South Delta smolt survival studies the reader is referred to Newman (2008).

Comment #41: Background info: Input data on exports, delta inflow, etc needed; All data used must be presented. There should be an overview of sources of data and time spans of various time series data used.

Response: Comment noted.

Comment Category 6. Presentation

Comment #42: Cohort reconstruction: Explanation of cohort calculation is needed.

Response: Comment noted. Explanation of cohort calculation is provided in both Table 7 (from the original CDFG model documentation report) and the notation provided underneath Table 7.

Comment #43: Flow relation with other causal mechanism should be elaborated to signify flow importance.

Response: Comment noted.

Comment #44: General: Non-standard presentation of model structure, Parameterization, and uncertainty of estimates.

Response: Comment noted. This general comment has been addressed by our remarks and changes in our models.

Comment #45: General: Terminology is not consistent.

Response: Comment noted.

Comment #46: Hatchery: Not clear how hatchery augmentation was included in the model.

Response: The mathematical computational detail for the model is included here (Appendix 7). In summary, hatchery production is added to natural production when the input knob for hatchery production is turned on in the model. When turned on, adults from tributary annual escapements are assigned to a "surrogate hatchery" on each tributary that is presumed to operate as has the Merced River Hatchery. Where: hatchery escapement is predicated upon in-river escapement, female hatchery escapement is a fraction of total hatchery escapement, eggs obtained is proportional to females spawned, smolts produced is proportional to eggs spawned. All hatchery smolts are released near the lower rim elevation dams (e.g. Crocker-Huffman on the Merced, La Grange Dam on the Tuolumne, and Goodwin on the Stanislaus) on a weekly time step and are subjected to the smolt vs. flow survival relationships for each tributary as described in Marston 2005. Once smolts survive to Mossdale then South Delta smolt vs. flow survival rates are applied. At the end of each year all smolts surviving through the Delta are summed and the number of brood year returning adults is estimated. The estimated number brood year production adults is then segregated into age groups 2 thru 5 and added to natural production. Annual escapements are then generated by summing the appropriate age abundances.

Comment #47: Inconsistency: Supporting files spreadsheet, model and Tables are not consistent.

Response: Comment noted.

Comment #48: Model description and recommendations should be separate documents.

Response: Comment noted.

Comment #49: Smolt: Explanation of Smolt abundance calculation at Mossdale is needed (assumptions are not clearly stated).

Response: Comment noted.

Comment #50: Summary Statistics: Basic summary statistics should be also presented for all data.

Response: Comment noted.

Comment #51: Exports: Effect of Delta exports is not well documented.

Response: Comment noted.

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Appendix 1

Tables and Figures

Table 1. Spring Vernalis Flow Levels 2000 thru 2008

Flow Level	**Frequency**
3,200	5
4,450	1
5,700	1
7,000	0
Non-VAMP (>7,000)	2

Table 2. Mossdale Smolt Production in Years with Elevated Escapement

Year	Fall Escapement	Smolt Production	Vernalis Flow	% of Minimum
1988	25,169	1,174,313	1,983	159%
1989	20,583	4,289,238	1,900	**581%**
2001	39,447	852,639	2,853	115%
2002	26,659	738,640	2,382	100%

Note: Smolt production values presented here differ slightly from those presented in Marston 2005 (e.g. Model Documentation) due to use of an updated smolt efficiency expansion relationship developed from data obtained in years 2006 thru 2008.

Table 3. Vernalis Flow Magnitude/Duration and Juvenile Salmon Out-migration

Vernalis Window Flow Magnitude/Duration and Juvenile Salmon Production							
WY Type	**Year**	**Start Date**	**End Date**	**# Days**	**Flow (average daily)**	**Ratio (Flow/days)**	**Juveniles Outmigrating**
C	1988	6-Apr	2-Jun	57	1936	34	1050122
C	1990	14-Apr	5-Jun	52	1296	25	256212
C	1991	5-Apr	22-May	47	1086	23	522441
C	1992	2-Apr	20-May	48	1277	27	265375
W	1993	2-Apr	19-May	47	3668	78	254092
C	1994	7-Apr	11-May	34	1993	59	417637
W	1995	17-May	10-Jun	24	21808	909	3078016
W	1996	6-Apr	12-Jun	67	7249	108	1145994
W	1997	4-Apr	8-Jun	65	4599	71	588882
W	1998	7-Apr	6-Jun	60	21080	351	2456575
AN	1999	15-Apr	10-Jun	56	5504	98	318432
AN	2000	3-Apr	1-Jun	59	4884	83	470538
D	2001	14-Apr	27-May	43	3671	85	752964
D	2002	9-Apr	23-May	44	2943	67	682884
BN	2003	10-Apr	19-May	39	2992	77	519659
D	2004	5-Apr	18-May	43	2936	68	321974
Multiple Regression							
# Days (x1) & Average Flow (x2) vs. Juvenile Salmon Out-migration (y)							
R-squared Value 0.89 (p<0.001)							
Equation ((#days*-6125.28)+(Average Flow*117.38)+467018.5)							
	Lower 95%			*Upper 95%*			
Intercept	-287591.6			1221629			
X1Variable	-20528.3			8278			
X2Variable	91.6			143			

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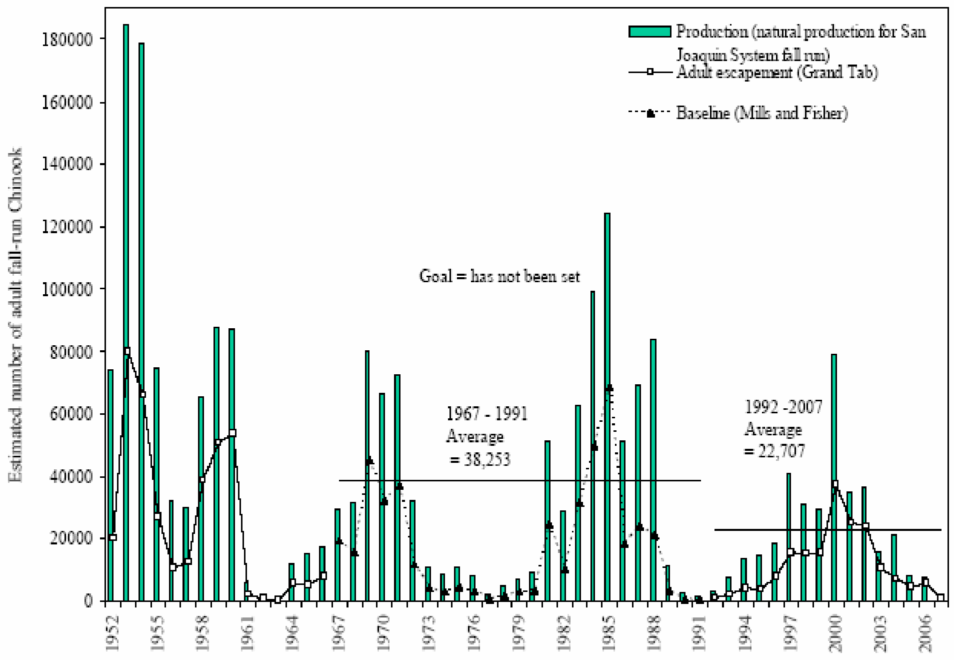
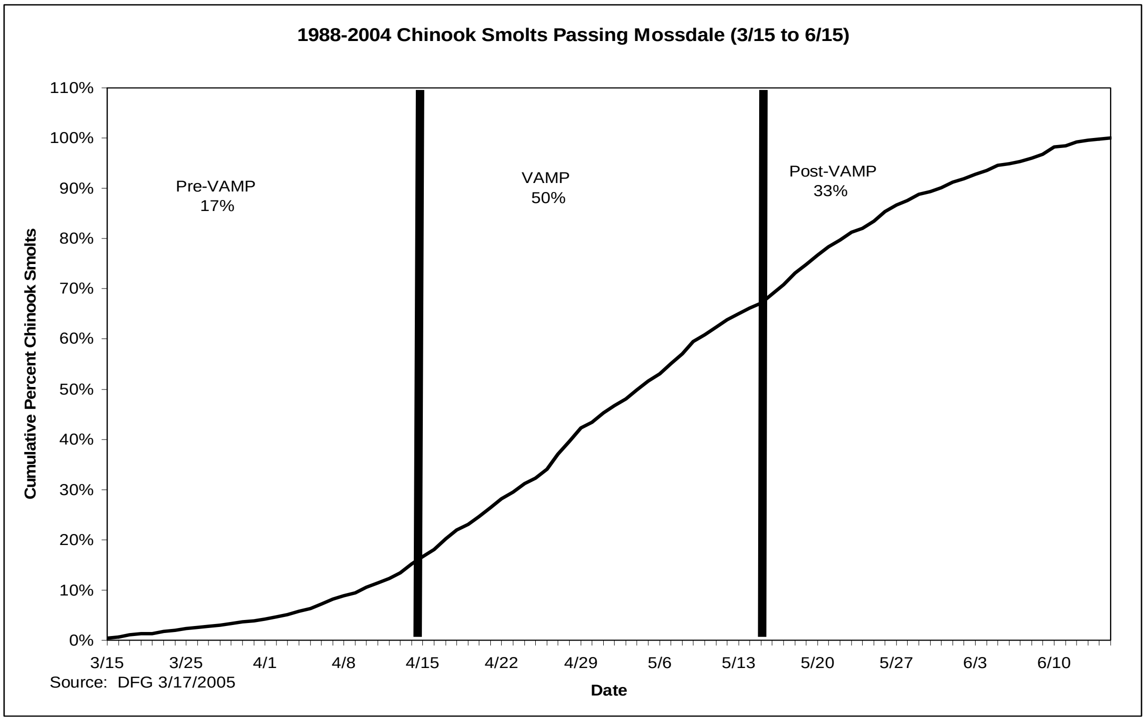


Figure 37. Estimated yearly natural production, and in river escapements of San Joaquin System adult fall-run Chinook salmon. The San Joaquin System is the sum of the Stanislaus, Tuolumne, and Merced Rivers. 1952 - 1966, and 1992 - 2006 numbers are from CDFG Grand Tab (August 20, 2007). Baseline numbers (1967 - 1991) are from Mills and Fisher (CDFG, 1994).

Figure 1. San Joaquin River Fall-run Chinook Salmon Production Trends.
Note: Graphic source is from the Central Valley Project Improvement Act-Anadromous Fish Restoration Act (AFRP) website.



Source: DFG 3/17/2005

Figure 2. Mossdale Smolt Out-migration Window.

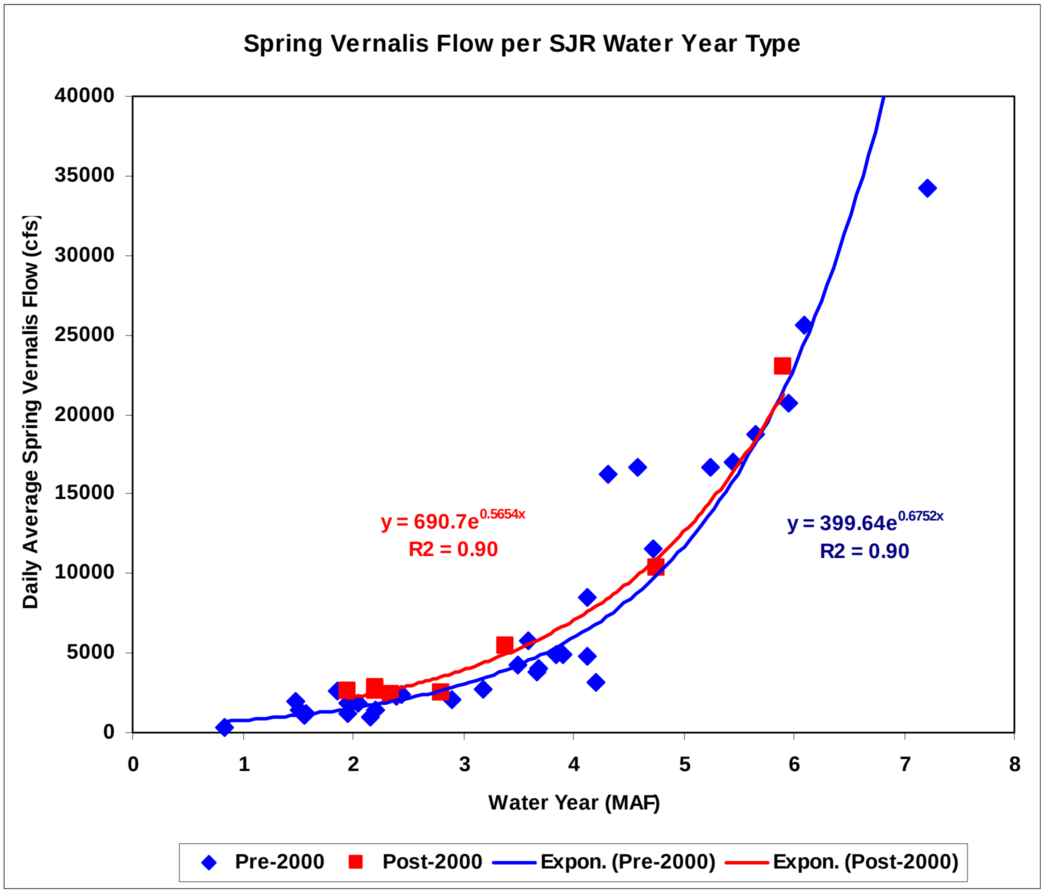


Figure 3. San Joaquin River Flow at Vernalis—Pre and Post VAMP. Note: Vernalis winter flow is primarily comprised of combined flow from the Stanislaus, Tuolumne, and Merced Rivers.

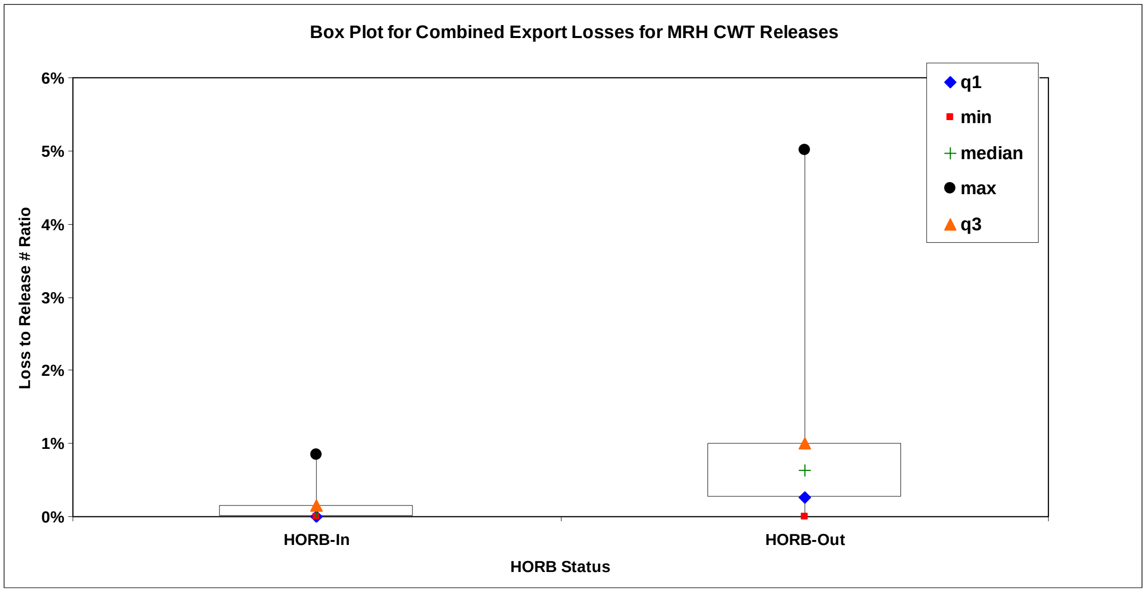


Figure 4. Recovery of Coded Wire Tagged Salmon by Export Facilities. This figure shows export loss of all Merced Hatchery coded wire tag release groups from 1994 through 2006. Both HORB-in and HORB-out have less than 1% loss.

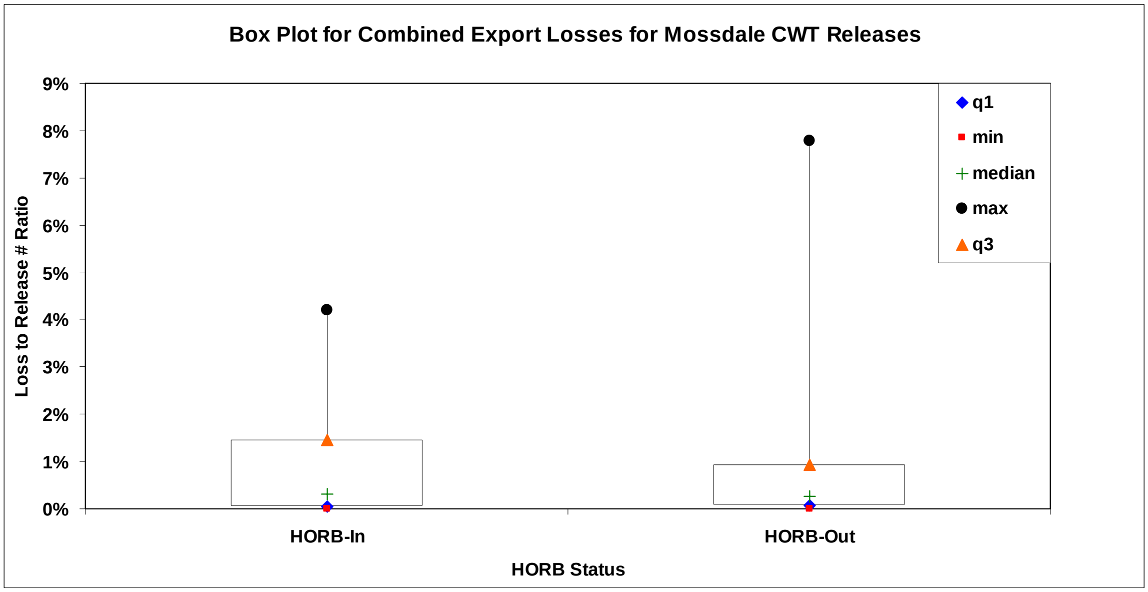


Figure 5. Recovery of Coded Wire Tagged Salmon by Export Facilities. This figure shows export loss of Merced Hatchery coded wire tag Mossdale release groups from 1994 through 2006. Both HORB-in and HORB-out have less than 1% loss.

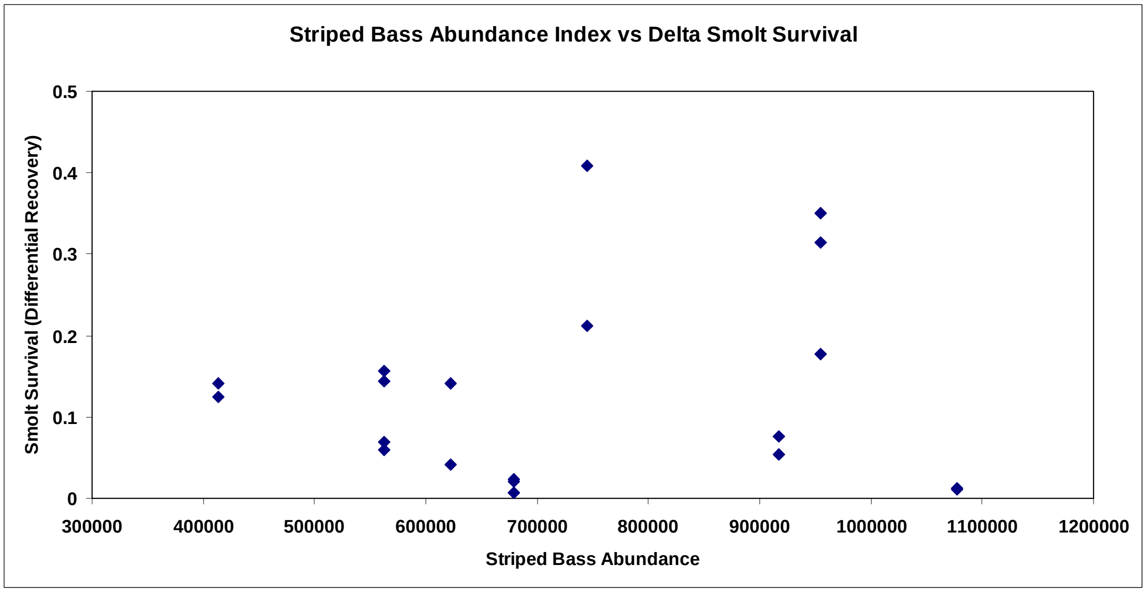


Figure 6. Striped Bass Abundance and Delta Smolt Survival.

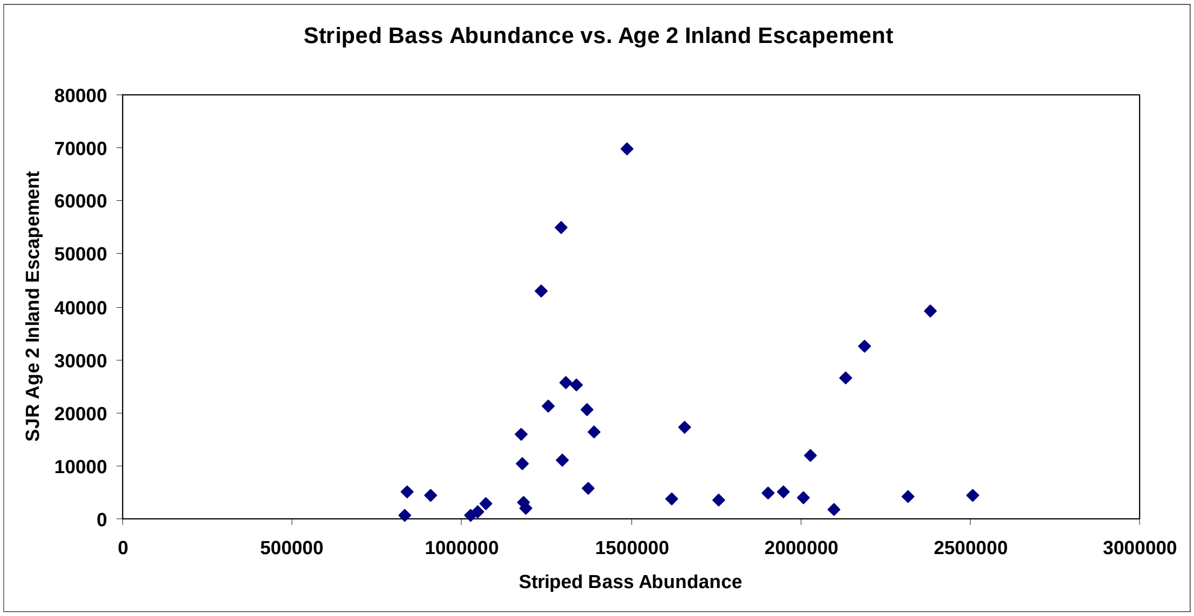


Figure 7. Striped Bass Abundance and Age 2 Inland Escapement.

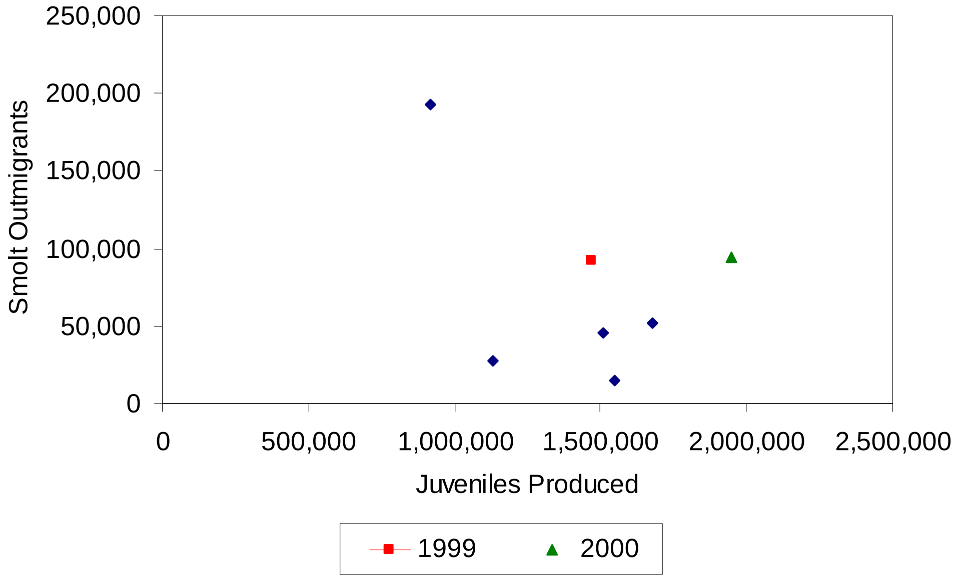


Figure 8. Juveniles Produced to Smolt Outmigrants-Stanislaus River**.** The estimated abundance of all sizes of juveniles that passed the Oakdale screw trap (RM 40) plotted with the estimated abundance of smolt out-migrants (≥ 70 mm Fork Length) at the Caswell State Park screw traps (RM 5) in the Stanislaus River from 1998 to 2004. The Knights Ferry Gravel Replenishment Project (KFGRP) constructed 18 spawning beds in the Stanislaus River in summer 1999. A comparison of the 1999 and 2000 estimates provides the best evaluation of the effects of gravel augmentation on juvenile and smolt production, because they occurred immediately before and after the KFGRP and they were both affected by similar spring flows between February 1 and June 15 (7,394 cfs and 6,940 cfs, respectively) and similar numbers of spawners (2,600 and 3,200 Age 3 equivalent fish, respectively).

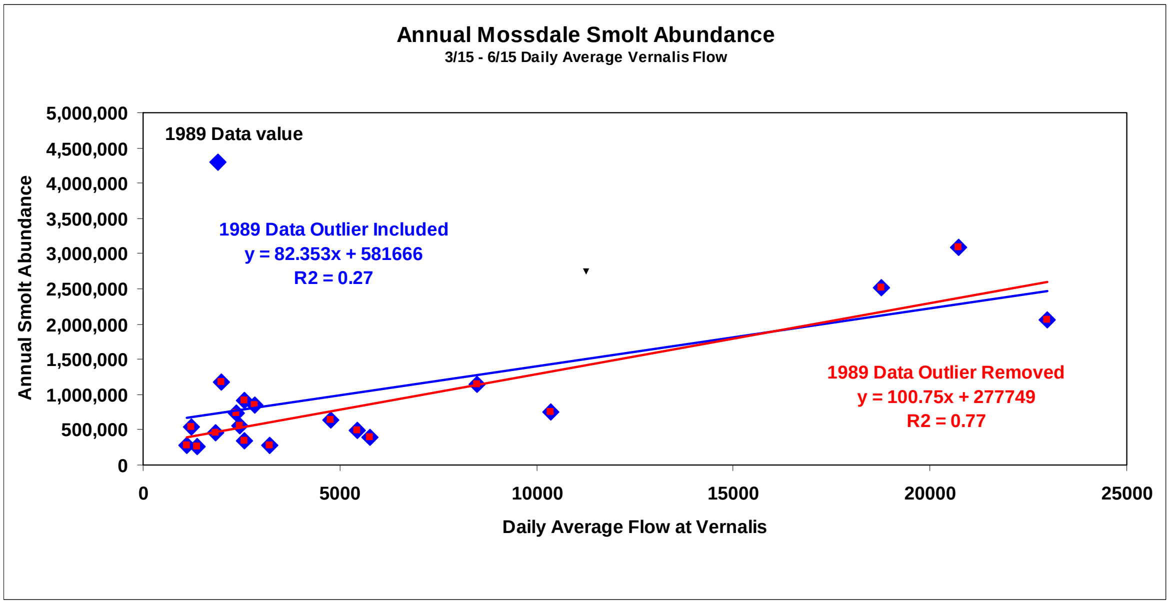


Figure 9. Mossdale Smolt Production with and Without Data Outlier.

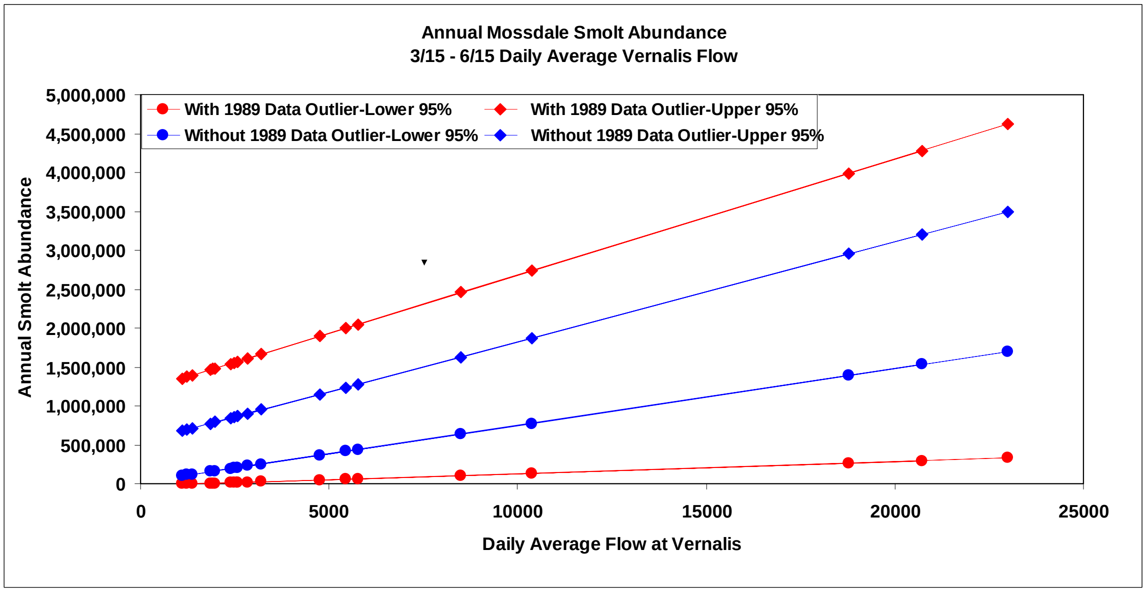


Figure 10. Mossdale Smolt Production with and Without Data Outlier-With 95% Upper and Lower 95% Confidence Band Widths.

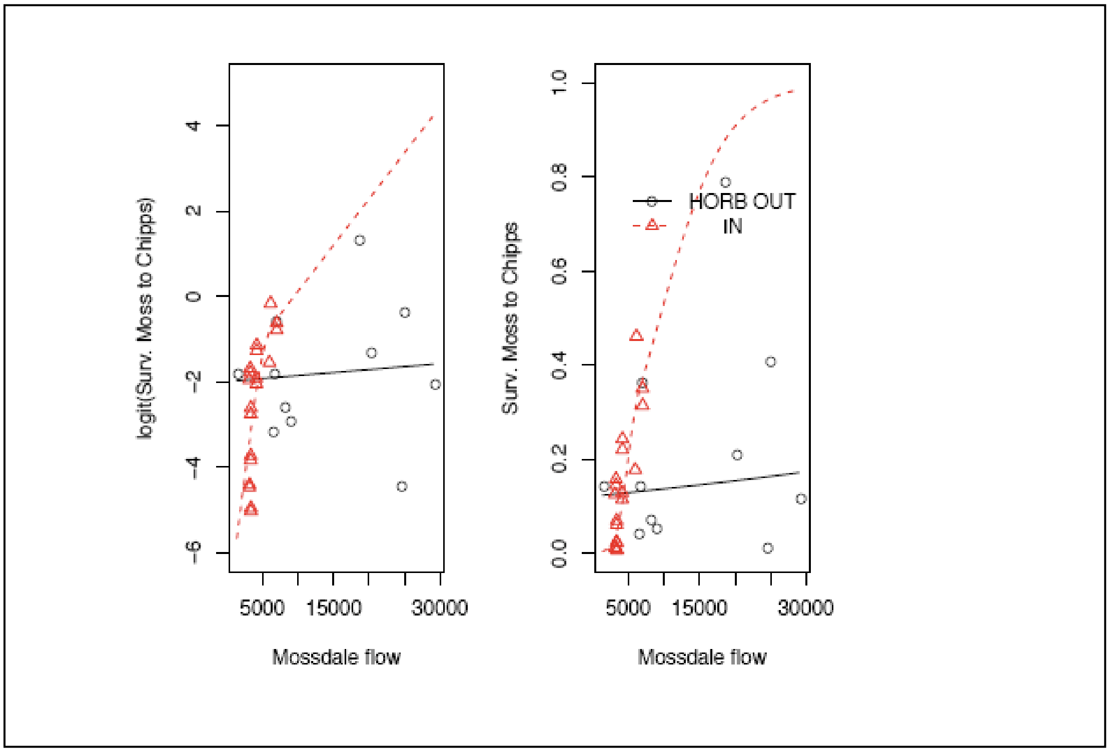


Figure 11. Results of GAM smoothe for survival from Mossdale/Durham Ferry to Chipps Island versus Mossdale flow separately by HORB in and out. The plot on the left is on logit scale, the right on probability scale.

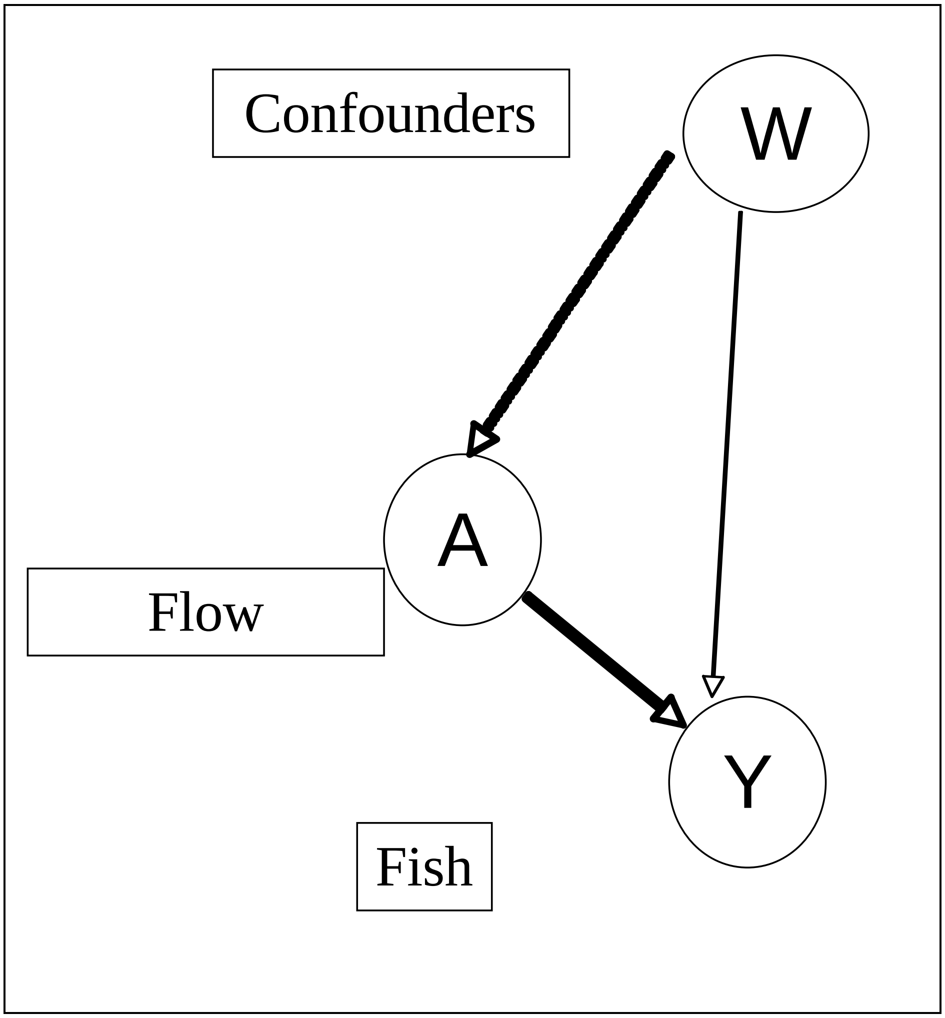


Figure 12. Causal diagram showing classing confounding.

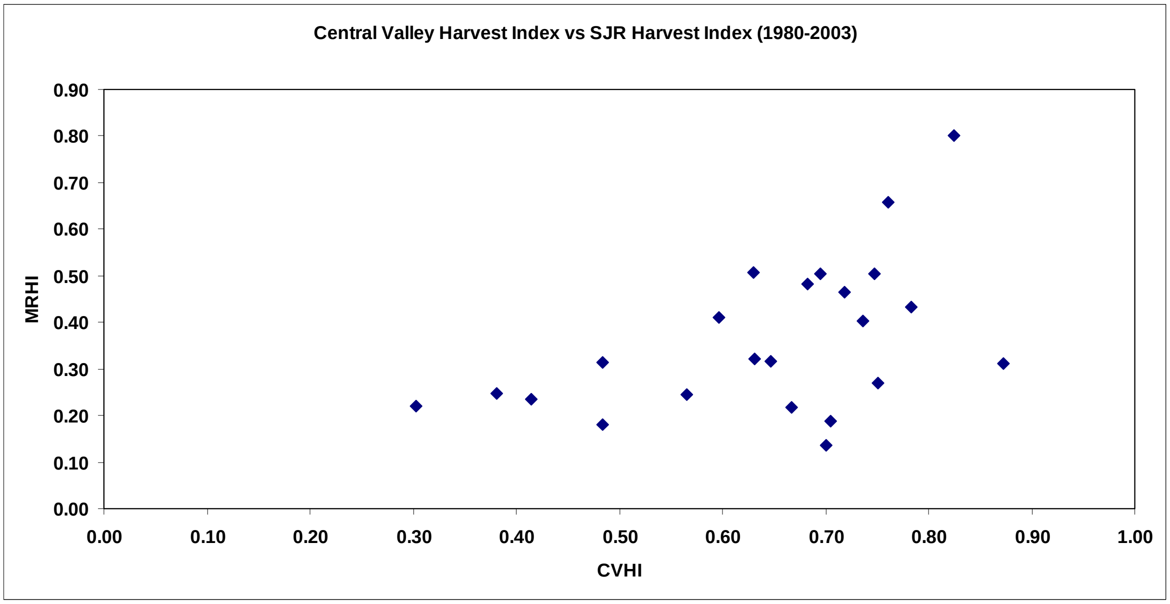


Figure 13. Comparison of Central Valley Harvest Index and SJR Harvest Index. Note: SJR harvest index based upon recovery of Merced River Hatchery coded wire tag salmon in ocean fisheries and inland escapement. Preliminary data and results indicate that the Central Valley Harvest Index is higher than the SJR harvest index suggesting that Sacramento fall-run are being harvested at a higher rate than SJR salmon indicating that adult production is lower than that which is reported by the CVPIA-AFRP. The significance of this is, SJR adult production is lower than what is currently being estimated.

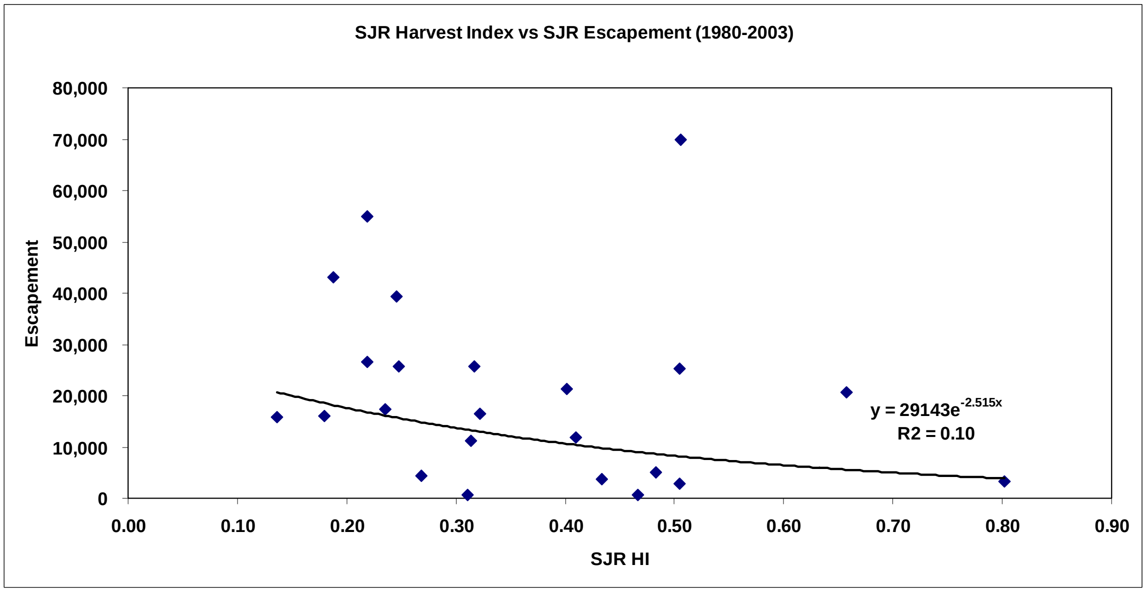


Figure 14. SJR Harvest Index vs. SJR Escapement. Note: SJR harvest index based upon recovery of Merced River Hatchery coded wire tag salmon in ocean fisheries and inland escapement. Preliminary data analysis indicates that the SJR harvest index explains only 10% percent of the variability in SJR escapement trends for the years 1980 to 2003. It is likely that the paucity of data at the upper end of the SJR harvest index is creating the appearance that there is a correlation between the SJR harvest index and SJR escapement.

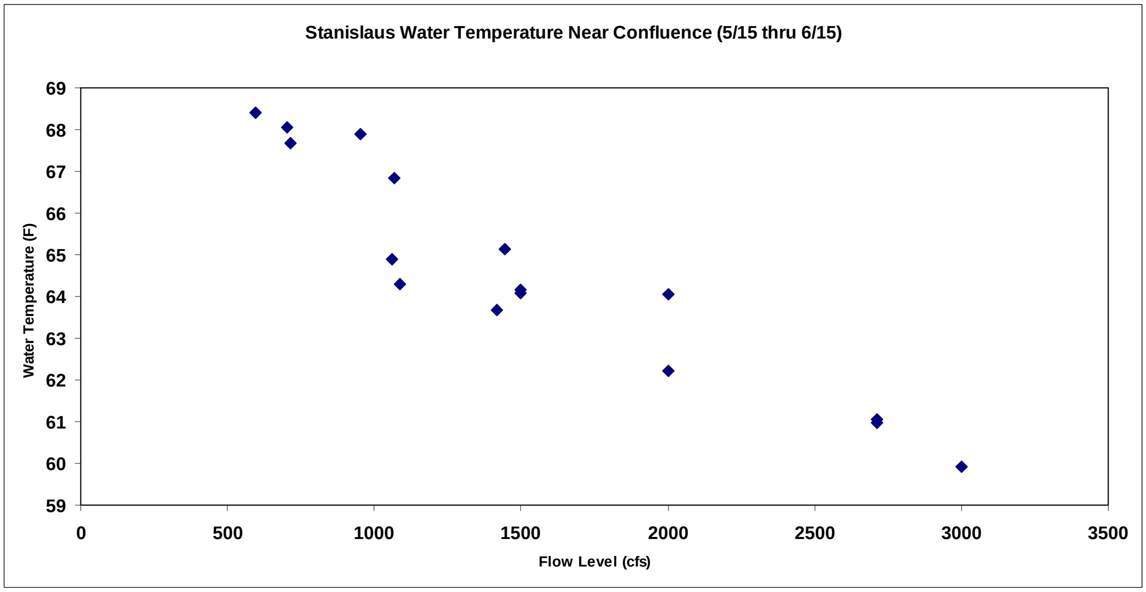


Figure 15. Spring Stanislaus River Water Temperature[1].

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[1] Data set includes historical flow and water temperature response data for years 1999 through 2006 (e.g. time frame is 5/15-6/15) as modeled with the SJR Basin HEC5Q Water Temperature Model Developed by Don Smith, Avry Dotan, and Mike Deas for the CalFed Ecosystem Restoration Program. Also included is new data generated by increasing flows during the 5/15-6/15 time frames and observing predicted water temperature response.

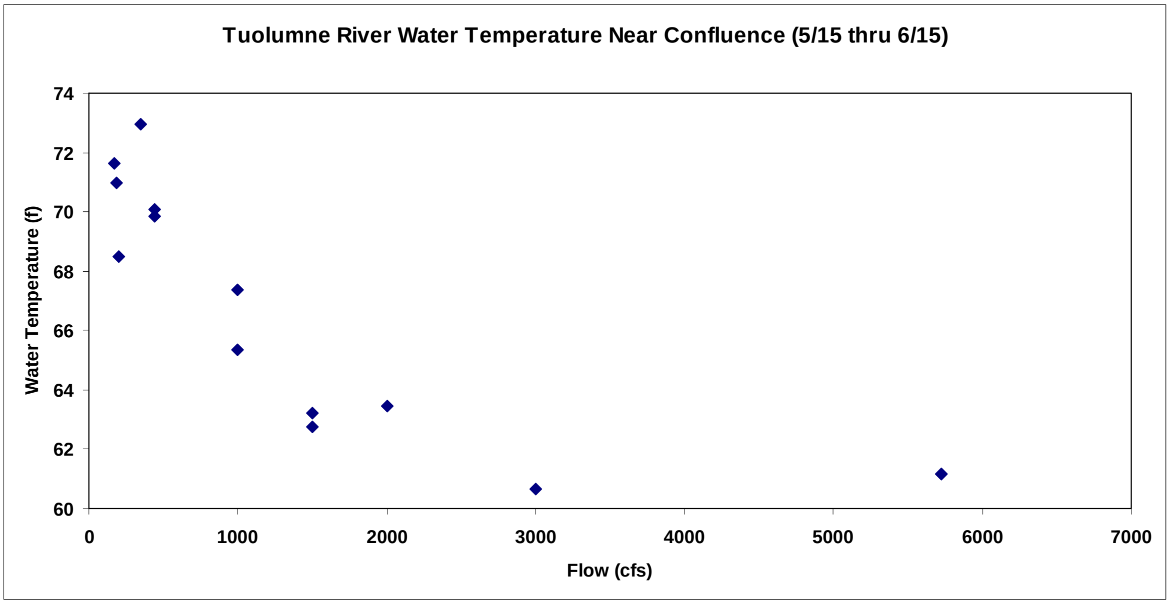

Figure 16. Spring Tuolumne River Water Temperature[2].

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[2] Data set includes historical flow and water temperature response data for years 1999 through 2006 (e.g. time frame is 5/15-6/15) as modeled with the SJR Basin HEC5Q Water Temperature Model Developed by Don Smith, Avry Dotan, and Mike Deas for the CalFed Ecosystem Restoration Program. Also included is new data generated by increasing flows during the 5/15-6/15 time frames and observing predicted water temperature response.

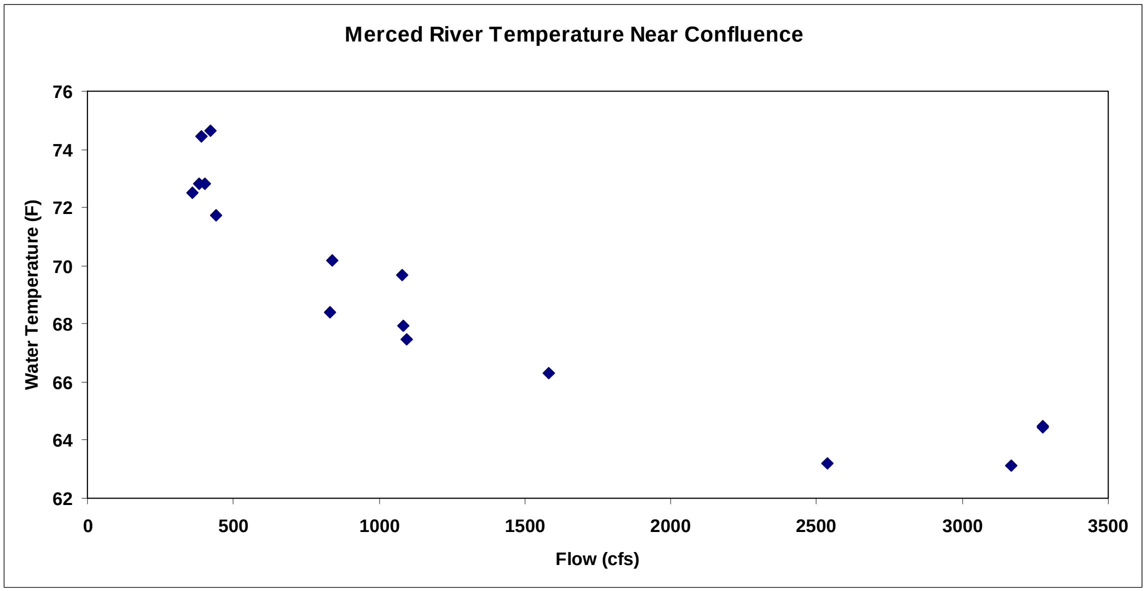

Figure 17. Spring Merced River Water Temperature[3].

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[3] Data set includes historical flow and water temperature response data for years 1999 through 2006 (e.g. time frame is 5/15-6/15) as modeled with the SJR Basin HEC5Q Water Temperature Model Developed by Don Smith, Avry Dotan, and Mike Deas for the CalFed Ecosystem Restoration Program. Also included is new data generated by increasing flows during the 5/15-6/15 time frames and observing predicted water temperature response.

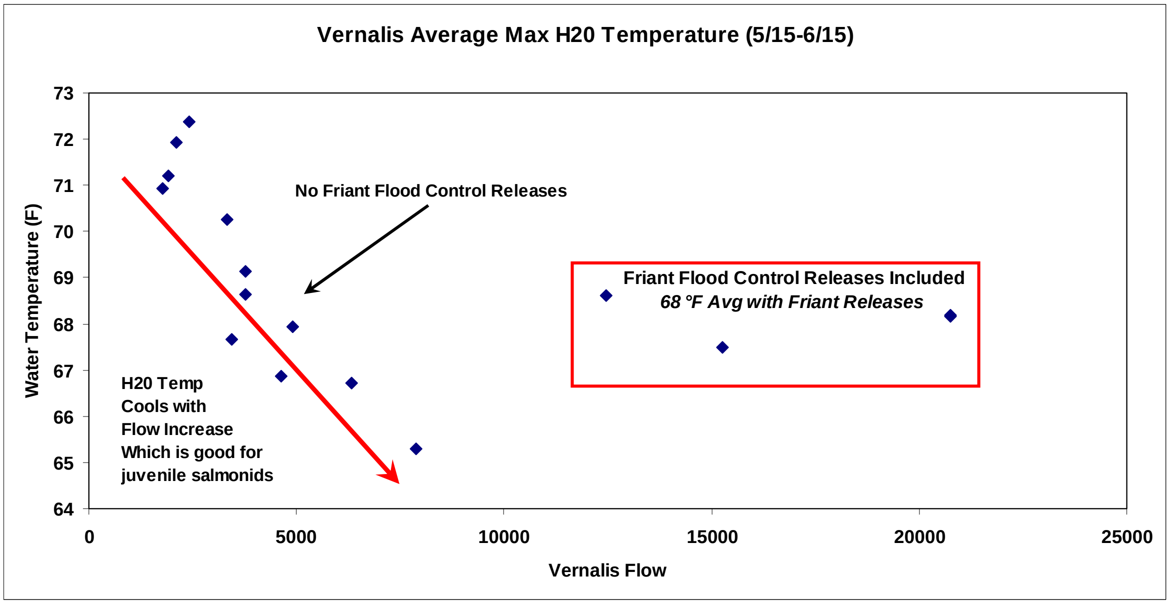

Figure 18. Water Temperature at Vernalis[4].

---

[4] Data set includes historical flow and water temperature response data for years 1999 through 2006 (e.g. time frame is 5/15-6/15) as modeled with the SJR Basin HEC5Q Water Temperature Model Developed by Don Smith, Avry Dotan, and Mike Deas for the CalFed Ecosystem Restoration Program. Also included is new data generated by increasing flows during the 5/15-6/15 time frames and observing predicted water temperature response.

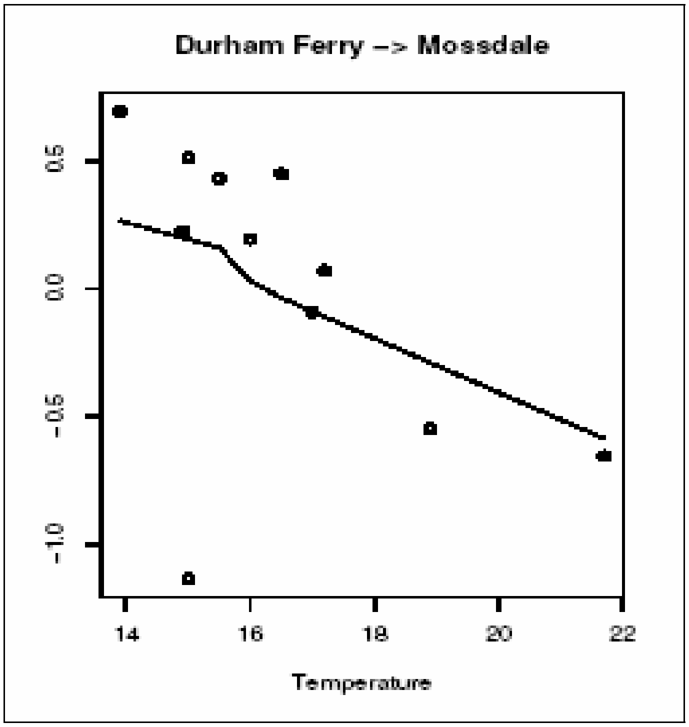

Figure 19. Smolt Survival and SJR water Temperature (From Newman 2008).

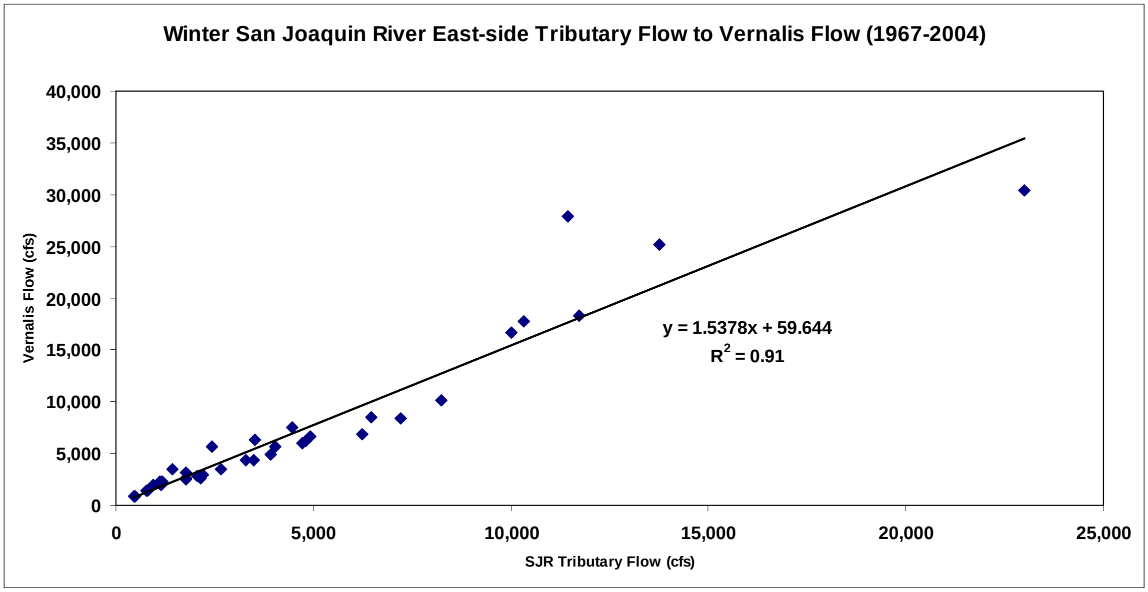

Figure 20. Winter San Joaquin River East-side Tributary Flow to Vernalis Flow.

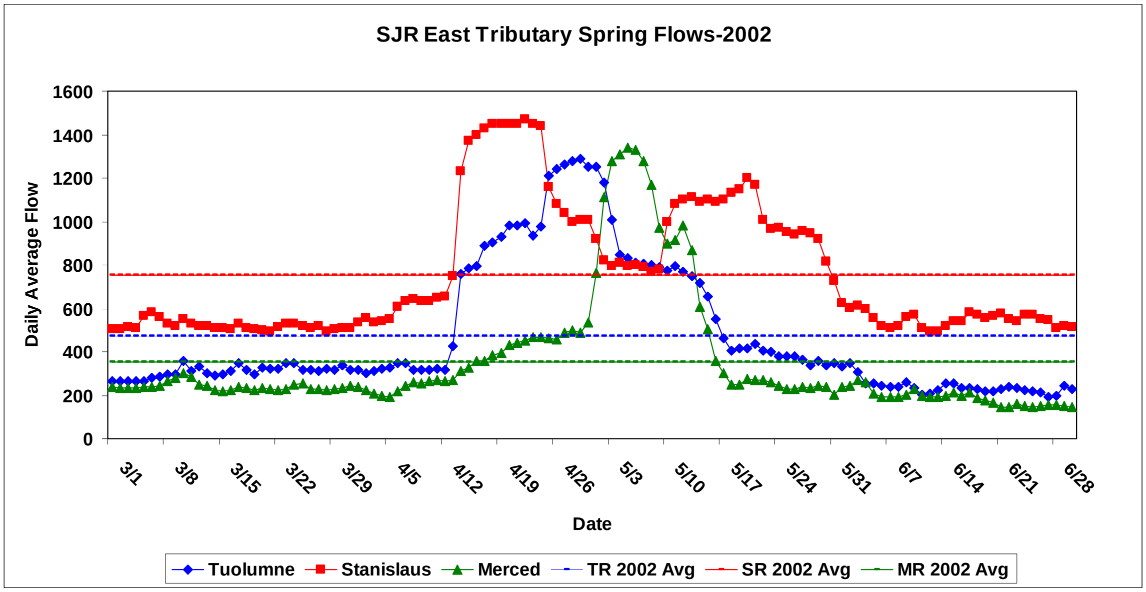

Figure 21. SJR Tributary Spring Flow Comparison-2002. Note: This SJR tributary flow hydrograph is representative of dry year flow schedules in the Stanislaus, Tuolumne, and Merced Rivers. The Stanislaus has highest instream flow levels, followed by the Tuolumne then the Merced Rivers. It is interesting to note that the Stanislaus had the higher instream flow in late May-early June which we know from water temperature, smolt physiology, and smolt out-migration studies provides an increased smolt out-migration protection window that affords increase smolt survival (by higher flow) and increased smoltification readiness (by reduced water temperatures).

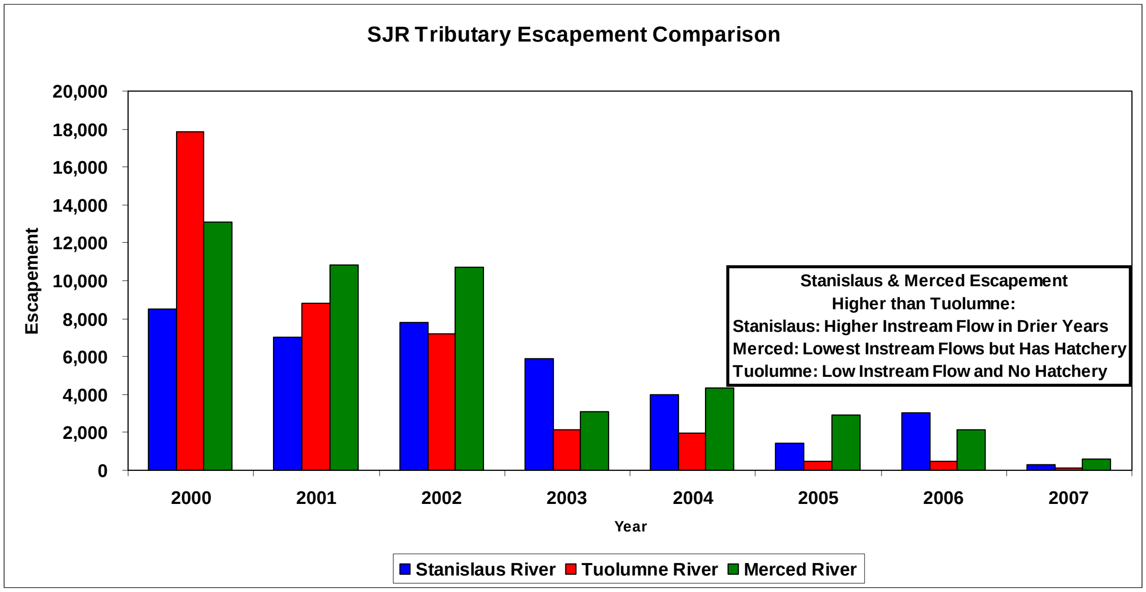

Figure 22. SJR Tributary Escapement Comparison. Note: The SJR escapement trend shows all three rivers salmon population crashed by 2007. However, the Tuolumne salmon population was the first to crash in 2005 while the Stanislaus and Merced lagged two years behind before bottoming out. The Stanislaus had the highest instream flow schedule in the drier years during the brood production years contributing to the 2002 thru 2007 escapements. The Merced, with the lowest instream flow schedule for the drier years contributing to the 2002 thru 2007 escapements augmented natural smolt production with artificial (e.g. hatchery) smolt production. The Tuolumne River with an in-between instream flow schedule and no hatchery augmentation showed the worst population resiliency and was the first to crash. It appears that hatchery augmentation can dampen population abundance stressors.

Appendix 2

Positive/Affirmative Comments from Cal-Fed Peer Review

CALFED Reviews—“Positive/Affirmative Comments”

Review #1:

“…model does an outstanding job of fitting the historical escapement record using an empirical approach”

“…such a model is accessible to those without a PHD in statistics (unlike some other models of salmon dynamics), and might lead to greater use by stakeholders.”

“I agree in principle, that physical barriers and those sorts of engineering solutions my not be the best long-term fixes, and that focusing on density-dependence could be used as a red herring…”

“I probably would not choose an alternative statistical approach to deal with this issue (e.g. collinearity…emphasis added), but the interpretation of the model should be carefully worded to acknowledge and describe collinearity between flow and other variables.”

“I don’t have any objection to calibrating against the replacement ratio…”

Review #2:

“The good fit of the model to the observed escapements is very surprising given the simplistic model structure.”

Review #3:

None.

Review #4:

“…the model is adequate to determine that higher flows released over a broader time window later in the season would benefit the salmon.”

“…the model was carefully thought out and the data carefully analyzed. The description of the model is generally thorough and report is generally well written and understandable.”

“The author lays out a very logical approach to developing the model.”

“The use interface is very nice…”

“The author does a nice job using a systematic approach to exploring how the magnitude and timing of flow would affect salmon management.”

“The actual conclusions in the report are reasonable; the specific recommendation in the Executive summary is OK…”

“The documentation is pretty good.”

“The treatment of water-type years is an excellent first step towards increasing reliability…”

“I personally think the results are probably pretty good…”

“I think the author tried to use available information.”

“Their must be and should be auto-correlation in fish calculations (escapement is comprised of multiple year classes)…I would not want it removed.”

“The way hatcheries were included was consistent with the general modeling approach used with natural fish.”

“Making ocean survival a constant is ok as a first step.”

“An adult replacement ratio is a reasonable health metric.”

“The model is best used to generate relative changes, which the author highlights in the result tables (percent change from historical).”

“If you want to use the model to suggest that more flow (within reason and practical amounts) and a longer, delayed time window would help the salmon, then I agree with the conclusions.”

“I agree that the Delta may not be a good place anymore for salmon.”

“The results are nicely presented.”

<u>Review #5:</u>

“The approach outlined in the documentation and supported by the spreadsheet model is consistent with this approach and well described in the documentation.”

“The modeling process has presented a useful framework for couching many of the factors thought to be important in fall-run Chinook salmon in the San Joaquin River.   The document and model have been largely successful in this manner.”

“The reviewer is very pleased that DFG is taking a highly proactive approach to the VAMP process and pressing hard questions prior to the completion of the 12 year program.”

“Development of a quantitative model to assess the response of fall-run Chinook salmon production is a valuable step in the overall recovery strategy and management of the San Joaquin River water resources and fisheries. The work completed by the Department allows additional questions to be asked and more refined hypotheses to be presented.”

“The product developed by the Department is a valuable first step in a longer process of sharing information and ideas, modifying model relationships, conceiving of new ideas and abandoning previous held beliefs, and along the way making progress in resources management.”

“The model provides additional insight into the role of spring flow, magnitude, duration, and frequency as these conditions relate to historical fall-run Chinook salmon in the San Joaquin River basin.”

“Construction of the model has allowed assessment of several factors as they relate to potential impacts of increased flows on salmon.”

“After examination of the available materials, the Reviewer identifies the role of this model as one tool that may provide insight into long term flow recommendations, but does not see the model as a stand alone tool to provide long-term flow recommendations.“

“The justification is apparent. Fishery numbers are not increasing and DFG is asking the hard questions (as are others): why not? Pursuing quantitative tools to assist in management actions and ongoing adaptive management frameworks is a laudable and necessary step.”

“The conceptual model and conversion of this to a quantitative tool in a spreadsheet environment is a method that has been employed by other agencies and entities (see CALFED, 2005, Appendix B). The methodology employed is transparent and the tool is
readily used by stakeholders.”

“The tool is valuable in assessing several factors associated with flow conditions as Vernalis as this factor relates to fall-run Chinook salmon production.”

“Modest improvement in documentation could go a long way in supporting this model as a useful tool in identifying and testing hypotheses, as well as formulate the basis for future modifications and expanded capabilities.”

“One key outcome of this model is the modification, or better yet, the augmentation of existing monitoring programs to fill identified data gaps and test sub-hypotheses (e.g. that increased export increases smolt survival).”

“The DFG report has presented an interesting and useful hypothesis—that not only do exports not significantly affect San Joaquin River fall-run Chinook salmon, but increased exports lead to increased survival…”

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Appendix 3

Re-Analysis of Statistical Models Used in California Department of Fish and Game's San Joaquin River Salmon Population Model Version 1.0

(Dr. Alan Hubbard)

Re-Analysis of Statistical Models used in California Department of Fish and Game's (CDFG) San Joaquin River Fall-run Chinook Salmon Population Model

August 22, 2008

1 Introduction

The purpose of this technical report is to re-analyze the original statistical models used in the CDFG San Joaquin River Fall-run Chinook Salmon Population Model (referred to subsequently as SJRModel). The analyses address a critique of the original models by fitting so-called proper models, which insure the outcome will be predicted to be in the appropriate range (i.e., a model that guarantees that survival probability is predicted to be between 0 and 1). This report also presents exploratory analyses, using smooth regression, used to empirically examine relationships of, for instance, flow and survival of smolts. Detailed descriptions of the data as well as how these statistical models are incorporated in the overall model can be read in the original description of the model, "FINAL DRAFT (11-28-05) San Joaquin River Fall-run Chinook Salmon Population Model".

2 Cohort Abundance

Cohort abundance is determined from a regression relationship between the annual calculated number of smolts arriving at Chipps and the estimated production year cohort (data for years 1988 through 2000 with 1989 being removed for reasons described in our response to the SJRGA report). We start using a generalized additive model (GAM) smooth of the estimated proportion of Chipp Smolts of a cohort that return to spawn versus the estimated number of smolts at Chipps ([Hastie & Tibshirani(1990)]). The automatic bandwidth selection available within the *gam* function in *R* ([R Development Core Team(2008)]) is used, which governs the smoothness of the curve. As one can see from figure 1, the logit model is not at all (logit)linear, but looks very much log-linear in the logit. Thus, we re-fit the smooth using the log(smolts) as the predictor.

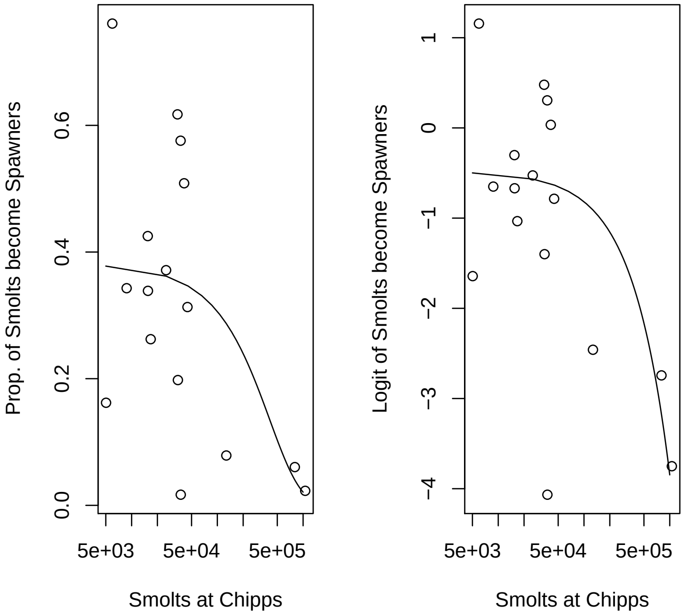

Figure 1: Original Data and GAM smooth on proportion (left) and logit scale (right) of Escapement vs. Chipps Smolts

```
> summary(glm.1)

Call:
glm(formula = prop ~ logsmolts, family = binomial(), na.action = na.omit)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7458  -0.2449  -0.1075   0.1788   0.6483

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   3.9312     4.9136   0.800    0.424
logsmolts    -0.4563     0.4819  -0.947    0.344

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 3.8585  on 15  degrees of freedom
Residual deviance: 2.7374  on 14  degrees of freedom
AIC: 21.933

Number of Fisher Scoring iterations: 4
```

As seen on the plot (Figure 2), both the smooth and the logit-linear model fit exactly the same trend, which results from the automatic bandwidth selection procedure that results in a line. This suggest, given the amount of data, the logit-linear is a relatively good fit. We now summarize this fit.

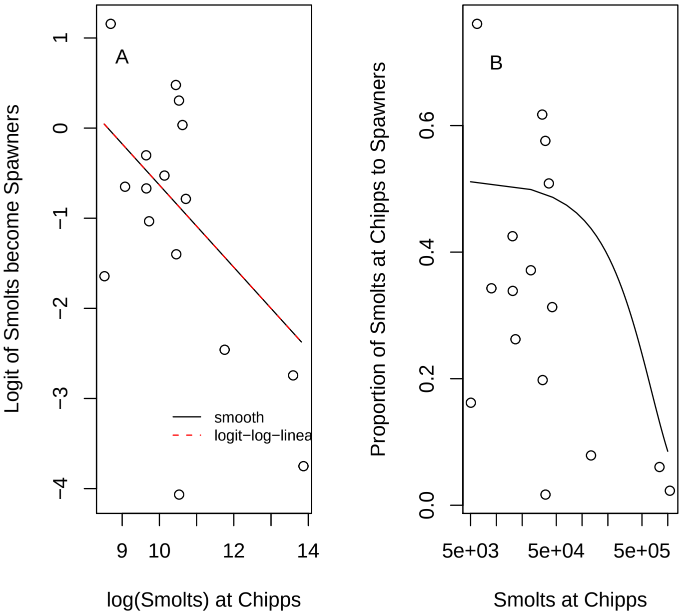

Figure 2: A) GAM smooth and GLM logit-linear model (with original data) on logit scale of Escapement vs. log(Chipps Smolts). B) Same GAM model on probability scale.

```
> summary(glm.1)

Call:
glm(formula = prop ~ logsmolts, family = binomial(), na.action = na.omit)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.7458  -0.2449  -0.1075   0.1788   0.6483

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   3.9312     4.9136   0.800    0.424
logsmolts    -0.4563     0.4819  -0.947    0.344

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 3.8585  on 15  degrees of freedom
Residual deviance: 2.7374  on 14  degrees of freedom
AIC: 21.933

Number of Fisher Scoring iterations: 4
```

This implies that for relatively low numbers of smolts at Chipps, high percentages on average return ultimately to spawn, whereas for high numbers, that percentage drops. At this point, this is just a black-box model, and there is no obvious biological interpretation for the negative association of the estimated number of Chipp smolts and the ultimate proportion (spawners/smolts) of returning spawners. In our Version 2.0 model, we will add much detail to the ocean component to try to estimate how changes in both ocean conditions and intensity of sports and commercial fishing will impact future populations relative to inland environmental factors.

3 Mossdale Smolt Production

The model presented in this section are used to predict the total number of smolts that will arrive at Mossdale as a function of number of SJR salmon escaping into east-side SJR tributaries in the previous fall-run escapement coupled with current year spring Vernalis Spring out-flow. The year 1989 was removed, believing this point to be unrepresentative of the data-generating distribution for which we are attempting to estimate relationships of annual smolts at Mossdale versus environmental factors and numbers of spawners the previous fall (see responses to SJRGA review for justification). We employ the same exploratory procedure to look at smolt production as we did for cohort production above. First, we examine smolt production (a count) as a function of spring Vernalis flow and previous year escapement, separately, using GAM smooths with log-link (Poisson). Note, by including the log(Escapement) as a

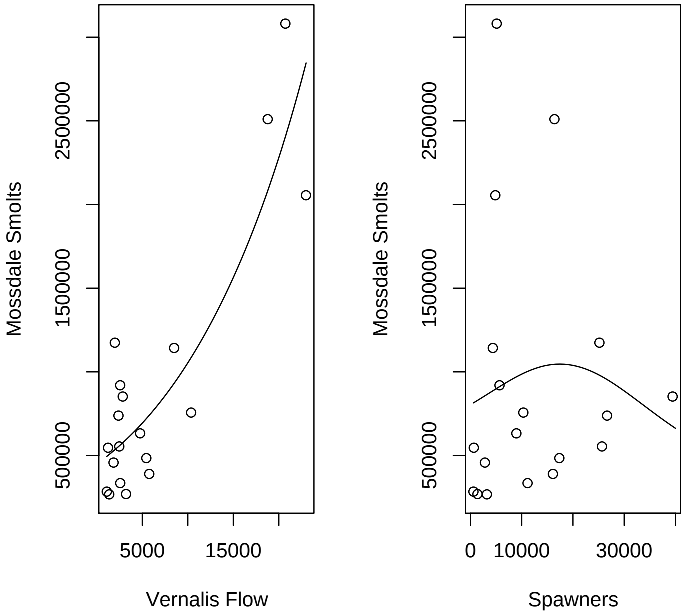

Figure 3: GAM smooth for flow (left) and number Spawners in Fall (right) done separately.

predictor, the class of models will include the possibility of density dependence (rate of smolts/spawner negatively associated with number of spawners). We will fit a more standard density-dependent model form as a follow-up to this analysis.

First, we examine separately the relationship of Vernalis flow and escapement in the fall to the estimated total numbers of smolts migrating out past Mossdale in the spring. Given the bandwidth chosen (based upon an algorithm attempting to balance bias and variance) the relationship with Vernalis flow (figure 3) looks almost perfectly log-linear, whereas that with previous fall's spawners looks quadratic (implying a density dependence). However, when we estimate a quadratic relationship and perform a permutation test to derive exact inference of the test of independence of Mossdale smolts and number of estimated spawners, the p-value is .85, suggesting no evidence of any bivariate statistical relationship of Mossdale smolts and estimated numbers of fall spawners. Next, we re-fit with GAM smooths that include both variables and examine whether this lack of relationship of spawners and smolts persists when both variables are in the model. Now, the pattern is concave up (still quadratic, but in the

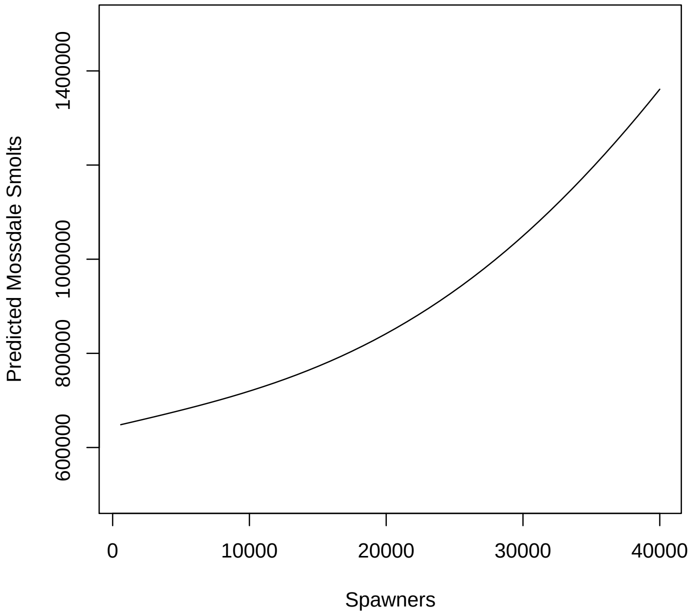

Figure 4: Results of GAM smooth when both Spawners and Vernalis flow are in the model. Plot shows the predicted number of smolts by Spawners when Vernalis flow is set at the average.

other direction) suggesting that number of spawners in fall and Vernalis flow confound one another in this model; there does appear to be a slight negative relationship of Vernalis Flow in the Spring and the number of spawners in the previous Fall - although certainly not causal, this empricial confounding could explain the difference in the relationship of fall spawners and spring smolts in the unadjusted (without flow) and adjusted (with flow) models. If the number of smolts at Mossdale is modeled as a quadratic (concave up) versus the number of fall spawners, it will blow-up the number of smolts produced if number of spawners gets very large (extrapolating beyond data). To avoid this, we fit a log-linear Poisson regression model of smolts versus log(spawners).

```
Call:
glm(formula = smolts ~ flow + logspawn, family = poisson)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-519.83  -324.37   -64.45   222.23   600.21

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept) 1.170e+01  2.410e-03  4857.0   <2e-16 ***
flow        8.082e-05  2.817e-08  2868.6   <2e-16 ***
logspawn    1.481e-01  2.595e-04   570.7   <2e-16 ***
---

    Null deviance: 9958794  on 18  degrees of freedom
Residual deviance: 2127786  on 16  degrees of freedom
AIC: 2128082

Number of Fisher Scoring iterations: 4
```

We then plot the results of the fitted model of predicted smolts versus Vernalis flow at different numbers of fall spawners (see figure 5).

3.1 Model based on Ricker Density Dependence

To examine empirical evidence of density dependence in this portion of the model, we re-fit the model discussed above with a form that practically guarantees some density-dependence (roughly equivalent to a regression of $log(Y/X)$ vs. X will result in a negative association even if Y and X are independent). We use a modified form of the Ricker density dependence (where this dependence can depend on flow) presented in [Speed(1993)], page 280:

$$log(S_t) = \alpha log(F_t) + log(E_{t-1}) - \beta E_{t-1}$$

where S_t is the total number of smolts surviving to Mossdale in year t, E_{t-1} is the number escaping the previous spring, F_t is Vernalis flow, and α and β are parameters. This model can be fit using Poisson regression (log-linear regression) of S_t versus and F and E_{t-1} and entering an offset of $log(E_{t-1})$. We fit this model and derived the following results:

```
> summary(glm.1)

Call:
glm(formula = smolts ~ flow + spawners + offset(logspawn), family = poisson)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
```

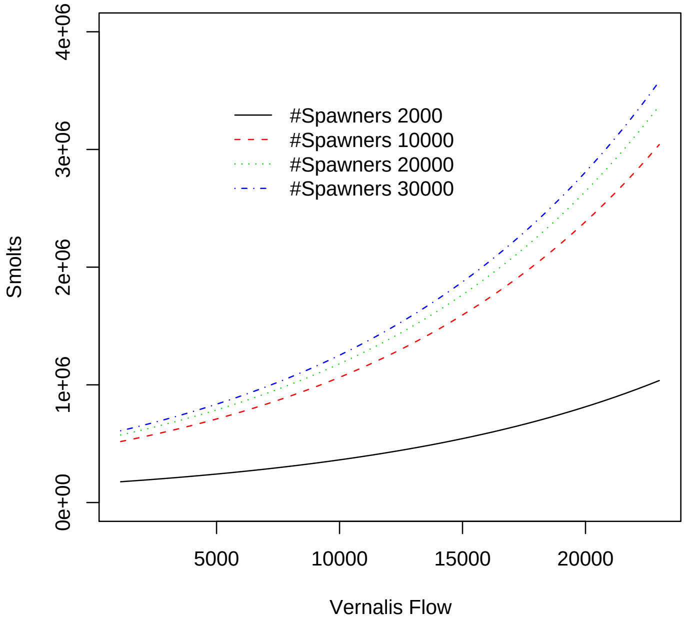

Figure 5: Poisson model showing predicted smolts versus flow at different numbers of fall spawners.

```
-752.30  -278.74    95.66   429.31   989.56

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)  4.969e+00  6.548e-04    7589   <2e-16 ***
flow         6.919e-05  3.143e-08    2201   <2e-16 ***
spawners    -7.304e-05  3.139e-08   -2327   <2e-16 ***
---

    Null deviance: 23077076  on 18  degrees of freedom
Residual deviance:  4567802  on 16  degrees of freedom
AIC: 4568099

Number of Fisher Scoring iterations: 5
```

which suggests a significant negative relationship of spawner abundance and smolts at Mossdale, or evidence of density dependence. We now plot predicted numbers of smolts versus flow at different numbers of fall escapement (figure 6).

Thus, though there is no strong bivariate relationship at all of spawners and smolts (see figure above), when a Ricker-type of model is used and flow is in the model, there is what appears to be a significant density-dependence relationship. Thus, whether or not there is density-dependence depends on what model is chosen to fit the data (this result appears to contradicts the model shown in figure 5). However, we follow-up by examining which of these two models fits the data better, providing evidence for or against strong density dependence. To do so, we use model selection criteria, Aikake's Information Criteria (or AIC), where the bigger the statistic, the worse the fit. The results suggest a much, much better fit to the data for the simple log-log linear model shown in figure 5 ($AIC = 2.12x10^6$) relative to the Ricker-type model shown in figure 6 ($AIC = 4.57x10^6$). Thus, the data suggests there is little evidence of density dependence being a driving factor given the recent historic numbers of spawners and flows, which make up the current data set.

4 Delta Survival

Once the annual smolt abundance is apportioned on a daily basis in each year (e.g., 1967 through 2000), using either HORB-in or HORB-out, a Delta smolt survival relationship is applied. The number of smolts arriving at Mossdale, combined with Vernalis flow level, are associated with the number of smolts reaching Chipps Island each day via a statistical model. In this case, we use the data provided by Ken Newman, when used VAMP-flow and combined both the release experiments at Durham Ferry and at Mossdale and adjust the survival estimates relative to releases at Jersey Point. Using Dr. Newman's notation, we have the survival estimate as:

$$\hat{S}_{DF\to CI} = \frac{(Y_{DF\to Ant} + Y_{DF\to CI} + Y_{DF\to Oc})/R_{DF}}{(Y_{JP\to CI} + Y_{JP\to Oc})/R_{JP}}$$

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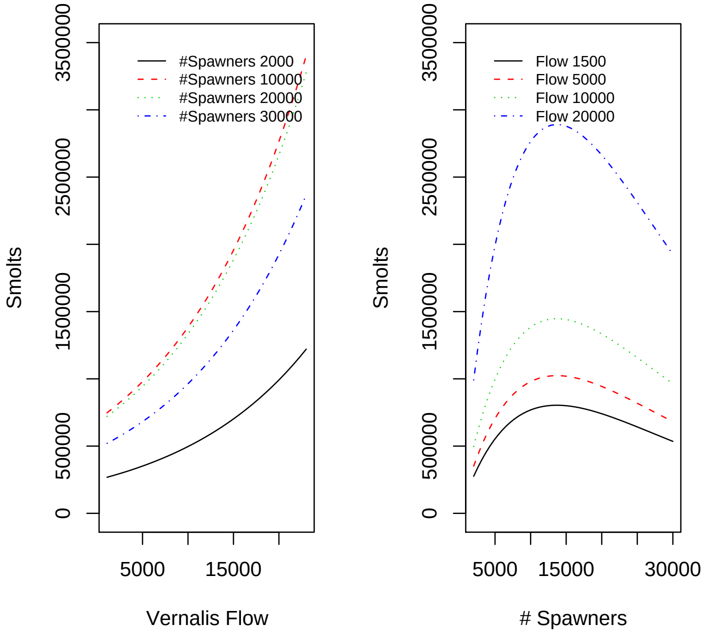

Figure 6: Poisson model showing A) predicted smolts versus Vernalis flow at different numbers of fall spawners for Ricker type of Model and for the same model B) predicted smolts versus number of spawners at different Vernalis flows.

with MD in place of DF when Mossdale is used. This resulted in the following data set used for this analysis.

Table 1: Survival Estimates using Ken Newman's approach for Estimating Survival

	VAMP.Year	HORB	surv.md.chipps	surv.DF.chipps	MD.flow.raw
1	1985.00	0.00			2475.00
2	1986.00	0.00			7140.00
3	1987.00	0.00			2480.00
4	1989.00	0.00			2500.00
5	1989.00	0.00			1945.00
6	1990.00	0.00			1400.00
7	1990.00	0.00			1400.00
8	1991.00	0.00			
9	1994.00	0.00	0.14		1580.00
10	1994.00	1.00	0.13		3115.00
11	1995.00	0.00	0.79		18700.00
12	1995.00	0.00			21250.00
13	1995.00	0.00			23100.00
14	1996.00	0.00	0.14		6665.00
15	1996.00	0.00	0.04		6565.00
16	1996.00	0.00			
17	1997.00	1.00	0.46		6135.00
18	1997.00	1.00			
19	1997.00	1.00			
20	1998.00	0.00	0.41		24950.00
21	1998.00	0.00	0.21		20250.00
22	1999.00	0.00	0.36		6905.00
23	2000.00	1.00	0.31	0.35	6995.00
24	2000.00	1.00		0.18	5969.00
25	2001.00	1.00	0.22	0.24	4170.00
26	2001.00	1.00	0.11	0.13	4145.00
27	2002.00	1.00	0.16	0.14	3255.00
28	2002.00	1.00	0.07	0.06	3356.00
29	2003.00	1.00	0.02	0.02	3345.00
30	2003.00	1.00	0.01	0.01	3370.00
31	2004.00	1.00	0.01	0.01	3160.00
32	2005.00	0.00		0.07	8195.00
33	2005.00	0.00		0.05	9085.00
34	2006.00	0.00	0.11		29350.00
35	2006.00	0.00	0.01		24650.00

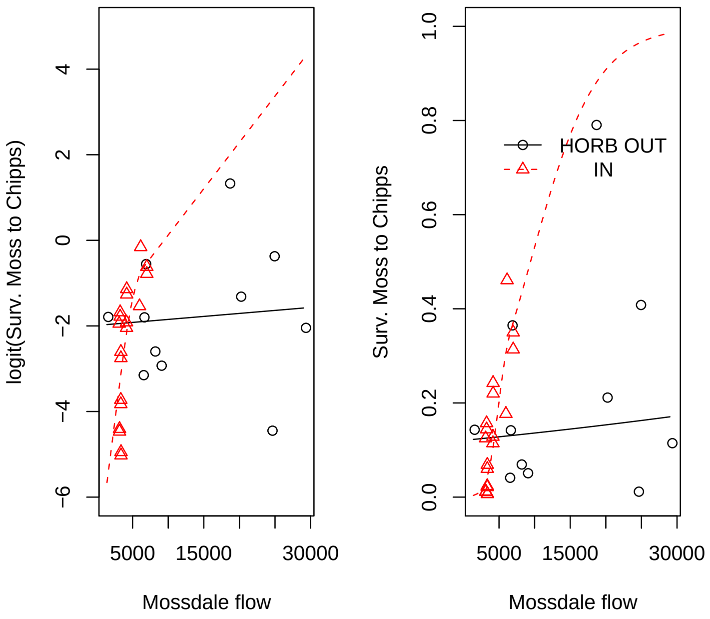

Figure 7: Results of GAM smooth for survival from Mossdale/Durham Ferry to Chipps Island versus Mossdale flow separately by HORB in and out. The plot on the left is on logit scale, the right on probability scale.

As above, we first fit *gam* smooths (logit link) to examine the smooths by HORB both in and out. Figure 7 shows that a logit-linear fit for the HORB out is suggested by the smooths, as well as a logit-linear fit for the HORB In (note, the bend at the end is pure extrapolation), so we used a linear regression model on the logit scale to derive the coefficients by HORB -status.

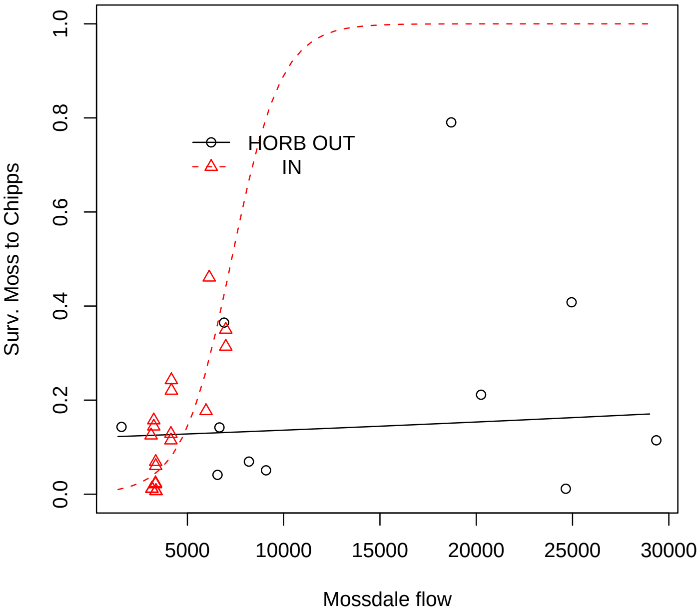

Figure 8: Results of LM fit for survival from Mossdale to Chipps Island versus Mossdale flow separately by HORB in and out.

Figure 8 suggests a strikingly different survival function depending on the HORB status, although there is not data for the HORB in at high flows, so the curve beyond a flow of around 7,000 is pure extrapolation.

5 Hatchery

The conceptual model for hatchery augmentation includes: 1) estimate the fraction of inriver escaping salmon that would migrate into the hatchery; 2) estimate the female fraction of total hatchery escapement ratio ; 3) estimate the number of smolts that would be produced by the number of salmon migrating into the hatchery ; 4) estimate salmon smolt survival as a function of spring flow in each SJR east-side tributary; 5) estimate hatchery smolt survival through the South Delta ; 6) estimate the adult salmon production cohort for each brood year; and 7) add hatchery cohort production to wild cohort production; 8) reconstruct combined wild and hatchery produced SJR salmon escapement; and 9) subtract hatchery escapement from wild escapement for future year cohort production and escapement prediction.

5.1 Fraction of Escapement that goes to Hatchery

Following the pattern of the above model fitting procedures, we first fit a logistic smooth of proportion of spawners entering hatchery in Merced River versus the total of escapement in that river.

Table 2: Data used to Estimate Proportion of Escapement Into Hatchery

	Year	X	MRH	Female	Male	In.River	Total
1	1970		100			4700	4800
2	1971		200			3451	3651
3	1972		120			2528	2648
4	1973		375			797	1172
5	1974		1000			1000	2000
6	1975		700			1700	2400
7	1976		700			1200	1900
8	1977		661			350	1011
9	1978		100			525	625
10	1979		227			1920	2147
11	1980		157			2849	3006
12	1981		924			9491	10415
13	1982		189			3074	3263
14	1983		1795			16453	18248
15	1984		2109			27640	29749
16	1985		1211			14841	16052
17	1986		650			6789	7439
18	1987		958	156	802	3168	4126
19	1988		457	206	251	4135	4592
20	1989		82	32	50	345	427
21	1990		46	14	32	36	82
22	1991		41	9	32	78	119
23	1992		368	41	327	618	986
24	1993		409	153	256	1269	1678
25	1994		943	282	661	2646	3589
26	1995		602	196	406	2320	2922
27	1996		1141	361	780	3291	4432
28	1997		946	397	549	2714	3660
29	1998		799	304	495	3292	4091
30	1999		1637	383	1254	3129	4766
31	2000		1946	937	1009	11130	13076
32	2001		1663	703	960	9181	10844
33	2002		1838	797	1041	8800	10638
34	2003		549	248	301	4110	4659
35	2004		1050			3000	4050

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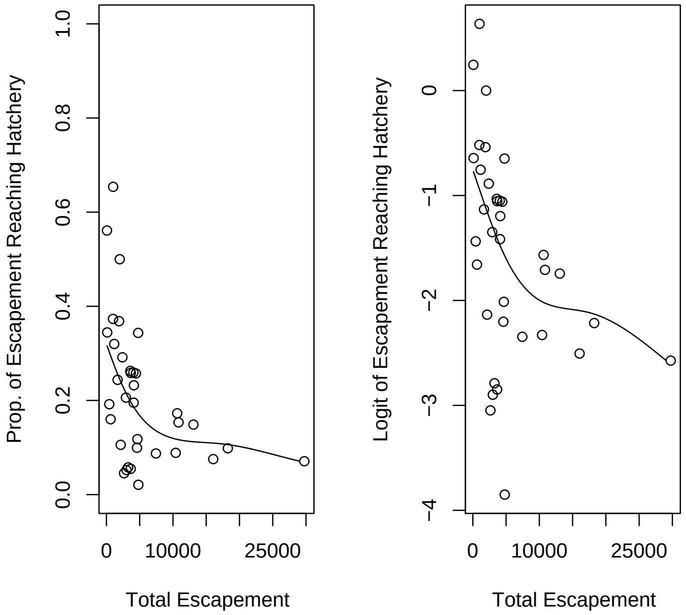

Figure 9: GAM smooth of Proportion of Escapement into Hatchery as function of total Escapement in Merced River in both probability (left) and logit (right) scale

Table 2 has the data used in the following analyses. Using this data and a generalized additive model approach, we get the following fits on both the probability and logit scale. Figure 9 indicates that something more quadratic than logit-linear might fit the data better, and so we fit the data with a quadratic model as follows:

$$Pr(Hatchery \mid TotalEscp) = \frac{1}{1 + exp(-(b_0 + b_1 TotalEscp + b_2 TotalEscp^2))}$$

Figure 10 shows that the quadratic curve is a good fit to the data, which is further supported by the following results of the model fit:

```
> summary(glm.1)

Call:
glm(formula = prop ~ wt + wt2, family = binomial(), weights = wt,
    na.action = na.omit)
```

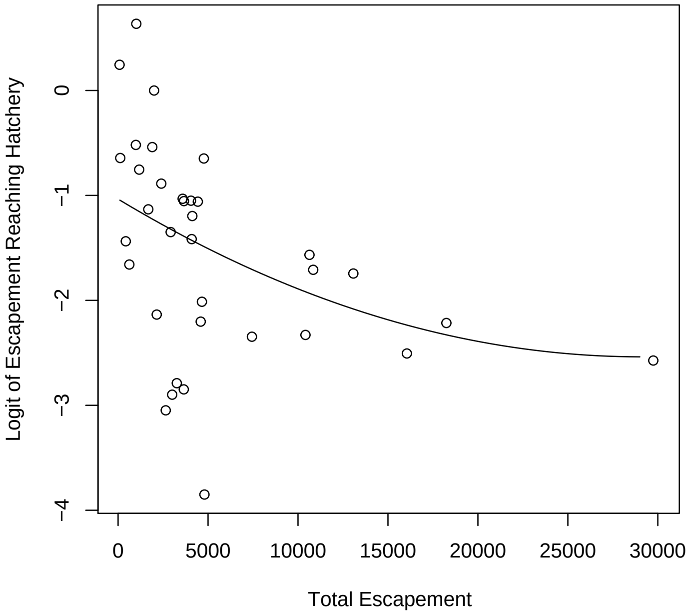

Figure 10: Quadratic GLM fit of Proportion of Escapement into Hatchery as function of total Escapement in Merced River in logit scale

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-35.741  -12.621    2.046    9.027   27.601

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.035e+00  1.558e-02  -66.43   <2e-16 ***
wt          -1.033e-04  2.906e-06  -35.54   <2e-16 ***
wt2          1.773e-09  9.442e-11   18.78   <2e-16 ***
---

    Null deviance: 12765.6  on 34  degrees of freedom
Residual deviance:  8356.7  on 32  degrees of freedom
AIC: 8634.7

Number of Fisher Scoring iterations: 4
```

which shows a significant quadratic term (wt2). We note that there is no easy biological explanation for this quadratic pattern, but for now we retain this functional form as it is a much better fit to the data than say the logit-linear model and given our philosophy surrounding Version 1.5 is to err on the side of empiricism. In Version 2.0, we will concentrate more on biological interpretation of the constituent models.

5.2 Proportion of Females versus Total Escapement into Hatchery

Going straight to the conclusion, the results here are identical to above - a quadratic logistic-linear model where the probability of being female is quadratically related to the total number of fish (males+females) escapement into the hatchery. The data used is precisely the same as shown in the table, for those years with observed numbers of females. Figure 11 indicates that something more quadratic than logit-linear might fit the data better, and so we fit the data with a quadratic model as follows:

$$Pr(Female \mid TotalHatchery) = \frac{1}{1 + exp(-(b_0 + b_1 TotalHatchery + b_2 TotalHatchery^2))}$$

Figure 12 shows that the quadratic curve is a good fit to the data, which is further supported by the following results of the model fit:

```
> summary(glm.1)

Call:
glm(formula = prop ~ wt + wt2, family = binomial(), weights = wt,
    na.action = na.omit)
```

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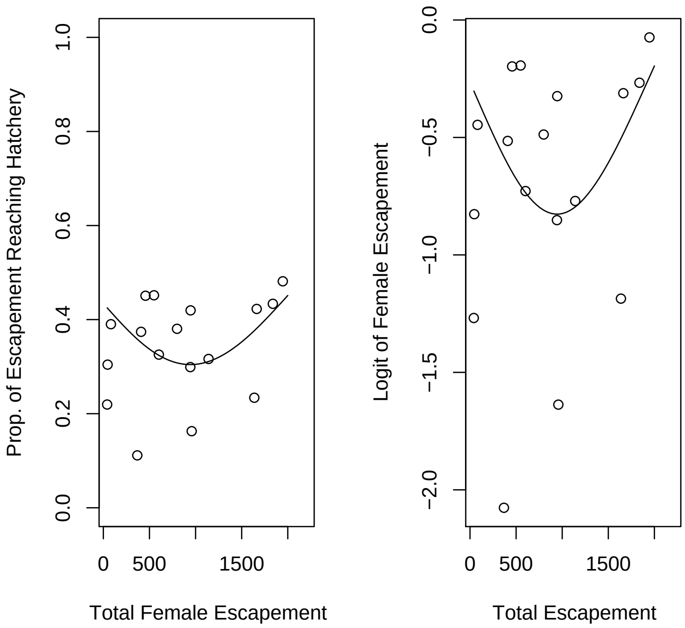

Figure 11: GAM smooth of Proportion of Females as function of total Escapement into Merced River Hatchery in both probability (left) and logit (right) scale

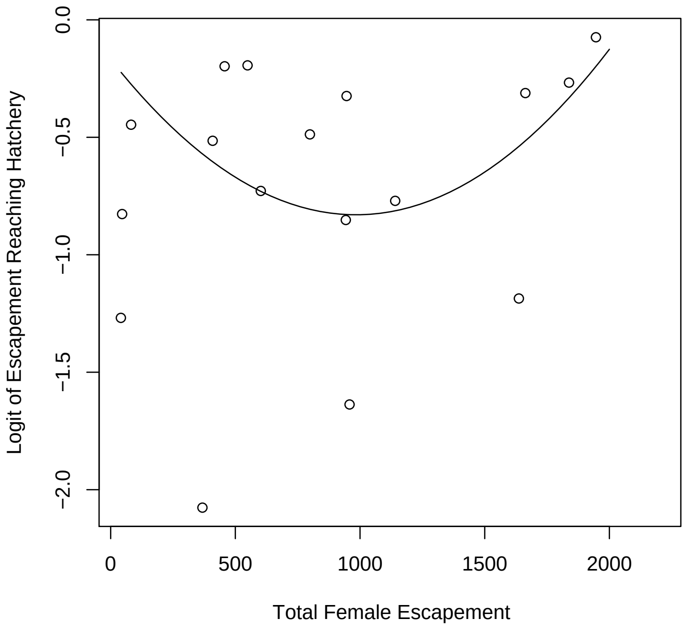

Figure 12: Quadratic GLM fit of Proportion of Females as function of total Escapement into Merced River Hatchery in logit scale

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-11.6746   -1.9276    0.6683    4.0782    7.5215

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.686e-01  9.741e-02  -1.730   0.0835 .
wt          -1.344e-03  1.843e-04  -7.293 3.03e-13 ***
wt2          6.827e-07  7.544e-08   9.050  < 2e-16 ***
---

    Null deviance: 696.83  on 16  degrees of freedom
Residual deviance: 528.32  on 14  degrees of freedom
  (18 observations deleted due to missingness)
AIC: 645.83

Number of Fisher Scoring iterations: 4
```

which shows a significant quadratic term (wt2).

5.3 Smolts per female

Table 3: Data used to Estimate Smolts/Female in Hatchery

	Year	totalescpape	mrhescape	Females	Total.Eggs	Eyed.Eggs	smoltsp
1	1987	3168	958	156	609133.00	445850.00	2286.41
2	1988	4135	457	206	1069258.00	790799.00	3071.06
3	1989	345	82	32	172053.00	103795.00	2594.88
4	1990	36	46	14	59919.00	23273.00	1329.89
5	1991	78	41	9	48075.00	19310.00	1716.44
6	1992	618	368	41	203454.00	121742.00	2375.45
7	1993	1269	409	153	740020.00	559721.00	2926.65
8	1994	2646	943	282	1569937.00	1047887.00	2972.73
9	1995	2320	602	196	977637.00	650031.00	2653.19
10	1996	3291	1141	361	1736391.00	1267974.00	2809.91
11	1997	2714	946	397	1985782.00	1661035.00	3347.17
12	1998	3292	799	304	1210055.00	1037789.00	2731.02
13	1999	3129	1637	383	1862840.00	1573540.00	3286.77
14	2000	11130	1946	937	5299480.00	3855560.00	3291.83
15	2001	9181	1663	703	2947812.00	1799565.00	2047.87
16	2002	8800	1838	797	3348581.50	2059304.70	2067.06
17	2003	4110	549	248	1249074.60	947082.00	3055.10

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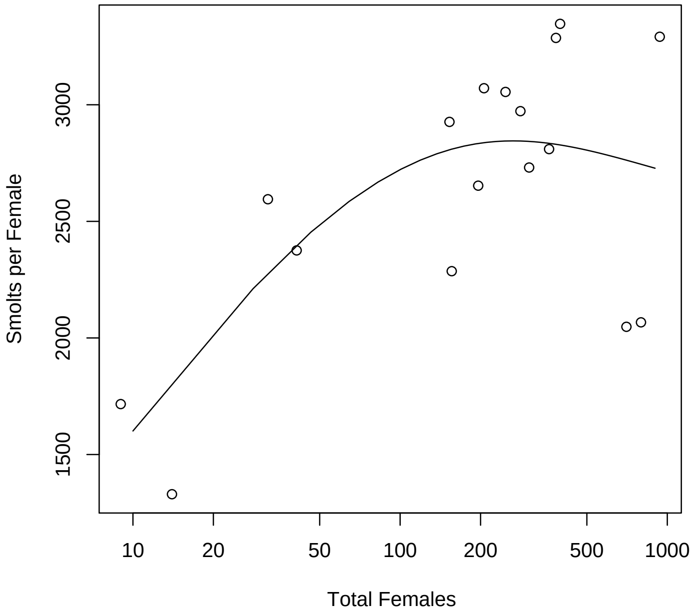

Figure 13: GAM smooth of smolts per female vs. log(females).

We use the data in table 3 to estimate the relationship of smolts per female and used the same sequence of analyses. Specifically, we look at the smolts per female as a function of the log(females) in the hatchery. Using a GAM approach, we see again that the curve looks somewhat quadratic (13).

Thus, we fit a quadratic curve:

$$E(Smolts|Females) = b_0 + b_1 Females + b_2 Females^2$$

resulting in the fit presented in figure 14. The resulting fit suggest that the quadratic effect fits significantly better than the linear model.

```
> summary(glm.1)

Call:
glm(formula = smoltsp ~ logfem + logfem2, data = smoltsper, na.action = na.omit)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-675.37  -209.34    86.95   273.57   659.25
```

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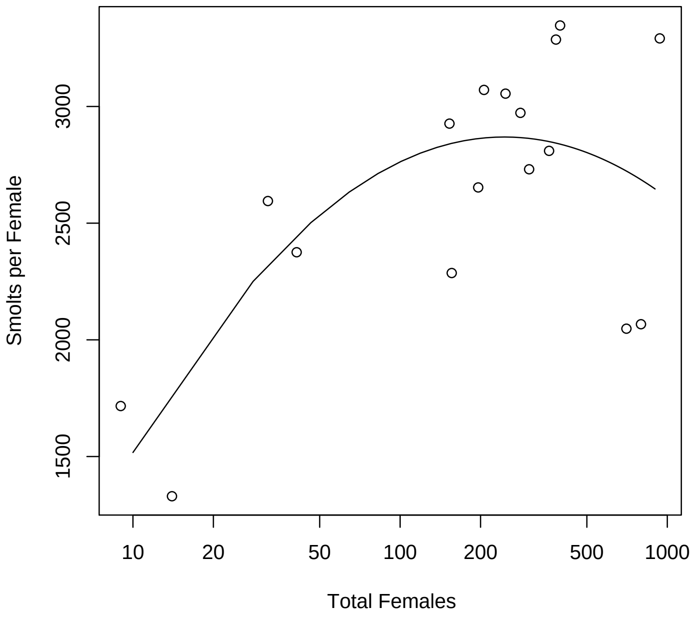

Figure 14: GLM fit of smolts per female vs. quadratic log(females).

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1127.35    1185.90  -0.951   0.3579
logfem       1452.38     550.09   2.640   0.0194 *
logfem2      -131.95      59.92  -2.202   0.0449 *
---

    Null deviance: 5371011  on 16  degrees of freedom
Residual deviance: 2569205  on 14  degrees of freedom
AIC: 258.98

Number of Fisher Scoring iterations: 2
```

One factor will make the number of smolts per female decline with increasing number of females and that is that the maximum egg retention is two million. Thus, after two million eggs, adding more females will just drop the rate of smolts per female as the number of eggs is no longer increasing. This is probably contributing to the curve starting to descend at higher numbers of females.

5.4 Survival of Smolts to Confluence with Main Stem

The final model for the hatchery is to migrate the hatchery smolts out of the tributary in the main stem and in this case we can use release-capture experiments to estimate the survival. In this case, we used data that includes calculated survival estimates for release experiments in the 3 tributaries and corresponding flow, shown in the following table:

Table 4: Data used for Estimating Survival of Smolts in Tributaries to confluence iwth main stem of SJR

	River	Year	Date	Flow	FlowIndexBankFull	Temperature	Surv
1	TR	2002	4/25/06	1274	0.42	15.90	0.53
2	TR	2001	4/23/05	635	0.21	17.30	0.18
3	TR	2000	4/14/04	2982	0.99	13.10	0.28
4	TR	1999	4/18/03	1960	0.65	14.20	0.19
5	TR	1998	4/16/02	4050	1.34	12.10	1.03
6	TR	1997	4/23/01	1436	0.48	14.70	0.44
7	TR	1996	4/27/00	2664	0.88	13.40	0.32
8	TR	1995	5/5/99	8217	2.72	11.30	0.79
9	TR	1990	5/1/94	241	0.08	19.40	0.30
10	TR	1987	4/17/91	563	0.19	17.60	0.42
11	SR	2003	4/26/07	1300	0.71	15.00	0.57
12	SR	2002	5/2/06	825	0.45	18.00	0.41
13	SR	2000	5/19/04	1500	0.82	16.10	0.57
14	SR	1989	4/21/93	900	0.49	17.80	0.37
15	SR	1988	4/27/92	900	0.49	15.60	0.54
16	SR	1986	4/29/90	1200	0.65	16.70	0.59
17	MR	2004	5/10/08	1600	1.20	18.70	0.36
18	MR	2004	4/20/08	480	0.36	13.00	0.16
19	MR	2004	4/28/08	846	0.63	15.00	0.12
20	MR	2003	4/26/07	570	0.43	18.00	0.26
21	MR	2003	5/5/07	1380	1.03	17.00	0.25
22	MR	2003	4/14/07	650	0.49	12.00	0.20
23	MR	2002	4/22/06	1800	1.35	16.90	0.18
24	MR	2002	4/1/06	400	0.30	16.40	0.01
25	MR	2001	5/9/05	1099	0.82	18.10	0.34
26	MR	2001	4/22/05	1165	0.87	16.40	0.32
27	MR	2000	4/28/04	1556	1.16	13.30	0.30
28	MR	2000	4/13/04	364	0.27	16.10	0.22
29	MR	1999	4/15/03	1700	1.27	14.40	0.70
30	MR	1999	5/6/03	1500	1.12	13.90	0.17
31	MR	1998	4/13/02	2600	1.94	10.00	1.02
32	MR	1998	5/4/02	2500	1.87	12.80	0.69
33	MR	1997	4/21/01	900	0.67	13.90	0.33
34	MR	1997	5/14/01	600	0.45	16.10	0.00
35	MR	1996	4/26/00	1300	0.97	14.40	0.82
36	MR	1995	5/4/99	3700	2.77	12.80	0.58
37	MR	1994	4/23/98	700	0.52	13.90	0.34

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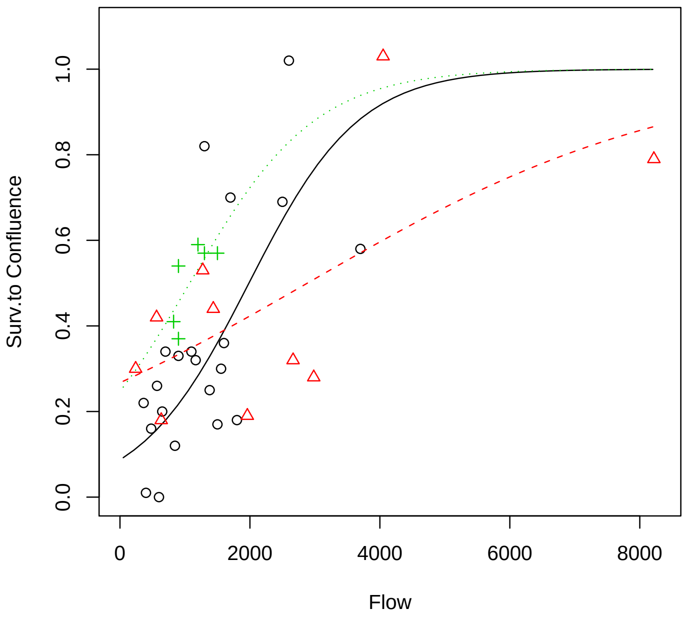


Figure 15: Results of least-squares logit fit for survival in tributaries to confluence with SJR.

We have very few data points per tributary, thus we have limited power to do exploratory analyses. Thus, we use a simple approach fitting logit-linear models of survival versus flow of the form:

$$Pr(Survive \mid flow, Trib = t) = \frac{1}{1 + exp(-(b_{t,0} + b_{t,1} flow))},$$

so for each tributary it is a 2 parameter model. As one can see, 2 of the data points have values with undefined logit transform (either 0 or > 1) - we used an arbitrary cut-off for these ”outliers”, truncating points at 0.05 and 0.95, respectively. The following shows the raw data (including these outliers at their original values) and the resulting fits by tributary.

References

[Hastie & Tibshirani(1990)] HASTIE, T. & TIBSHIRANI, R. (1990). *Generalized additive models*. New York: Chapman and Hall.

[R Development Core Team(2008)] R DEVELOPMENT CORE TEAM (2008). *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL `http://www.R-project.org`.

[Speed(1993)] SPEED, T. (1993). Modelling and managing a salmon population. In V. Barnett & K. Turkman, eds., *Statistics for the Environment.* New York: Wiley, 267–93.

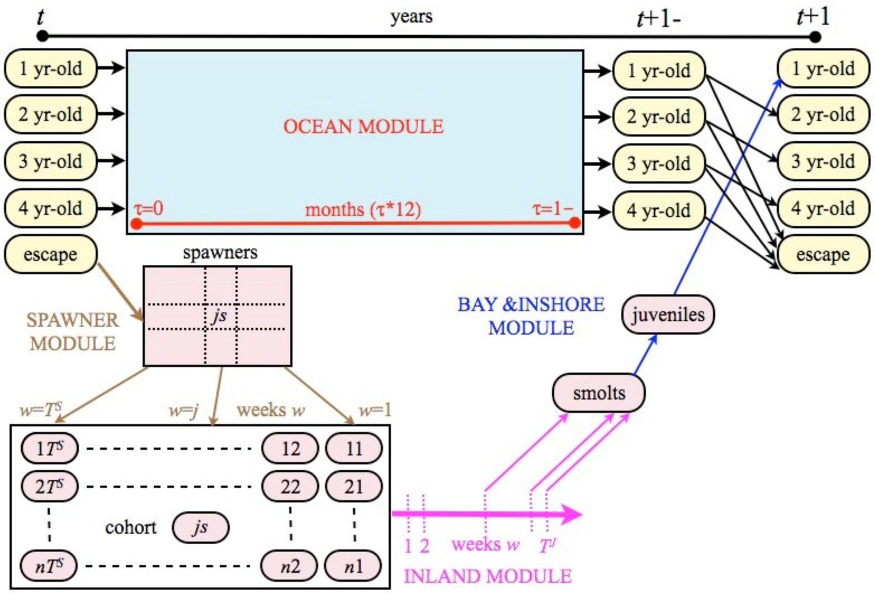
Appendix 4

Structure of new model (V 2.0) and its relevance to criticisms of the previous model (V 1.0)

(Dr. Wayne Getz)

Structure of new model (V 2.0) and its relevance to criticisms of the previous model (V 1.0)

A. Model Structure (see Supplemental Material A for larger version of figure below)



This new San Joaquin River (SJR) fall-run Chinook salmon population model is an extension of the previous version to include more mechanistic descriptions of all major elements of the system. It consists of four interrelated modules: 1. INLAND, 2. BAY & INSHORE, 3. OCEAN, and 4. SPAWNER. Detailed equations and algorithmic procedures governing the calculations performed by each module are given in the Supplemental material below. Here we provide an overview of each of these components, and how this new structure addresses the questions and perceived limitations of the previous version.

1. INLAND JUVENILE PRODUCTION MODULE:

This module tracks cohorts of juvenile salmon generated by the SPAWNER MODULE and describes how, on a weekly iteration interval, they decline in number, move within the San Joaquin River (SJR) system, and grow-on-average in size as a function of the weekly average temperature profiles and flow rates in different parts of the SJR system. The module is structured spatially to include upper and lower reaches of the three primary tributaries, as well as spatial elements between the confluence of each tributary and the SJR mainstem, and between the Friant dam and Merced river confluence. This refined life-cycle structure addresses the requests of reviewers (See Item 1 of Table). The weekly iteration interval permits us to parse out the effect of flows at different times of the year so that we can better evaluate the effects of intra-season flow variability (Items 31 and 32), and asses the effects of exports (Items 20 and 22) and HORB status (Item 6). This refined spatial and temporal resolution provides a more biologically relevant basis for evaluating the impact of hatchery releases on the population than did the previous model (Items 23 and 47) as well as the likely impact of improving the upper reaches of the SJR (Friant segment) for future spawning activities. The weekly time iteration interval also provides a link to water management at an appropriate temporal level of resolution: daily is too fine to be meaningful for the accuracy and precision of the model or water release schedules, while monthly is too coarse to capture releases that are scheduled over numbers of weeks rather than numbers of months.

The more than 400 coded wire tagged smolt releases in the SJR are being analyzed to estimate reach specific juvenile salmon survival rates for this inland module. A preliminary look at these data supports the observations of the Tuolumne report (Stillwater Ecosystems, Watershed & Riverine Sciences 2005), and suggests similar positive effects of flow on survivorship in the Merced River. The small number of releases in the Stanislaus will limit estimation from this tributary. Future analyses of these data will include estimates of smolt survivorship on the three main SJR tributaries and sections of the SJR mainstem as a function of both temperature and flow.

2. BAY & INSHORE MODULE:

This module describes the fate of outmigrating juvenile salmon after passing Mossdale, to calculate the proportion that eventually enter the ocean fishery. Time for this module is iterated on an annual cycle because the available biological data is insufficient for a finer scale, mechanistic description of the various factors affecting survival of the smolts in this component of the SJR system. Within this time frame it is still possible to incorporate salinity effects on survival (Item 25), to the extent that salinity conditions in drought years can be contrasted with normal and wet years. Further, this model can account for other factors, such as variability in habitat suitability (Items 4 and 22) or the prevalence of predators in the delta, which may be important.

3. OCEAN FISHERY MODULE:

This module is iterated on a monthly basis because the operation of the fishery is managed as a seasonal enterprise and hence requires a more refined time interval than an annual iteration interval. The module structure permits the incorporation of both inter- and intra-annual variability associated with the operation of the fishery (Item 17). This module also generates the escapement without lumping cohorts, thereby addressing issues referred to in Item 14.

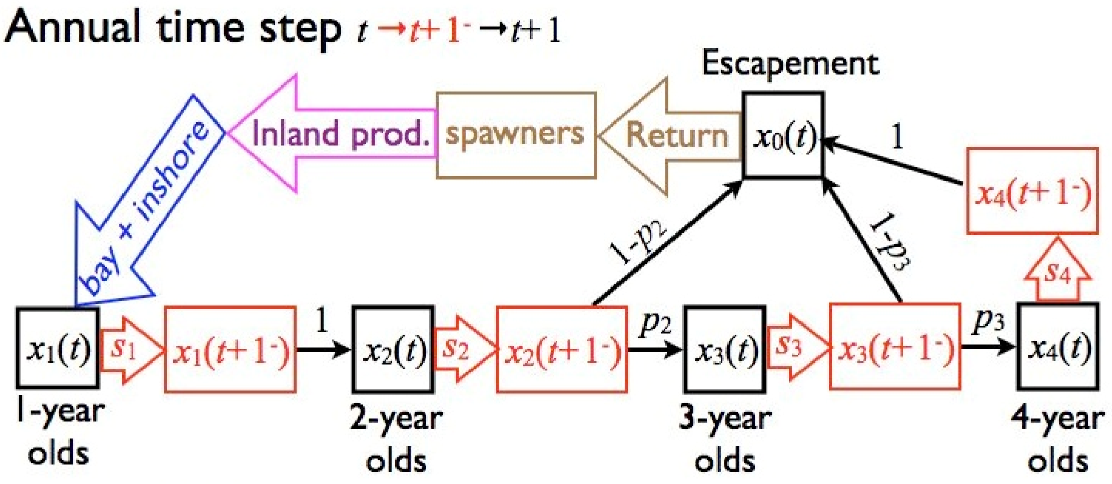
4. SPAWNER MODULE:

This final component links back to the INLAND JUVENILE PRODUCTION MODULE by describing how the yearly escapement population relates to juvenile salmon production. Escapement is distributed over time (weekly) and space (the different spawning reaches) to provide an estimate of the numbers of adults spawning in each reach each week. The fact that the aggregated escapement variable is disaggregated at this spatio-temporal level of resolution allows the effects of October flow on returning adults to be addressed (Item 19 in terms of up-river survivorship), with possible density-dependent effects (Items 10 and 27, and indirectly Item 28). Density dependence will also be incorporated into weekly viable egg production that generates the eggs for each weekly cohort in each spawning reach (again addressing Items 10 and 27, and indirectly Item 28). Calculating the effects of density is a complex problem that will be dealt with in a relatively simple way in this module (see our “Response Comment” for Item 22). However, the simulations will allow stock and recruitment data to be generated. These data can then be used to generate a stock-recruitment function (of the type mentioned under Item 28) for assessment and evaluation.

Supplemental material

Supplemental material A: Model details

Below is a cartoon of the system with colors used to identify the different modules of the model. The model is best considered hierarchically: annual iterations (black boxes) and inter-annual iterations (colored boxes and modules represented by large colored arrows). The black boxes are the annual variables, which are simply the age classes $x_i(t)$, $i=1,\ldots,4$ and for convenience a variable $x_0(t)$ is used to denote the escapement population entering through the Golden Gate in the fall each year. Although individual fish may return over a couple of months, we can arbitrarily think of time t being identified with September 1 each year (or some other suitable date that reflects the start of the escapement event). At the annual iteration level, the model thus has five aggregated variables $x_i(t)$, $i=0,\ldots,4$, with $x_i(t+1)$, $i=0,2,3,4$ being calculated within the OCEAN FISHERY MODULE (red) from a knowledge of $x_i(t)$, $i=1,\ldots,4$; but calculation of $x_1(t+1)$ from $x_0(t)$ requires more detailed computation using the SPAWNER MODULE (brown) followed by the INLAND JUVENILE PRODUCTION MODULE (purple) followed by the (BAY/INSHORE MODULE). The specifics are given on the next page



$$x_1(t+1) = \{(\text{Bay+In-Shore})\otimes\text{Inland}\otimes(\text{Spawners}\otimes\text{Return})\}(x_0(t)) \equiv F(x_0(t))$$

$$x_{i+1}(t+1) = p_i\, x_i(t+1^-), \quad i=1,2,3 \quad (p_1=1)$$

$$x_0(t+1)(t+1) \equiv (1-p_2)x_2(t+1^-)+(1-p_3)x_3(t+1^-)+x_4(t+1^-)$$

$$\{\text{Ocean}\}: x_i(t+1^-) = s_i\, x_i(t), \quad i=1,2,3,4$$

Fig. 1. Cartoon of system organized to reflect annual (black) and inter-annual (colored) components of the model

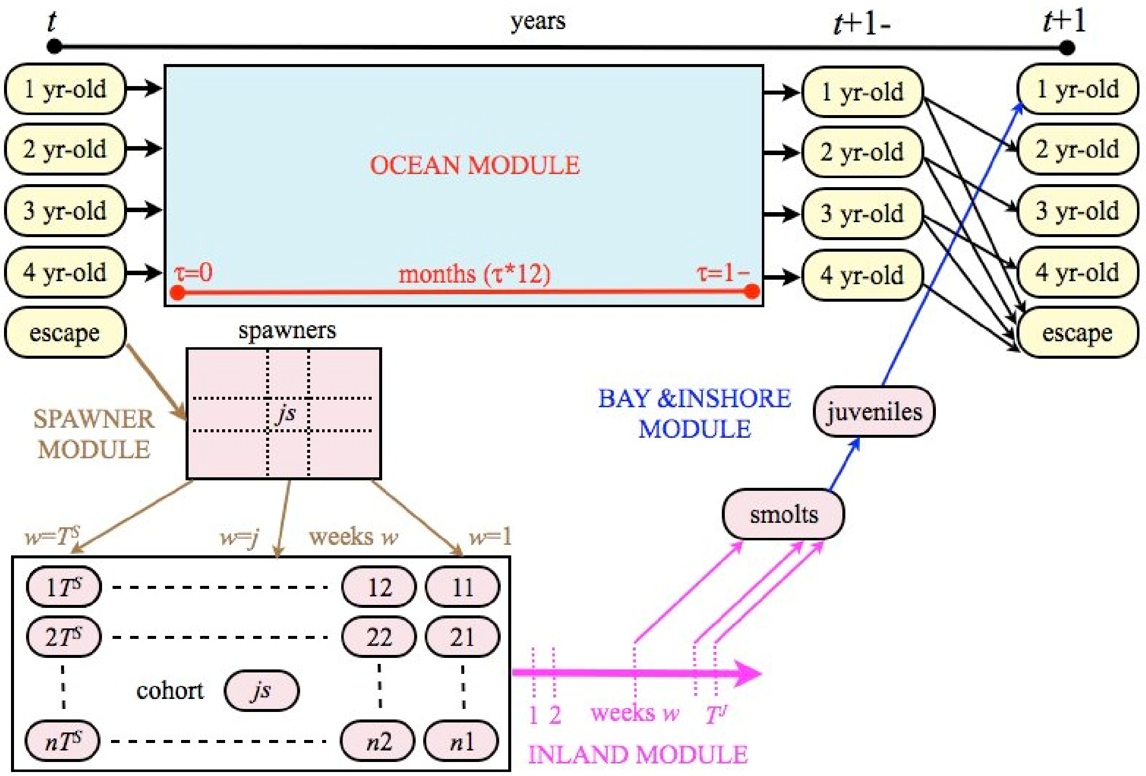


Fig. 2. Cartoon of system with more explicit temporal structure to components

Annual Iterations.

For t=0,1,2,…, the basic annual iteration of the model is:

$$x_0(t+1)=\sum_{i=1}^{4} s_i p_i x_i(t)$$
$$x_1(t+1)=F\big(x_0(t)\big)$$
$$x_{i+1}(t+1)=s_i(1-p_i)x_i(t),\quad i=1,2,3,$$

where, in our specific case, $p_1=0$, $0\le p_2<1$, $0\le p_3<1$, $p_4=1$.

Before considering the particulars of the intra-annual modules used to generate the function F and the survivorship proportions s_i in the above model, we introduce a running time variable $\tau\in[0,1]$ that indicates how far into the year we have progressed in each time interval $[t,t+1]$.

Consider an aggregated one-effort-level fisheries model (more than one effort level is needed when differentiating, say, a commercial from a sports fishery), in which an age-dependent natural mortality rate α_i operates in the ocean and the age-dependent fishing mortality is determined by an age-specific catchability coefficient q_i multiplied by a constant harvest effort variable v_t that is only applied on the intervals $[t+\tau_1,t+\tau_2]$ each year, where $0\le\tau_1<\tau_2\le 1$. In this case, the survivorship coefficients s_i are described by the equation

$$s_i(t)=\exp\big(-\alpha_i-q_i v_t(\tau_2-\tau_1)\big),\ i=1,\ldots,4,\ t=1,2,3\ldots .$$

Further, in an aggregated fishery the function F is assumed to have some two or three-parameter form, a rather general one being the Deriso-Schnute function

$$F(x_0) = \beta_1 x_0 \left(1 - \beta_2 \beta_3 x_0\right)^{1/\beta_3} \quad \text{with } \beta_1 > 0 \text{ and } \beta_2 > 0.$$

In our model, we construct F from a spatially explicit detailed process in which environmental variables (covariates) relating to river temperature and flow, and ecological variables such as predator levels are included. We can also make the ocean model spatially explicit, if necessary, but it is not necessary to iterate the ocean model on a monthly basis if using the variables τ_i to control fishing season.

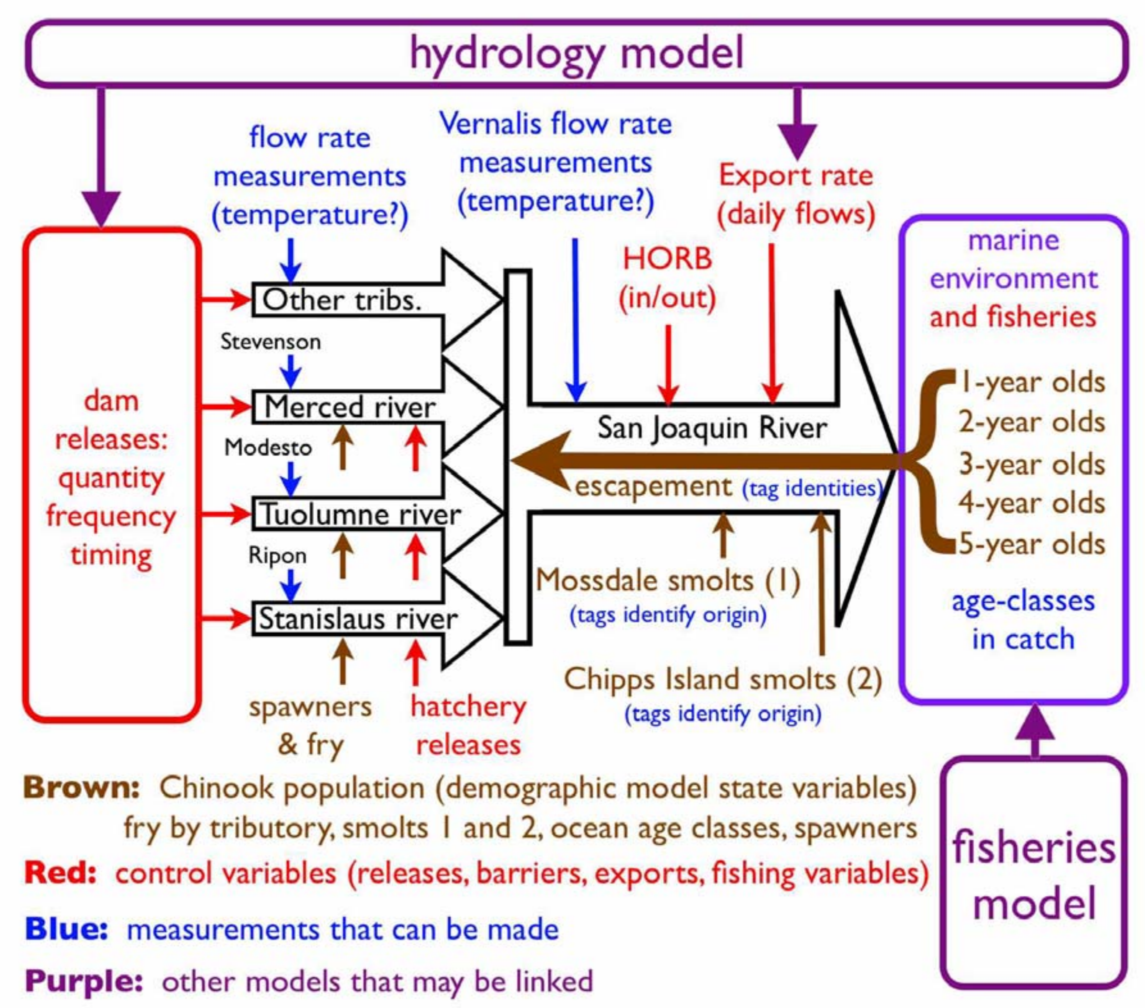


Figure 3: Cartoon of model making spatial structure more explicit.

Ocean Module

If the ocean is divided into several spatially distinct regions R_k, k=1,2,..,K, there are several scenarios possible, each more complex than the previous:

1. Individuals in an area remain in that area for the whole year and are only redistributed to other areas during the age-transition calculation, at which time a space transition calculation is also included.
2. A point in time is identified during which individuals move from one area to another. This generalizes 1. above to allow the migration calculation to be done at a point other than the time of age transition (nominally, September 1 each year).
3. Individuals in an area move to other areas at a continuous rate throughout the year.
4. Migration occurs over particular intervals that are larger than a point in time but smaller than the whole year.

In all but scenario 1, the OCEAN MODULES s_i (depicted in Fig. 1 in red) can ignore inter-region movements and consider them purely along with the age transition and escapement production components of the model. In this simplest case, the model has the following form. First define $x_{i,k}$ to be the number of age *i* individuals in region *k*. Let $p_{i,kl}$ represent the proportion of age *i* individuals in region *k* that make the transition to region *l* at the end of each year, and define $p_{i,k0}$ as the proportion of age *i* individuals in region *k* that return to join the escapement population at the end of the year (nominally, August 31). In this case the computation is split into:

$$x_{i,k}(t+1^{-}) = s_{i,k}x_{i,k}(t), \quad i=1,2,3,4, \text{ and } k=1,2,\ldots,K$$

and

$$x_{i+1,k}(t+1) = (1-p_{i,k0})\sum_{l=0}^{K} p_{i,lk}x_{i,l}(t+1^{-}), \quad i=1,2,3, \text{ and } k=1,2,\ldots,K.$$

Note, in the formula below, $p_{4,k0}=1$ for all *k*, which is why the second set of equations above can be truncated beyond *i*=3. The escapement each year is given by

$$x_0(t+1) = \sum_{i=1}^{4}\sum_{k=0}^{K} p_{i,k0}x_{i,k}(t+1^{-})$$

For scenario 1, the OCEAN MODULES s_i are functions purely of natural and fishing mortality. In what follows, we focus on the particular case of a sports and a commercial fishery operating in parallel. In developing the ocean model, we assume that at any time $t+\tau$ (recall that *t* is an integer variable and τ a continuous variable on [0,1]) the fishing efforts associated with the sport and commercial fisheries are $v_{st}(\tau)$ and $v_{ct}(\tau)$ respectively. If fishing mortality is proportional to the product of fishing effort and stock density, with the factor of proportionality being length-specific catchability and natural mortality is also length specific but depends on an ocean factor θ (and environmental "covariate variable" that accounts in an aggregated way for the effects of marine predators and other ecological factors) then we calculate the impact on the stock using variables $x_{i,tk}(\tau)$ (the number of individuals of age *i* at time $t+\tau$ in region *k*)

$$\frac{dx_{i,tk}}{d\tau} = -\big(\alpha_k(i+\tau,\theta) + q_{sk}(i+\tau)v_{stk}(\tau) + q_{ck}(i+\tau)v_{ctk}(\tau)\big)x_{i,tk}$$

where $x_{i,tk}(0) = x_{i,k}(t)$. In this formula, as in our aggregated-fishery model above, the α's are natural mortalities and the q's are catchabilities, the latter subscripted by s and c for the sports and commercial fishery. These parameters and the fishing effort variables are subscripted by k to allow variation across space, although it is unlikely that catchability needs to depend on k. The way the natural mortality and catchability parameters have been set up is to make them a function of age $a = i+\tau$. Further, for the natural mortality we assume that the effects of age and environmental state θ are separable, so that we can write

$$\alpha_k(a,\theta) = \alpha_k^0(a)\alpha_k^1(\theta).$$

An aside on functions.

We standardize all monotonic functions $z=f(w)$ to have the following four parameter ($\rho>0$, $\kappa>0$, z_1, z_2) form that switches on the interval $[w_1, w_2]$ (or $[w_1, w_2]$ to facilitate left-right symmetry in the family of functions) between values (specified or estimated) $z_1 = f(w_1)$ and $z_2 = f(w_2)$:

$$f_{w_1w_2}(w) = z_1 + \frac{\left(\dfrac{w-w_1}{w_2-w_1}\right)^{\rho}\left(1+\left(\dfrac{1}{\kappa}\right)^{\rho}\right)}{1+\left(\dfrac{w-w_1}{\kappa(w_2-w_1)}\right)^{\rho}}\big(z_2-z_1\big).$$

Although this monotonic family of functions has four parameters ($\rho>0$, $\kappa>0$, z_1, z_2), it is very well-behaved and reduces to a line joining z_1 and z_2 whenever ρ is not too large but $\kappa >> \max\{z_1, z_2\}$ or a switching function that rapidly switches values from z_1 to z_2 around the point $\kappa \in [w_1, w_2]$ whenever $\rho >> 1$. Further, note that a scaling transformation that sets $z_1=0$, $z_2=1$, $w_1=0$, and $w_2=1$ simply reduces this function to $f_{01}(w) = \dfrac{w^{\rho}\left(\kappa^{\rho}+1\right)}{\kappa^{\rho}+w^{\rho}}$, which makes transparent its fundamental form.

To continue, if we ignore possible dependence on region k, we assume that each of the functions $\alpha^0(a), \alpha^1(\theta)$, $q_s(a)$, and $q_c(a)$ have the above functional forms. The fisheries model for scenario 1 is obtained by directly integrating the differential equation for $x_{i,tk}(\tau)$ to obtain

$$x_{i,tk}(\tau) = x_{t,k}(t)\exp\left(-\int_0^{\tau}\big(\alpha_k^0(i+\zeta)\alpha_k^1(\theta(t+\tau)) + q_{sk}(i+\zeta)v_{stk}(\zeta) + q_{ck}(i+\zeta)v_{ctk}(\zeta)\big)d\zeta\right).$$

If we now discretize intra-annual time in the ocean fisheries model to a monthly time step, then we essentially work with a set of values $\{\tau_j = j/12 | j=1,\ldots 12\}$. Further, over any interval $[\tau_{j-1}, \tau_j]$, we approximate the functions with their values at the midpoint of these intervals, then we have

$$\int_{\tau_{j-1}}^{\tau_j}\big(\alpha_k^0(i+\zeta)\alpha_k^1(\theta(t+\zeta)) + q_{sk}(i+\zeta)v_{stk}(\zeta) + q_{ck}(i+\zeta)v_{ctk}(\zeta)\big)d\zeta = \alpha_{kij}^0\alpha_k^1(\theta_{tj}) + q_{skij}v_{stkj} + q_{cktj}v_{cikj}$$

where the effort levels v_{stkj} and v_{ctkj} are constant value inputs for each month, the values θ_{tj} are environmental inputs for month *j* in year *t*, and the functions that depend on the age of the stock, assuming independence of *k*, are

$$\alpha_{ij}^0 = \alpha^0(i+(j-0.5)/12),\ q_{sij} = q_s(i+(j-0.5)/12) \text{ and } q_{cij} = q_c(i+(j-0.5)/12).$$

With all this machinery, the survival term $s_{i,k}$ in the fisheries equation $x_{i,k}(t+1^-) = s_{i,k}(t)x_{i,k}(t)$ is:

$$s_{i,k}(t) = \exp\left(-\sum_{j=1}^{12}\alpha^0(i+(j-0.5)/12)\alpha^1(\theta_{tj}) + q_s(i+(j-0.5)/12)v_{stkj} + q_c(i+(j-0.5)/12)v_{ctkj}\right).$$

In summary, the ocean module requires:

- Inputs: fishing efforts v_{stkj} and v_{ctkj} (year *t*, month *j*, and region *k*)
  environmental conditions θ_{tj} (which can be spatially structured if desired)
- Functions: estimates of 4 parameters for each of the natural mortality and two catchability functions dependent on age, and 4 for the effects of environmental on put on survival (16 parameters in total)
- Movement: estimates for mixing parameters $p_{i,kl}$ and escapement parameters $p_{i,k0}$.

Spawner Module

The escapement time series $x_0(t)$ is most appropriately thought of in terms of adult fish re-entering the San Francisco Bay at time *t* (nominally September 1 each year) after completing the ocean component of their life cycle. In the simplest, case $x_0(t)$ can be identified with the spawning adults *A*(*t*) defined in the INLAND JUVENILE PRODUCTION MODULE presented next, with the partitioning of *A* into cohort spawning classes $A^{js}(t)$ by week *j* and region or segment *s* (tributary or sub-tributary) (this index *s* should not be confused with survivorship parameters *s*) (i.e. $A(t) = \sum_{j=1}^{n}\sum_{s=0}^{T^S-1} A^{js}(t)$). If necessary we can develop a more complex model in which the survival and distribution of $x_0(t)$ into $A^{js}(t)$ is influenced by weekly flow rates from both the San Joaquin and Sacramento rivers.

Inland Juvenile Production Component

Spatial Structure

Overall we assume a linear spatial structure tree-like structure with three initial branches/tributaries (Stanislaus (St), Tuolumne (Tu), and Merced (Me) rivers) that merge into the San Joaquin river (SJR) and including the mainstem SJR reach above its confluence with the Merced up to the Friant dam (Fr) and below the Stanislaus into the delta and ultimately the ocean. With this in mind we define four "running distance variables" l^{St}, l^{Tu}, l^{Me} and l^{Fr} that tell us how far downstream we are from the upper most edge of the upper most reach of each of the tributaries all the way down to some selected point at the month to the San Francisco Bay where the "ocean population begins."

The coarsest spatial resolution that we might consider is to identify four "lumped" reaches, followed on by the San Joaquin river divided into linear segments from the Stanislaus to Tuolumne confluences (ST), the Tuolumne to Merced confluences at Vernalis (TV), the from Vernalis and Mossdale (VM), Mossdale and Chipps Island (MC), and finally Chipps Island to the ocean (CO). At a finer resolution we can segment the three tributaries and upper SJR (FR) into string of n^{St}, n^{Me} n^{Tu} and n^{Fr} reaches. Using the index j, we can number all these spatial segments from up to downstream in each tributary and along the SJ itself:

The reaches of the Stanislaus: $j=1,\ldots, n^{St}$
The ST segment: $j=n^{St}+1$
The reaches of the Tuolumne: $j=n^{St}+2,\ldots, n^{St}+n^{Tu}+1$
The TV segment: $j=n^{St}+n^{Tu}+2$
The reaches of the Merced: $j=n^{St}+n^{Tu}+3,\ldots,n^{St}+n^{Tu}+n^{Me}+2$
The reaches of the Friant section of SJR: $j=n^{St}+n^{Tu}+n^{Me}+3,\ldots,n^{St}+n^{Tu}+n^{Me}+n^{Fr}+2$
The VM segment: $j=n^{St}+n^{Tu}+n^{Me}+ n^{Fr}+3$
The MC segment: $j=n^{St}+n^{Tu}+n^{Me}+ n^{Fr}+4$
The CO segment: $j=n=n^{St}+n^{Tu}+n^{Me}+ n^{Fr}+5$

It may be necessary to lump or split some of the segments on the SJR or in the Delta, but as formulated above, the model allows flexibility in specifying the number of reaches including the simplest case $n^{St}=1$, $n^{Me}=1$, $n^{Tu}=1$ and $n^{Fr}=1$ (as in the 1991 EA model). Note that the different reaches and spatial segments will each have a beginning and an end (i.e. boundaries) defined by the l^{Trib} values, where *Trib=St, Tu, Me* or *Fr* depending on the tributary in which the segment lies, and segments below more than one tributary will have more then one running length variable defining its boundaries.

Temporal Structure

A monthly resolution is likely to be too coarse to capture temperature sensitive phenological processes that will be included in the model (e.g. development of eggs into alevins, fry, fingerlings, and smolts through temperature driven growth rates) because temperature changes over some months (e.g. November) can be quite considerable. On the other hand, a daily resolution is unnecessarily refined because the biological data to support this level of detail is not available. Thus we select a weekly resolution. For each annual cycle of this inland juvenile developmental component of the model, time begins when the first fall run adult spawners lay eggs in one of the spatial segments listed above. Let us denote this week as $w=0$, and define $w=T^S-1$ as the week in which the last of the adults spawn in the fall run season. Also define T^J to be the week in which the last juvenile produced in the annual cycle being considered enters the ocean. The model is thus run for $w=0,\ldots,T^J$; at $w=0$ it is initialized using a spawner input distribution (as described below) and over the course of the interval $[1, T^J]$ it delivers a cohort of juveniles (entering first year-class) to the ocean population (with most of the individuals being delivered over the final several weeks of the interval $[1, T^J]$).

Environmental Drivers

A hydrological model will be used to generate average weekly profiles $\phi\,(l^{Trib}, w)$ for flow rate and $\psi(l^{Trib},w)$ for temperature as a function of week w and distance variable l^{Trib}, for *Trib=St, Tu, Me* or *Fr* as appropriate.

State Space Structure

State of the system at any time w=0,…,T^J is represented by the values of the elements of nT^S (recall $n=n^{St}+n^{Tu}+n^{Me}+n^{Fr}+5$) cohort vectors $\mathbf{x}^{js}(w)$, j=1,…,n, s=1,…,T^S, and w=0,…,T^J a number of which, as discussed below, are **0** (i.e. all elements are zero) for all w=0,…,T^J. For clarification, j and s are the place and week in which the particular cohort is produced while w represents the week for evaluating the state of this cohort. Each $\mathbf{x}^{js}(w)$ is at least a three dimensional vector with elements $x^{js}{}_1(w)$, $x^{js}{}_2(w)$ and $x^{js}{}_3(w)$ representing respectively the number of individuals in the cohort , the average size (probably length) of in each individual in the cohort, and the running length variable l^{Trib} - where *Trib=St, Tu, Me* or *Fr* depending on where the cohort originated. The dimension of each cohort vector can be increased; for example in the case where we might want to have a fourth value $x^{js}{}_4(t)$ that represents the average health of an individual in the cohort, as would be needed to account for toxic substances in the river, turbidity of the water, or other factors that may affect the health of individual salmon.

Initial State

Either a set of $(n^{St}+n^{Tu}+n^{Me}+n^{Fr}+5)T^S$ empirical values, A^{js}, j=1,…, $n^{St}+n^{Tu}+n^{Me}+n^{Fr}$ 5 and s=0,…,T^S-1, or a spawner distribution model that distributes the total number of spawners, A, returned by the ocean fisheries model back to the delta in any particular year into a set of spawners, A^{js}, satisfying $A=\sum_{j=1}^{n}\sum_{s=0}^{T^S-1}A^{js}$, are used to determine the "initial cohort numbers" $x^{js}{}_1(s+1)$. In particular, if ε^{js} is the number of eggs spawned by each adult (female if only counting females) A^{js} in week s and $p^{ej}(\phi,\psi)$ is the proportion of individuals (initially laid as eggs, and possibly still eggs) that survive the first week in spatial segment j as a function of flow rate ϕ a temperate ψ, then relationship of the form

$$x^{js}{}_1(s)=p^{ej}(\phi,\psi)\varepsilon^{js}A^{js}(s-1),\quad s=1,\ldots,T^S,\ j-1,\ldots,n,\quad (1)$$

holds. Note that for all $w \le s$, $x^{js}{}_1(w)=0$ since the spawners have not yet arrived to spawn. Also many other cohorts $x^{js}{}_1(w)$ maybe 0 for $w>s$, since not all spatial segments will have spawners each week.

Similar relationships hold for updating the developmental markers (either length after hatching or a nominal length that is a surrogate for degree-day time remaining to hatching: the latter length can be 0 immediately when eggs are laid and the average length of a hatchling at the time of hatching, with lengths between these two lengths representing "proportional progress" to hatching). In this case, we need a relationship $g(\phi,\psi,x^{js}{}_2,l^{Trib})$ that specifies how much an individual of length $x^{js}{}_2$ at position l^{Trib} will grow over the next week if the average flow and temperature for the week have values ϕ and ψ respectively:

$$x^{js}{}_2(s)=x^{js}{}_2(s-1)+g(\phi,\psi,x^{js}{}_2,l^{Trib}),\quad s=1,\ldots,T^S,\ j=1,\ldots,n.\quad (2)$$

Similarly, we need a relationship $d(\phi,\psi,x^{js}{}_2,l^{Trib})$ that specifies how much an individual of length $x^{js}{}_2$ at position l^{Trib} will on average move over the next week. If the average flow and temperature for the week have values ϕ and ψ respectively

$$x^{js}{}_3(s)=l^{Trib}(j)+d(\phi,\psi,x^{js}{}_2,l^{Trib}),\quad s=1,\ldots,T^S,\ j=1,\ldots,n. \qquad (3)$$

holds.

Dynamic Updating

In each week w three state variables characterizing each cohort are updated based on their current values and the anticipated flow and temperature profile variables $\phi_w(l^{Trib},w)$ and $\psi_w(l^{Trib},w)$ respectively. To update the number of individuals in the cohort we define $p(\phi,\psi,x_2,l^{Trib})$ to be a proportion of individuals of size x_2 at location l^{Trib} that survive the week as a function of average flow rate and temperature values ϕ and ψ respectively. Thus the equation for updating the number $x^{js}{}_1(w)$ of individuals in cohort js (cf. equation (1))) is in terms of the current average size $x^{js}{}_2(w)$ and $x^{js}{}_3(w)$ (the latter is interpreted in terms of the appropriate length variable determined by the initial cohort spawning reach j) given by equation

$$x^{js}{}_1(w+1)=p\Big(\phi\big(x^{js}{}_3(w),w\big),\psi\big(x^{js}{}_3(w),w\big),x^{js}{}_2(w),x^{js}{}_3(w)\Big)x^{js}{}_1(w),\quad w=1,\ldots,T^J,\ j=1,\ldots,n \qquad (4).$$

Similarly, equations for updating the remain two variables (cf. equations (2) and (3) are:

$$x^{js}{}_2(w+1)=x^{js}{}_2(w)+g\Big(\phi\big(x^{js}{}_3(w),w\big),\psi\big(x^{js}{}_3(w),w\big),x^{js}{}_2(w),x^{js}{}_3(w)\Big)\quad w=s+1,\ldots,T^J,\ j=1,\ldots,n. \qquad (5)$$

and

$$x^{js}{}_3(w+1)=x^{js}{}_3(w)+d\Big(\phi\big(x^{js}{}_3(w),w\big),\psi\big(x^{js}{}_3(w),w\big),x^{js}{}_2(w),x^{js}{}_3(w)\Big)\quad w=s+1,\ldots,T^J,\ j=1,\ldots,n. \qquad (6)$$

Observed Variables

In any week, we can calculate the number of individuals that move past selected points in the system and we can also calculate aggregated variables of numbers of individuals that pass these points (e.g. Vernalis) over the total season, or by week or by month. Other variables can be accumulated (e.g. number of individuals by size that are delivered to the ocean fishery each season) and with so-called “state space estimation methods” used to estimate the parameters of the survivorship (p), growth (g) and distance moved (d) functions of flow (ϕ) temperature (ψ), size x_2 and location x_3. Density-dependence can be introduced by making p, g, and d, functions of x_1 as well, although as a first cut we may want to confine considerations of density dependence purely to the egg spawner-relationship formulated in equation (1). Of course the simplest relationships are linear ones, which will be assumed at the outset.

Stochasticity

Relationships (4) to (6) can be made stochastic by appropriate random variable perturbations, with Monte Carlo methods used to generate distributions of the variables. Further observations can include error variables as well. Details of these approaches will be discussed by the group.

Bay and Inshore Component

Define T^{js} to be the first week that x^{js}_3 exceeds the distance from its starting point to the last census point (e.g. Chipps Island). Then at time $w=T^J$ the number of juveniles x^J that have passed the last census point over the whole season is

$$x^J(t) = \sum_{j=1}^{n} \sum_{s=1}^{T^S} x^{js}_1(T^{js}).$$

A proportion s^J of these then survive to join the ocean fishery as one-year olds at time t+1, where we assume that s^J depends on an environmental variable δ_t (in this case we will probably use stripped bass population levels as the dominate variable affecting juvenile survivorship) to yield the equation

$$x_1(t+1) = s^J(\delta_t)x^J(t)$$

We then feed this number into the ocean module after using fisheries data to partition the one year olds into region classes $x_{1,k}$ ensuring that

$$x_1(t) = \sum_{k=1}^{K} x_{1,k}(t).$$

Supplemental material B. Coding Framework

Inland Juvenile Component: cohort progression.

Variables:

The model is iterated over weekly time *t*. At time *t*, each cohort (*s*,*j*) is represented by the values of a set of variables $\{\text{NUM}(t), \text{SIZE}(t), \text{LOC}j(t); \text{DD}(t)\}_{s,j}$, where s=1,…,T^S, is the number of weeks in the spawning season, and *j*=1,…,6 is the number of nominal spawning locations (*j*=1,2 is the upper and lower reaches of the Merced; *j*=3,4 is the upper and lower reaches of the Toulumne; *j*=5,6 is the upper and lower reaches of the Stanislaus). The definitions of these variables are:

NUM(*t*): the number of individuals in the cohort at the beginning of week *t*.
SIZE(*t*): the average size of an individual in the cohort at the beginning of week *t*.
LOC*j*(*t*): the nominal location of individuals in the cohort at the beginning of week *t*.
DD(*t*): the accumulated number of degree-days in °C above 0 to which the cohort has been exposed. (Jager et al. 1997 have a more complicated definition in which they discount degree-days in °C on days when the temp is between 0 and 5 by a factor of 0.5 but it is not clear whether this adjustment will make much difference).

Constants:

SH: nominal size (length) of individuals at hatching (value from literature, possibly 25 mm)
SA: nominal/average size of alevin at transition to fry (value from literature, possible 35 mm—see $L_{\min}$ in Jager et al. 97)
SF: nominal/average size of fry to smolt at transition to juvenile (value from literature, possible 70 mm—see $L_{\min}$ in Jager et al. 97)
MAXS: nominal maximum size of smolts (may be set from literature or estimated)
ΔSIZE: smolt growth rate parameter (may be set from literature or estimated)
LOC1*j*, *j*=1,…,6: distance from nominal spawning site at location *j* to sampling site at confluence of associated tributary. (These values to be supplied by Avry and Dean or may be estimated)
LOC2*j*, *j*=1,…,6: distance from nominal spawning site to Mossdale sampling site. (These values to be supplied by Avry and Dean)
DDE: number of degree-days in °C above 0 (e.g. average week temp of 10 °C = 70 DD) for egg development to hatching as alevins (literature suggests a value of 500—see Jager et al. 97; Quinn et al. 01))
DDA: number of degree-days in °C above 0 for alevin development into frys (literature suggests a value of 400)
DDF: number of degree-days in °C above 0 for fry development into smolts (literature suggests a value of 1100) at which state individuals migrate to bay to adapt to saltwater for exiting to ocean.

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Inputs:

There is a matrix of initial values NUM(s,j), s=1,…,T^S, j=1,…,6, that are the number of eggs generating each cohort is obtained either as inputs (estimate of spawner biomass * eggs-per-unit-biomass) or generated by an ESCAPEMENT/SPAWNER MODULE.

A TEMP (temperature) and FLOW data base is provided such that in for any week t=1,…,T^J and LOCj (interpolation may be needed to get this value between data at nodes of a spatial grid) we can obtain values TEMP(t, LOCj) and FLOW(t, LOCj).

The flowing functions are provide:
F_{SE}(TEMP): the proportion of eggs surviving as a function of average temperature for the week.
F_{SA}(TEMP): the proportion of alevins surviving as a function of average temperature for the week.

Parameters that will be estimated: (using equations below)
a_{FLOW}, b_{FLOW}: smolt movement parameters
a_{SS}, b_{SS}, c_{SS}: smolt survival parameters
(may be set from literature or estimated) MAXS: nominal maximum size of smolts
(may be set from literature or estimated) ΔSIZE: smolt growth rate parameter
(may be set or estimated) LOC1j, j=1,…,6: distance from nominal spawning site at location j to sampling site at confluence of associated tributary.

Pre-Initialization: (t<s), s=1,…,T^S , t=0,…,s-1

At t=0 we have {0, 0, 0}.
For t=0,…,s-1, {NUM(t), SIZE(t), LOCj(t); DD(t)}$_{s,j}$= {0, 0, 0, 0}

Initialization: (t=s), s=1,…,T^S

DD$_{s,j}$(0)=0
{NUM(0), SIZE(0), LOCj(0) ; DD(t)}$_{s,j}$ = {NUM(s,j), 0, 0, 0}

Updating: (t>s), s=1,…,T^S, t=s+1,…, T^J (STOPCONDITION)
{Note 1. For simplicity drop subscripts j and s
Note 2. We first update DD, then LOCj, then NUM, then SIZE}

STOPCONDITION: If LOCj(t)>LOC2j for all j, then t=T^J

DD(t+1)= DD(t)+ TEMP(t, LOCj(t)) where TEMP is in °C above 0

$$\mathrm{LOC}j(t+1)=\begin{cases} \mathrm{LOC}j(t) & \begin{cases}\text{for } \mathrm{DD}(t)<\mathrm{DDE{+}DDA}\\ \text{and } \mathrm{DD}(t+1)\le \mathrm{DDE{+}DDA}\end{cases}\\ \mathrm{LOC}j(t)+a_{FLOW}+b_{FLOW}*\mathrm{FLOW}(t,\mathrm{LOC}j(t)) & \text{for } \mathrm{DD}(t)\ge \mathrm{DDE{+}DDA}\\ \text{otherwise} & \\ \mathrm{LOC}j(t)+\alpha\left(a_{FLOW}+b_{FLOW}*\mathrm{FLOW}(t,\mathrm{LOC}j(t))\right) & \alpha=\dfrac{\mathrm{DDE{+}DDA{-}DD}(t)}{\mathrm{DD}(t+1)-\mathrm{DD}(t)} \end{cases}$$

The following equation assumes that DD(t) will always have one value of t for which it falls between DDE and DDA (i.e. temperature conditions are such that alevin development will always take more than one week—this assumption can be checked).

$$\mathrm{NUM}(t+1)=\begin{cases} F_{\mathrm{SE}}(\mathrm{TEMP}(t,\mathrm{LOC}j(t)) & \begin{cases}\text{for } \mathrm{DD}(t)<\mathrm{DDE}\\ \text{and } \mathrm{DD}(t+1)\le \mathrm{DDE}\end{cases}\\ \begin{array}{c}(1-\alpha 1)F_{\mathrm{SE}}(\mathrm{TEMP}(t,\mathrm{LOC}j(t))+\\ \alpha 1F_{\mathrm{SA}}(\mathrm{TEMP}(t,\mathrm{LOC}j(t)))\end{array} & \begin{cases}\text{for } \mathrm{DD}(t)<\mathrm{DDE}\\ \text{and } \mathrm{DDE}<\mathrm{DD}(t+1)<\mathrm{DDE{+}DDA}\end{cases}\\ \text{Where } \alpha 1=\dfrac{\mathrm{DDE}-\mathrm{DD}(t)}{\mathrm{DD}(t+1)-\mathrm{DD}(t)} & \\ F_{\mathrm{SA}}(\mathrm{TEMP}(t,\mathrm{LOC}j(t)) & \begin{cases}\text{for } \mathrm{DDE}\le\mathrm{DD}(t)<\mathrm{DDE{+}DDA}\\ \text{and } \mathrm{DDE}<\mathrm{DD}(t+1)<\mathrm{DDE{+}DDA}\end{cases}\\ \begin{array}{c}(1\text{-}\alpha 2)F_{\mathrm{SA}}(\mathrm{TEMP}(t,\mathrm{LOC}j(t))+\\ \alpha 2F_{\mathrm{SS}}(\mathrm{TEMP}(t,\mathrm{LOC}j(t))\end{array} & \begin{cases}\text{for } \mathrm{DDE}\le\mathrm{DD}(t)<\mathrm{DDE{+}DDA}\\ \text{and } \mathrm{DD}(t+1)\ge\mathrm{DDE{+}DDA}\end{cases}\\ \text{Where } \alpha 2=\dfrac{\mathrm{DDE{+}DDA{-}DD}(t)}{\mathrm{DD}(t+1)-\mathrm{DD}(t)} & \text{and } F_{\mathrm{SS}}(x)=\dfrac{a_{\mathrm{SS}}}{1{+}(b_{\mathrm{SS}}x)^{c_{\mathrm{SS}}}}\\ F_{\mathrm{SS}}(x)=\dfrac{a_{\mathrm{SS}}}{1{+}(b_{\mathrm{SS}}\mathrm{TEMP}(t,\mathrm{LOC}j(t))^{c_{\mathrm{SS}}}} & \text{for } \mathrm{DD}(t)\ge\mathrm{DDE{+}DDA} \end{cases}$$

The next equation assumes growth is controlled by DD accumulation up to smolt size SF and then by a constant increment $\Delta\mathrm{SIZE}$ times the size-to-go to maximum size MAXS

$$\mathrm{SIZE}(t+1)=\begin{cases} \left(\dfrac{\mathrm{DD}(t+1)}{\mathrm{DDE}}\right)\mathrm{SH} & \mathrm{DD}(t+1)\le\mathrm{DDE}\\ \mathrm{SH}+\left(\dfrac{\mathrm{DD}(t+1)-\mathrm{DDE}}{\mathrm{DDA}-\mathrm{DDE}}\right)(\mathrm{SA\text{-}SH}) & \text{for } \mathrm{DDE}\le\mathrm{DD}(t+1)\le\mathrm{DDA}\\ \mathrm{SA}+\left(\dfrac{\mathrm{DD}(t+1)-\mathrm{DDA}-\mathrm{DDE}}{\mathrm{DDF}-\mathrm{DDA}-\mathrm{DDE}}\right)(\mathrm{SA\text{-}SF}) & \text{for } \mathrm{DDA}\le\mathrm{DD}(t+1)\le\mathrm{DDF}\\ \mathrm{SF}+\left(\dfrac{\mathrm{DD}(t+1)-\mathrm{DDF}}{\mathrm{DD}(t+1)-\mathrm{DD}(t)}\right)\Delta\mathrm{SIZE}\left(\mathrm{MAXS}-\mathrm{SIZE}(t)\right) & \begin{array}{l}\text{for } \mathrm{DD}(t)\le\mathrm{DDF}\\ \text{and } \mathrm{DD}(t+1)>\mathrm{DDF}\end{array}\\ \mathrm{SIZE}(t)+\Delta\mathrm{SIZE}\left(\mathrm{MAXS}-\mathrm{SIZE}(t)\right) & \text{or } \mathrm{DD}(t)>\mathrm{DDF} \end{cases}$$

Observables:

The expected number of individuals passing the sampling points at the confluences of the tributaries and Mossdale are:

Merced Census:

For $j = 1,2$

$$\mathrm{YM}j(t) = \begin{cases} \mathrm{NUM}_{s,j}(t) & \mathrm{LOC}j(t-1) \le \mathrm{LOC1}j \text{ and } \mathrm{LOC}j(t) > \mathrm{LOC1}j \\ 0 & \text{otherwise} \end{cases}$$

$$\mathrm{YM}(t) = \sum_{j=1}^{2} \mathrm{YM}j(t)$$

Toulumne Census:

For $j = 3,4$

$$\mathrm{YT}j(t) = \begin{cases} \mathrm{NUM}_{s,j}(t) & \mathrm{LOC}j(t-1) \le \mathrm{LOC1}j \text{ and } \mathrm{LOC}j(t) > \mathrm{LOC1}j \\ 0 & \text{otherwise} \end{cases}$$

$$\mathrm{YT}(t) = \sum_{j=3}^{4} \mathrm{YT}j(t)$$

Stanislaus Census:

For $j = 5,6$

$$\mathrm{YS}j(t) = \begin{cases} \mathrm{NUM}_{s,j}(t) & \mathrm{LOC}j(t-1) \le \mathrm{LOC1}j \text{ and } \mathrm{LOC}j(t) > \mathrm{LOC1}j \\ 0 & \text{otherwise} \end{cases}$$

$$\mathrm{YS}(t) = \sum_{j=5}^{6} \mathrm{YS}j(t)$$

Mossdale Census:

For $j = 1,...,6$

$$\mathrm{YMD}j(t) = \begin{cases} \mathrm{NUM}_{s,j}(t) & \mathrm{LOC}j(t-1) \le \mathrm{LOC1}j \text{ and } \mathrm{LOC}j(t) > \mathrm{LOC1}j \\ 0 & \text{otherwise} \end{cases}$$

$$\mathrm{YMD}(t) = \sum_{j=1}^{6} \mathrm{YMD}j(t)$$

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Appendix 5

Limiting Factors Analyses for Chinook Salmon in the San Joaquin Basin, California

(Zac Jackson et al.)

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Limiting Factors Analyses for Chinook Salmon in the San Joaquin Basin, California[1]

Zac Jackson[1], Carl Mesick[2], Dean Marston[3], and Tim Heyne[4]

Our analysis of limiting factors for the fall-run Chinook salmon populations in the Tuolumne and Stanislaus rivers was based on the relationships between fish production (adults and juveniles), parental stock (spawner) abundance, and key environmental conditions over time.

Linear-regression indicates that the mean flow in the San Joaquin River near Vernalis between March 1 and June 15, when the fish were rearing in the tributary, explained 93% of the variation ($r2 = 0.93$) in subsequent adult recruitment from 1980 to 2004 (Figure 1). Flows in the Tuolumne River are also strongly correlated with the number of smolt-sized juvenile outmigrants from 1998 to 2005 ($r2 = 0.77$; Figure 2), suggesting flow in the Tuolumne River and Delta are both important.

Flows in February and March strongly affected the abundance of smolt-sized juveniles outmigrating the Tuolumne and Stanislaus rivers in April and May (rotary screw trap estimates). In the Stanislaus River during 1998, 1999, and 2000 flows were high in winter and the number of juveniles surviving to smolt through the lower river range from 67.4% to nearly 100%). In addition, more smolt-sized fish reached the terminal end of the river (Caswell) than left the spawning grounds (Oakdale) in spring, suggesting that juveniles were successfully rearing in the lower river (e.g., 2000 data in Figure 3).

In contrast, during 2001-03 when flows were low in February and March, juvenile survival averaged 12.8% (range 7.4% to 17.4%) and there was no evidence of successful rearing in the lower river (e.g., 2001 data in Figure 4). These data suggest that flow during February and March might be an important determinant of the number of fry that survive to a smolt size and migrate.

Rotary screw trap surveys on the Tuolumne River at the Grayson site (RM 5.2) conducted between January and late May from 1998 to 2006 show the same pattern as the Caswell trap site. Fry, parr, and smolt passage was high during wet years (e.g., 2000) with extended periods of high flows in February and March (Figure 5), moderate during some dry years (e.g., 2001) with moderate periods of high flows in February and March (Figure 6), and low during some dry years (e.g., 2002) when only base flows were released between February and early April (Figure 7).

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[1] Poster presented by the U.S. Fish and Wildlife Service at the 2008 Salmonid Habitat Restoration Conference in Lodi.

[2] U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program, 4001 N. Wilson Way, Stockton, CA 95205

[3] California Department of Fish & Game, 1234 E. Shaw Ave., Fresno, CA 93710

[4] California Department of Fish & Game, Tuolumne River Salmon Restoration Center, P.O. Box 10, La Grange, CA 95329

Rotary screw trap data also suggests that although the spawning habitat in the Stanislaus and Tuolumne Rivers is highly degraded, more fry are produced than can be supported by the rearing habitat. After 18 spawning beds were restored in the Stanislaus River in 1999, fry production increased by 46% to a total of nearly 2,500,000 juveniles, but with no increase in the number of smolts migrating from the river compared to the previous year (spawner abundance and flows similar; Figure 8). In the Tuolumne River during 1999 and 2000, only 0.4% and 1.4%, respectively, of the estimated number of juveniles leaving the spawning reach survived to a smolt-sized fish leaving the river.

The limiting factors analysis provides evidence supporting three hypotheses regarding the production of adult fall-run Chinook salmon in the San Joaquin Basin: 1) the most critical life history stages are the rearing juveniles and outmigrating smolts; 2) the critical life history stages are strongly affected by conditions in the tributaries as well as conditions in the Delta, Estuary, and the ocean; and 3) the most important environmental factor that affects the critical life history stages is stream flow (i.e., floodplain inundation) during late-winter and spring.

It is likely that high flows increase smolt production and survival by improving or ameliorating a combination of limiting factors, which include food resources, predation, disease, water temperatures, contaminants, water quality, harvest, and entrainment. The regression models of adult recruitment indicate for every cubic-foot-per-second of flow, there have been 2.8 and 1.0 adult salmon produced on the Tuolumne and Stanislaus rivers, respectively. The relatively low production of salmon on the Stanislaus River is probably caused in part by the lack of functional floodplain habitat on the Stanislaus River compared to the Tuolumne River. We speculate that floodplain inundation increases the availability of food resources and reduces predation of juvenile salmon and that increased food resources improve the ability of juvenile salmon to tolerate other stressors such as high water temperatures, disease, and unsuitable water quality. We believe that restoring floodplain habitats in the San Joaquin tributaries to be inundated between February and June will increase adult salmon production.

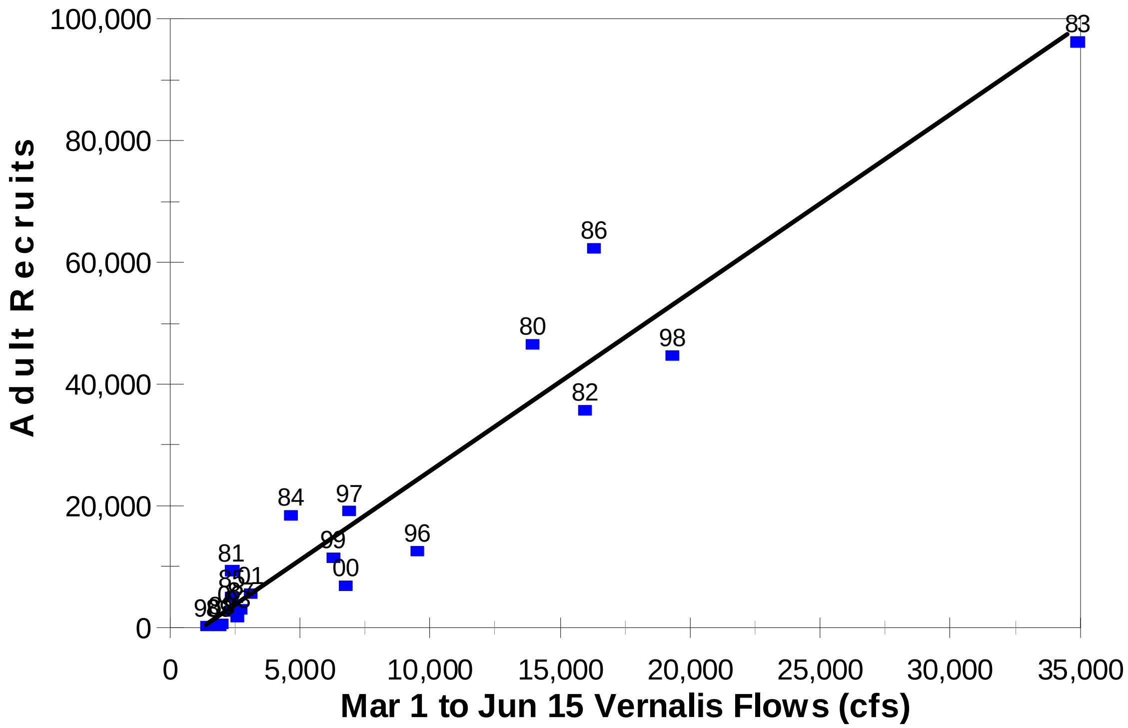

Figure 1. Number of fall-run Chinook salmon recruits to the Tuolumne River from 1980 to 2004 relative to the mean flow in the San Joaquin River at Vernalis from March 1 to June 15 when the fish reared in the tributary (Mesick and Marston 2007). Recruitment is the total number of adult salmon in the same cohort that are harvested in the ocean and return to spawn in the escapement. This analysis excludes recruitment estimates that were affected by a low number of spawners (< 500 Age-3 equivalent fish) to better illustrate the relationship with flow. The recruitment estimates are labeled according to the year when the fish outmigrated as smolts. The regression model has an *r2* of 0.93 and *P* < 0.0001.

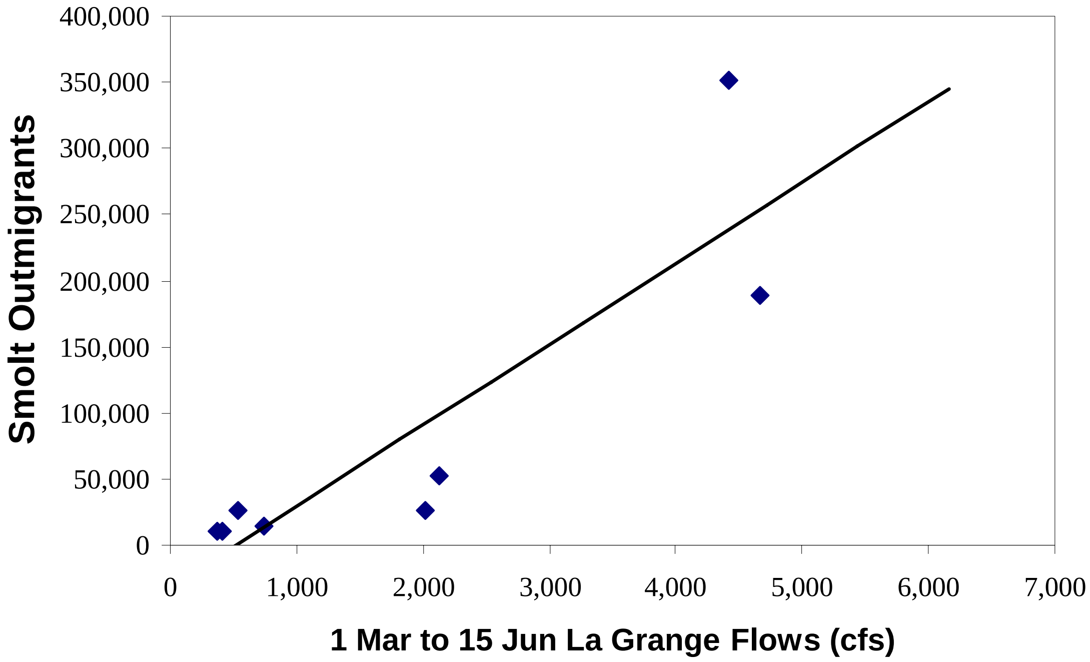

Figure 2. Number of smolt-sized Chinook salmon outmigrants (fork length ≥ 70 mm) passing the Grayson rotary screw trap site (RM 5) plotted with flows at La Grange between March 1 and June 15 in the Tuolumne River from 1998 to 2005 (Mesick and Marston 2007). This analysis excludes smolt outmigrant estimates that were affected by a low number of spawners (< 700 Age-3 equivalent fish) to better illustrate the relationship with flow. The regression model has an *r2* of 0.77 and *P* = 0.004. The screw trap estimates are preliminary because the trap efficiency models have not been finalized (CDFG unpublished data).

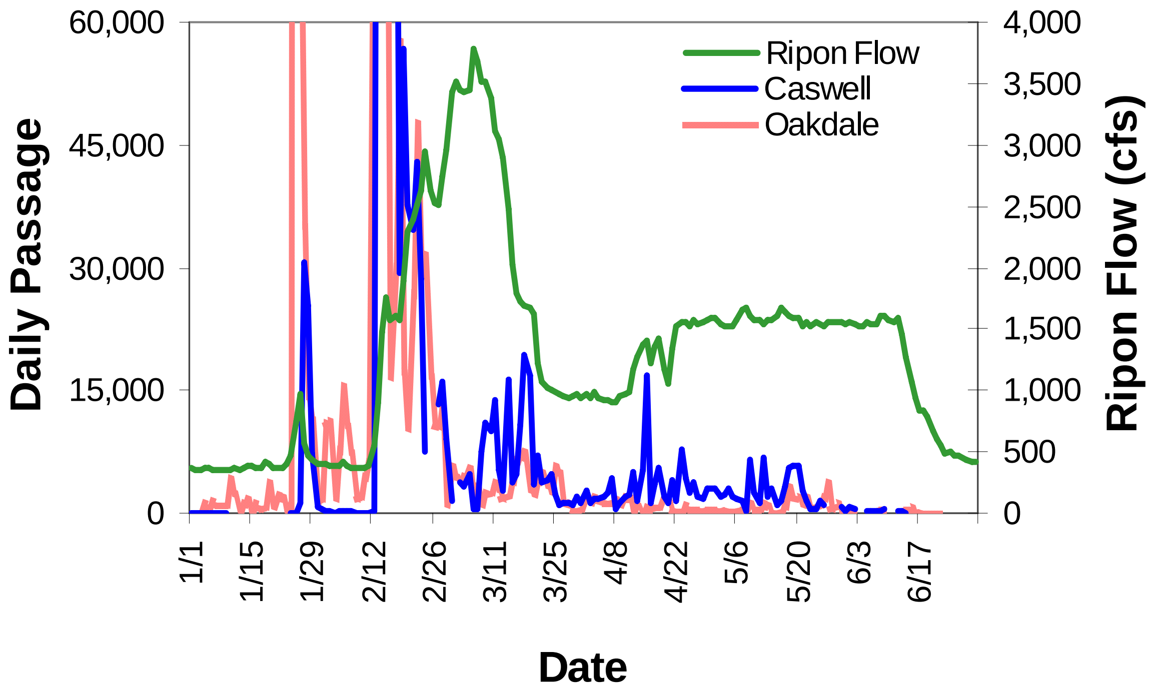

Figure 3. The estimated daily passage at the Oakdale and Caswell Park screw traps plotted with the mean daily flow at Ripon in the Stanislaus River during spring 2000, an above normal water year. Overall juvenile survival between the Oakdale and Caswell traps was 67.4 percent in 2000.

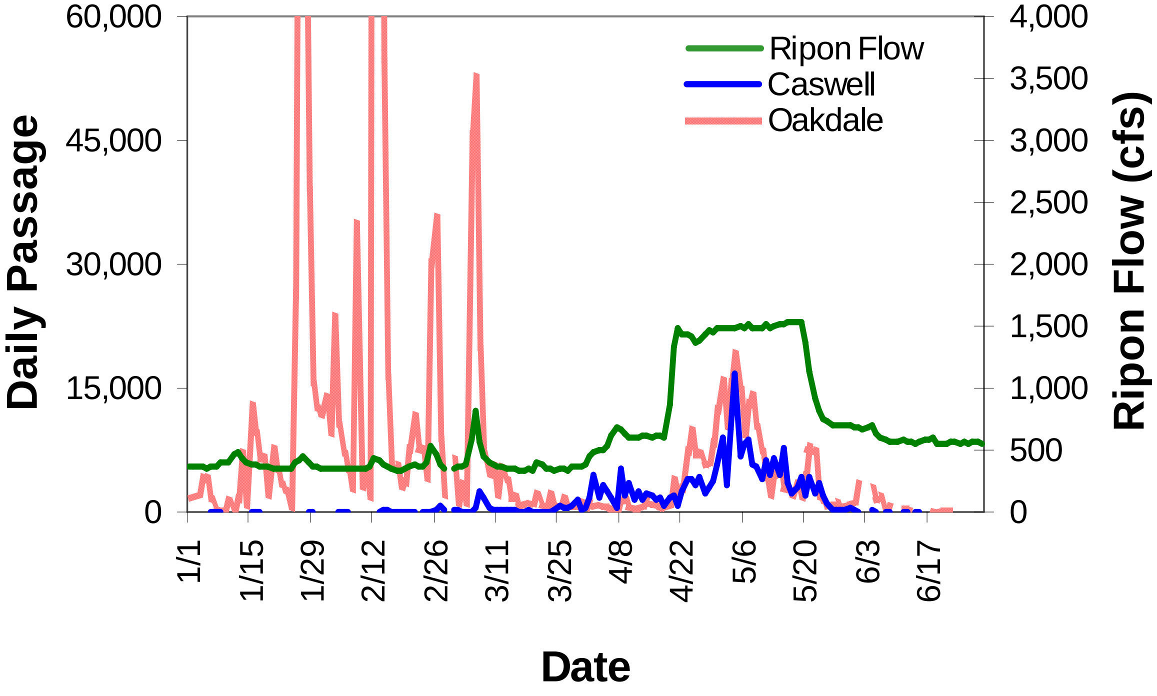

Figure 4. The estimated daily passage at the Oakdale and Caswell Park screw traps plotted with the mean daily flow at Ripon in the Stanislaus River during spring 2001, a dry year. Overall juvenile survival between the Oakdale and Caswell traps was 13.7 percent in 2001.

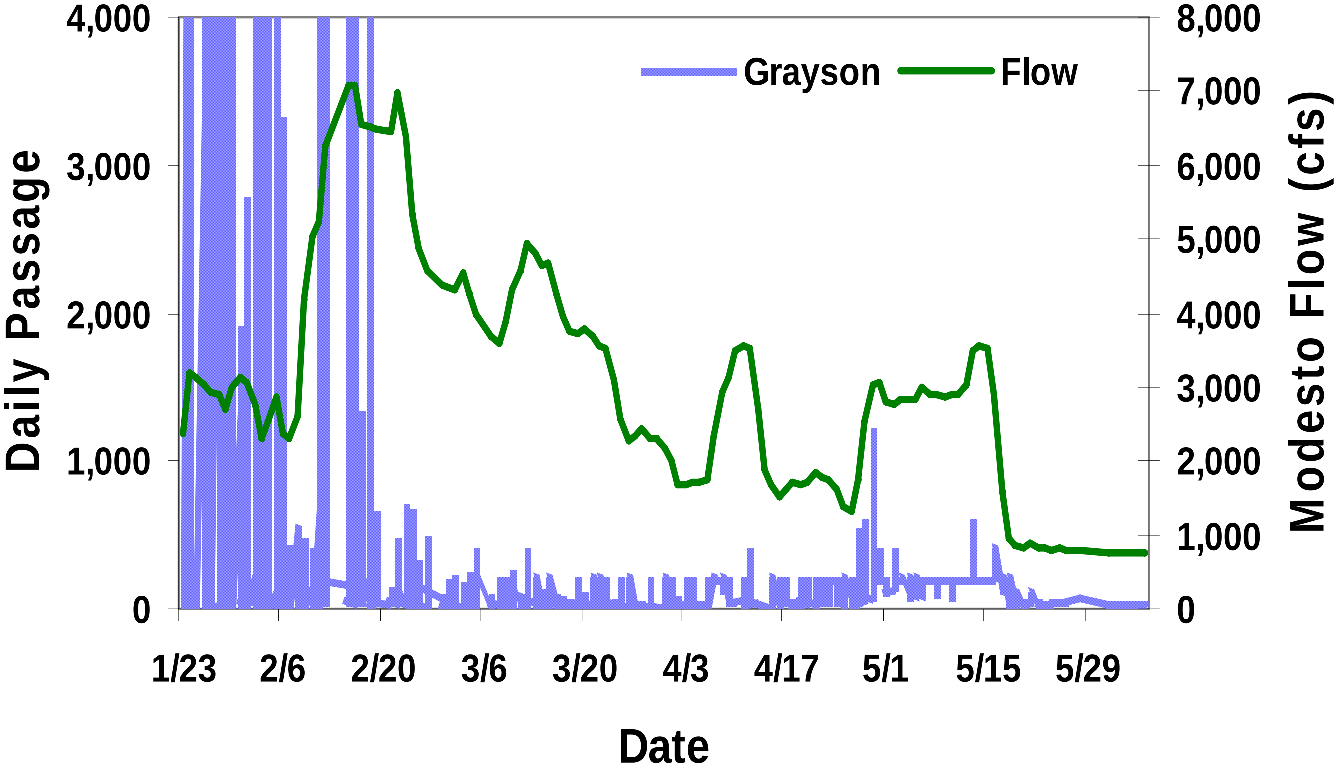

Figure 5. The estimated daily passage (truncated at 4,000 fish/day) at the Grayson screw trap plotted with the mean daily flow at Modesto in the Tuolumne River during spring 1999, an above normal water year. The total number of all sizes of juvenile outmigrants and smolt-sized (fork length ≥ 70 mm) outmigrants was 455,079 and 62,168, respectively.

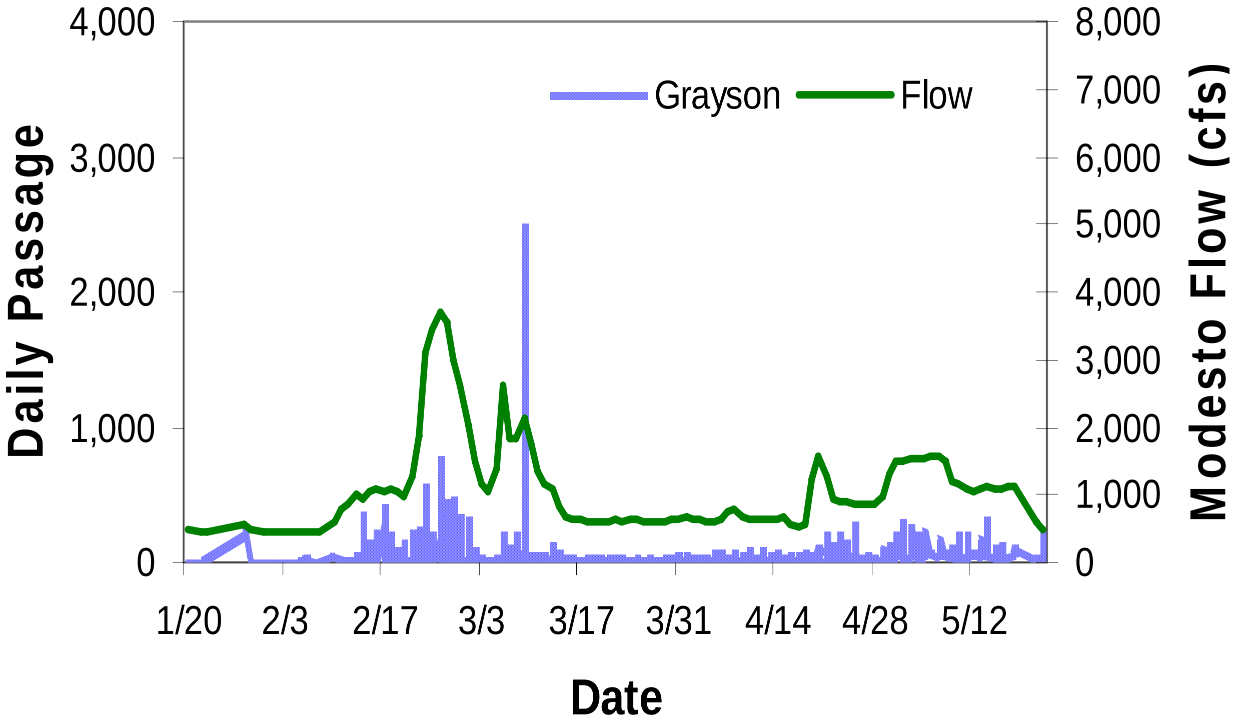

Figure 6. The estimated daily passage at the Grayson screw trap plotted with the mean daily flow at Modesto in the Tuolumne River during spring 2001, a dry year. The total number of all sizes of juvenile outmigrants and smolt-sized (fork length ≥ 70 mm) outmigrants was 111,254 and 34,824, respectively

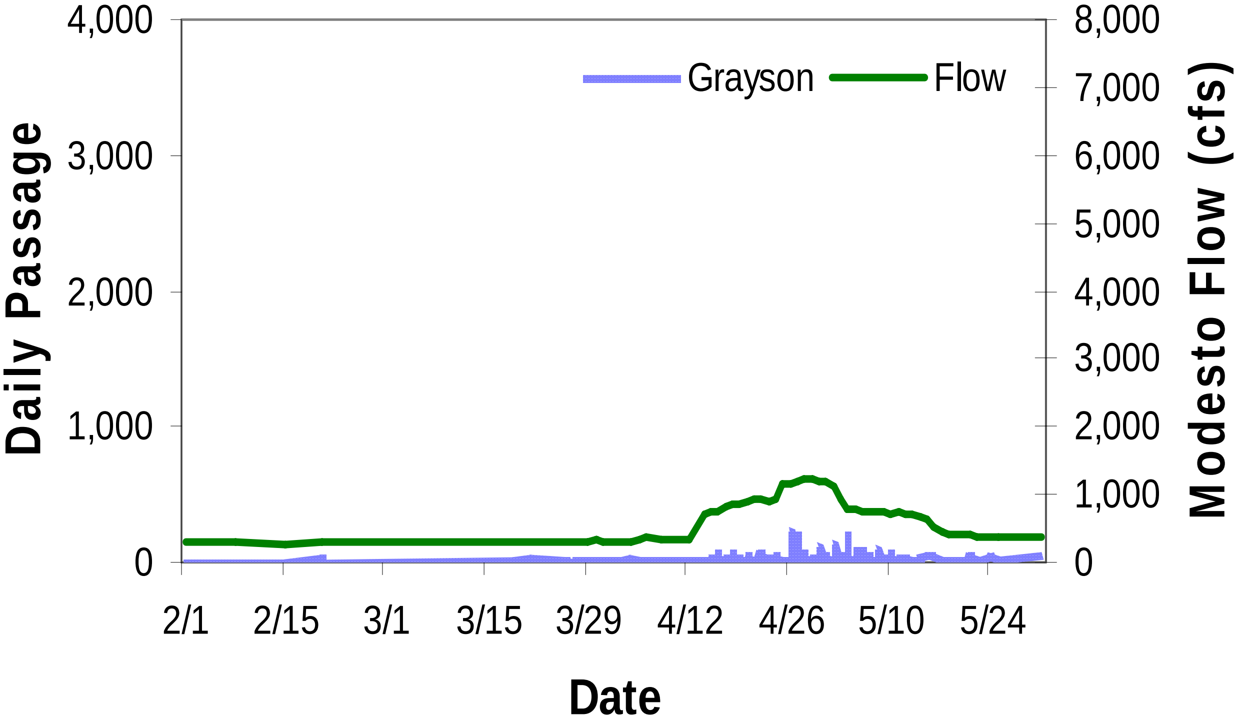

Figure 7. The estimated daily passage at the Grayson screw trap plotted with the mean daily flow at Modesto in the Tuolumne River during spring 2002, a dry year. The total number of all sizes of juvenile outmigrants and smolt-sized (fork length ≥ 70 mm) outmigrants was 13,442 and 13,076, respectively.

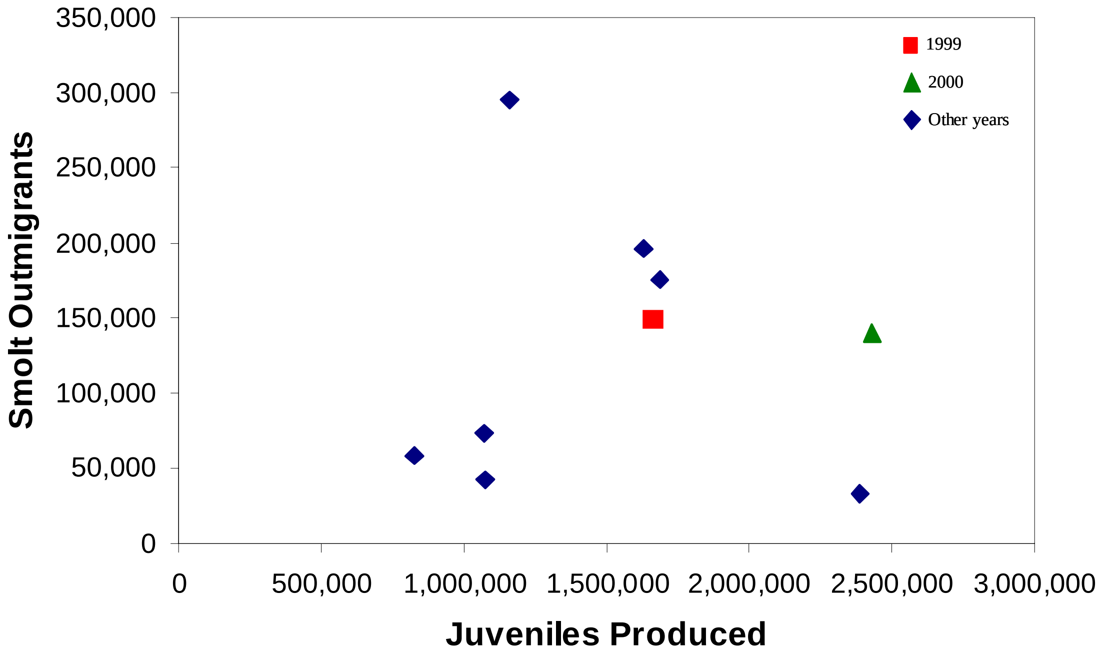

Figure 8. The estimated abundance of all sizes of juveniles that passed the Oakdale screw trap (RM 40) plotted with the estimated abundance of smolt outmigrants (fork length $\geq$ 70 mm) at the Caswell State Park screw traps (RM 5) in the Stanislaus River from 1998 to 2004. A comparison of the 1999 and 2000 estimates provides an evaluation of the effects of gravel augmentation on juvenile and smolt production, because the outmigration occurred before and after gravel augmentation and they were both affected by similar winter and spring flows as well as similar numbers of spawners.

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Appendix 6

San Joaquin River Fall-run Chinook Salmon and Steelhead Rainbow Trout Historical Population Trend Summary

(Dean Marston)

San Joaquin River Fall-run Chinook Salmon and Steelhead Rainbow Trout Historical Population Trend Summary

Dean Marston
California Department of Fish & Game
September 2007

Acknowledgment

The author wishes to genuinely thank, and give due recognition to, the following individuals for their contributions to this report: Dr. Carl Mesick, Dr. Andy Gordus, and Mr. Dale Mitchell.

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Abstract

In response the continued declining trend of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead rainbow trout (*Onchorhynchus mykiss*) in the San Joaquin River Basin[1] and the associated elevated water temperature trends during key life history phase time periods, the California Department of Fish and Game submitted a proposal to the California Central Valley Regional Water Quality Control Board to list water temperatures in the lower Stanislaus, Tuolumne, Merced, and San Joaquin Rivers as water temperature impaired. The Central Valley Regional Board asked the Department to submit information regarding the historical trends of salmon and steelhead in the San Joaquin River Basin (excluding the Mokelumne and Cosumnes Rivers). Substantial declines in fall-run Chinook salmon in the San Joaquin, Stanislaus, Tuolumne, and Merced Rivers has occurred since the 1940's and 1950's. Since the year 2000, when the most recent salmon escapement abundance high occurred, escapement has substantially declined in the Stanislaus, Tuolumne and Merced Rivers between the years 2000 and 2006. Consistent with this decline has been the associated reduction in spring flow magnitude and duration which has resulted in an increase in water temperature in the lower reaches of the San Joaquin east-side tributaries, during the later part of the spring smolt out-migration season. The salmon and steelhead populations that once existed in the mainstem San Joaquin River upstream of Friant were extirpated by the early 1950's. Little is known regarding steelhead abundance, and trends, in the San Joaquin River basin. Anecdotal reports from anglers and guides suggest that steelhead catch increases consistent with good, instream flow related, habitat quality (e.g. cool water temperature) exists.

Introduction

The purpose of this paper is to afford the California Department of Fish and Game (CDFG) the opportunity to document for the California Central Valley Regional Water Quality Control Board (CVRWQCB) a summary of the present, and historical, status of salmon and steelhead in the Stanislaus, Tuolumne, and Merced Rivers (i.e. principal east-side tributaries to the San Joaquin River). The CVRWQCB is presently considering, based upon a proposal by the California Department of Fish & Game, whether to list the lower reach of the San Joaquin River (e.g. Vernalis) and the lower reaches of the major east side tributaries (e.g. Stanislaus, Tuolumne, and Merced Rivers) as water temperature impaired for fall-run chinook salmon (*Oncorhynchus tshawytscha*) and steelhead rainbow trout (*Onchorhynchus mykiss*). The CDFG asserts that current water temperature regimes in the Stanislaus, Tuolumne, and Merced Rivers are not protecting the fall-run chinook salmon and steelhead beneficial uses in these rivers. The CDFG is providing this documentation to the CVRWQCB as a line of evidence to support a water temperature impairment designation for the lower San Joaquin, Stanislaus, Tuolumne, and Merced Rivers. Excessive water temperature is associated with the recent (e.g. since year 2000) substantial decline in abundance of fall-run chinook salmon and is believed to be likewise responsible for steelhead rainbow trout abundance trends as well.

The material provided herein is not intended to be an exhaustive account of the historical salmon and steelhead resources of the San Joaquin River (SJR) and its three southern

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[1] Excluding the Cosumnes and Mokelumne Rivers.

most east-side tributaries (e.g. Stanislaus, Tuolumne, and Merced Rivers) rather, it is a summary of the historical trends of the fall-run chinook salmon populations in each of these rivers providing a partial documentation of the declining trend of both salmon and steelhead in these rivers.

Physiologically speaking, water temperature has the capacity to control every aspect of a an anadroumous fishes life. Water temperature determines: i) whether or not adults successfully migrate into nursery areas to spawn, ii) where and when adults spawn, iii) whether or not eggs will be fertile (e.g. are viable) at time they are spawned and once, deposited, when they will hatch; iv) where juveniles will take up residence; and v) the on-set and duration of smoltification (e.g. release of hormones enabling salt water transition). Water temperature influences disease prevalence within salmonids, and both predation, and growth rates, of salmonids. Water temperature has the ability to be a population controlling (e.g. limiting) factor. In short, water temperature is an extremely important parameter in the production of anadromous salmonids within the SJR basin.

Historically speaking, salmon and steelhead populations once thrived in the San Joaquin River basin to a level of abundance that it has been said that San Joaquin River salmon abundance once rivaled that of the Klamath River at its salmon production apex. Today the once mighty San Joaquin, and its vast salmon and steelhead resources, are but a shadow of its once mighty stature. Where once salmon were so numerous one could walk across the river on the backs of salmon, today they are extinct in the mainstem San Joaquin and are in relatively poor condition in the Merced, Tuolumne, and Stanislaus Rivers.

Many factors have been suggested for the decline of San Joaquin River salmon and steelhead such as dams, water diversion, mining, and harvest. Around 1870 the California Fish Commission, in response to declining salmon population abundance, introduced fishing seasons, take limits, and gear restrictions in an effort to reduce the population decline. However as water development and mining continued unabated, San Joaquin River salmon abundance fell precipitously so much so that by the 1950's salmon became extinct in the mainstem San Joaquin River and populations of less than 500 were an all too common an occurrence in the Merced, Tuolumne, and Stanislaus Rivers (Figure 1). Since the 1950s, the trend in the abundance of adult salmon in all three tributaries has been highly correlated with the magnitude and duration of streamflow during the winter and spring when the juvenile fish rear and then migrate toward the ocean (Mesick & Marston)[2]. During dry and normal years, when flows are highly regulated during the winter and spring, very few salmon smolts outmigrate from the rivers and few adults from that cohort return over the next few years. However during wet years when high flows occur over several months, numerous salmon smolts outmigrate and many adults return over the next few years. The gradual decline in salmon abundance is clearly a result of increased water diversions that has led to unsuitably high water temperatures and a lack of floodplain inundation, which augments

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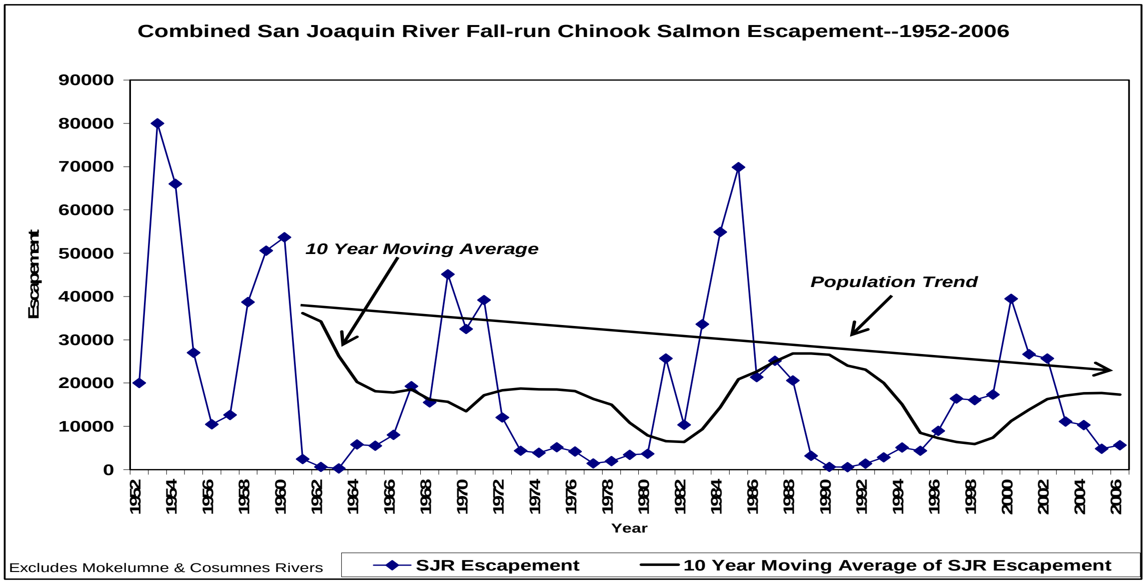
[2] Mesick, C. and D. Marston. 2007. Relationships Between Fall-run Chinook Salmon Recruitment to the Major San Joaquin River Tributaries and Streamflow, Delta Exports, the Head of the Old River Barrier, and Tributary Restoration Projects From the Early 1980's to 2003. Provisional Draft.

food resources and provides refuge from predation, during the rearing and outmigration periods. It is likely that high water temperatures have direct impacts as well as indirect impacts on juvenile survival. For example, high water temperatures increase the susceptibility of the juveniles to disease, predation, and contaminants increases (Myrick and Cech 2001[3]).

Figure 1. San Joaquin River Fall-run Chinook Salmon Annual Escapement Trends—1952 to 2006



The blue dotted line represents the combined annual San Joaquin River fall-run Chinook salmon escapement (e.g. for the Stanislaus, Tuolumne, and Merced Rivers). Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1952 there have been several peak escapement periods. The 10 year moving average[4] of escapement trends has the overall affect of reducing individual escapement peak amplitude and allowing visual determination of overall escapement trend over time (e.g. is trend increasing or declining). Overall San Joaquin River annual escapement is declining over time.

It should be noted that both steelhead and various runs of salmon were once abundant in the San Joaquin River basin. However, now: i) all runs of salmon and steelhead are extinct in the mainstem San Joaquin River[5]; ii) spring, winter, and late-fall run salmon are rare in the SJR east-side tributaries; iii) fall-run salmon in the Stanislaus, Tuolumne, and Merced Rivers are so low in abundance that they are considered to be in poor condition; and iv) steelhead are listed as a Federally Threatened species. Consistent with these declines has been the substantial reduction, over time, of spawning and rearing habitat

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[3] Myrick, C.A. and J.J. Cech, Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Published electronically by the Bay-Delta Modeling Forum at http://www.sfei.org/modelingforum/. Technical Publication 01-1.

[4] The 10 year moving average is a continuous moving average of 10 year blocks over the period of record. The first average (e.g. point along the line depicted) is the 1952 to 1962 annual escapement average. The second average is the 1953 to 1963 annual escapement average. The 20 year annual escapement averages continue up to the 1996 to 2006 time period.

[5] Occasionally in very wet years, salmon produced in other rivers stray into the mainstem SJR reach above the confluence with the Merced River.

quantity and quality caused primarily by water development (e.g. construction of dams and diversion of water). However, despite this substantial reduction one race of salmon (e.g. fall-run chinook) have shown the resiliency, as a population, to be able to rebound to, comparatively speaking, larger runs when favorable water quantity and quality conditions exist. Because water quality (e.g. temperature level) is largely dependent upon reservoir storage and release levels[6], managing water quantity is a necessary precursor to managing water quality. It is imperative that adequate water quality (e.g. temperature) exist to protect the beneficial use of both salmon and steelhead in the Stanislaus, Tuolumne, and Merced Rivers.

It should also be noted that the CDFG and the Oakdale, South San Joaquin, and Stockton East Water Districts, the U.S. Bureau of Reclamation, and the CALFED Ecosystem Restoration Program (collectively referred to as Stanislaus River Stakeholders) has funded and constructed a water temperature model for the lower Stanislaus River in response to substantial concerns regarding elevated water temperatures in the Stanislaus Rivers. The primary result of this effort has been to gain a better understanding of how reservoir storage and release volume influence water temperture trends in the lower Stanislaus River. A completed model and report are available upon request. Additionally, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the Modesto and Turlock Irrigation Districts, and the Merced Irrigation District, in response to elevated water temperature and declining salmon and steelhead trends in both the Tuolumne and Merced Rivers, have joined the Stanislaus River Stakeholders in the construction of a water temperature model for the lower SJR basin[7]. This model will allow resource managers the opportunity to understand how the systems parts can be operated dependently to reduce water temperature impairment in the SJR basin. This model, and documentation, will be available this fall.

It is also noted that there is comprehensive restoration project recently initiated for the Friant reach of the mainstem San Joaquin River. How this project will influence water temperature impairment (e.g. improve or worsen) in the lower SJR remains to be seen. The CDFG recognizes that the SJR is a system comprised of dependent parts (e.g. mainstem and tributaries) that collectively have the capacity to exacerbate or ameliorate water temperature impairment in the SJR basin.

A summarized description of the decline of salmon and steelhead resources in the mainstem San Joaquin River and its three east-side tributataries the Stanislaus, Tuolumne, and Merced Rivers is now provided.

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[6] Meteorological conditions also influence water temperature response. However, both reservoir storage volume and reservoir release volume level can substantially delay water warming as water flows downstream of the reservoir.

[7] This Army Corp of Engineer based model (HEC5Q) simulates reservoir storage and lower river release for the Stanislaus, Tuolumne, and Merced Rivers. This model includes the SJR reach from SJR at Stevinson to the SJR at Mossdale.

Stanislaus

The California Fish Commission, in 1886, stated the Stanislaus River mirrored the Tuolumne River as a preeminent salmon stream, but that by 1886 only an occasional salmon was seen trying to get over its numerous dams. Damming and diversion of water for hydraulic gold mining and agricultural use of Stanislaus River water began soon after the gold rush circa 1850. At this time there was approximately 124 miles of the Stanislaus River available to salmon for use. In 1913 Goodwin Dam, at 20 feet in height, was built. In 1926 Old Melones Dam, a 200 foot high dam was built.[8]

In 1929 G.H. Clark noted: "The Stanislaus has a good spring and fall-run of salmon. The spawning grounds extend from the marsh lands above Oakdale to Knights Ferry, a distance of 10 miles. The Stanislaus like the other rivers, has dams which hinder and block the salmon. There was a small power dam built in 1910 at Knight's Ferry but it was replaced in 1913 by the Goodwin Dam, situated 18 miles above Oakdale. The dam is 20 feet high and has a fishway so that the salmon can spawn between the dame and the Melones Dam, which is a short distance above the old town of Melones in Iron Canyon. It is 210 feet high and was dedicated in 1926. The dam of course is an impassable barrier to salmon. It is a combination power and irrigation project. The abundance of salmon in the Stanislaus is about the same as in the Tuolumne. The rivers are very nearly alike and what is true in one is true in the other." [9]

In 1958 present Day Tulloch Dam was built. New Melones Dam construction was completed in the late 1970's, with Melones Reservoir filling for the first time in 1984. Prior to the dams, spring-run was the predominate race of salmon in the Stanislaus River. After the dams were built, fall-run became the predominate race of salmon. Today 58 miles of the Stanislaus River are available to salmon use, a 53% loss from historical levels. When only spawning and rearing habitat miles are considered, the loss is even greater (80% loss) as approximately 25 miles are left for salmon spawning and rearing today.[10]

Per Figure 2, prior to the construction of present day Tulloch Dam (1958) the average annual fall-run Chinook salmon escapement averaged 10,300 spawners[11]. Post Tulloch Dam Stanislaus River escapement declined to an average of 4,300 spawners. Post New Melones Reservoir operation annual escapement has further dropped to an average of 3,600 spawners. There continues to be a decline in the amplitude of annual escapement as water impoundment and diversion capability has increased on the Stanislaus River.

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[8] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

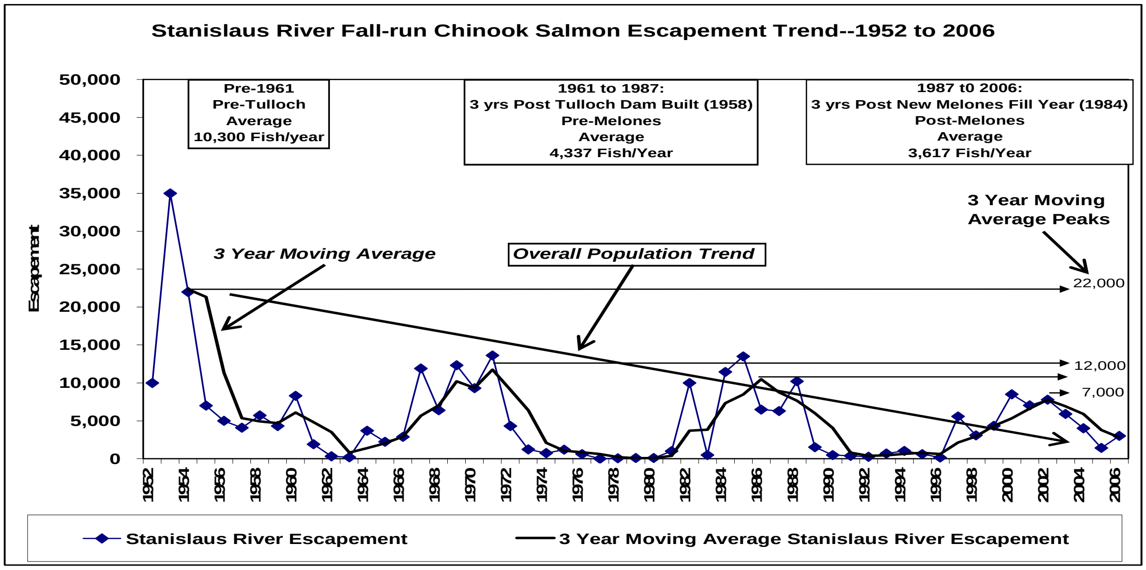
[9] From G.H. Clark. 1929. Sacramento-San Joaquin Salmon (*Onchorhynchus tschawytscha*) Fishery of California. Fish Bulletin No. 17. Division of Fish and Game of California.

[10] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

[11] Escapement Data from California Department of Fish & Game's Central Valley Fall-run Salmon Escapement Estimate GrandTab Table dated August 2007.

Between 1952 and 2006 the Stanislaus River fall-run escapement population has oscillated over time and has dropped to levels less than 1,000 on several occasions. The average escapement of fall-run salmon in the Stanislaus River declined post New Melones time frame (Figure 2). Since 2000, the Stanislaus River escapement population has steadily declined and by 2006 (3,000 salmon) had dropped to about 65% percent below the year 2000 peak abundance of 8,500 salmon (Figure 3). It is important to note that this salmon production decrease in the Stanislaus River occurred at the same time both Delta exports and ocean harvest was reduced for the same time period (CDFG July 2007 Letter to the Federal Energy Regulatory Commission) which, strongly suggests that in-tributary factors, rather than out-side or downstream factors, are controlling salmon production in the Stanislaus River.

Figure 2. Stanislaus Fall-run Chinook Salmon Escapement Trend 1952 to 2006



The blue dotted line represents the annual historical Stanislaus River fall-run Chinook salmon escapement. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1952 there have been several peak escapement periods. The 3 year moving average[12] of escapement trend is intended to account for the various ages of salmon that comprise an annual escapement. Juvenile salmon produced in one year (e.g. brood year) typically return as adults to spawn as age 2, 3, or four year old salmon. The three year moving average is intended to cover the three year period that salmon return to spawn post brood production year. The three year moving average indicates that the overall Stanislaus annual escapement is declining over time. This declining trend is consistent with the overall declining trend observed in Figure 1 for the SJR salmon escapement trend.

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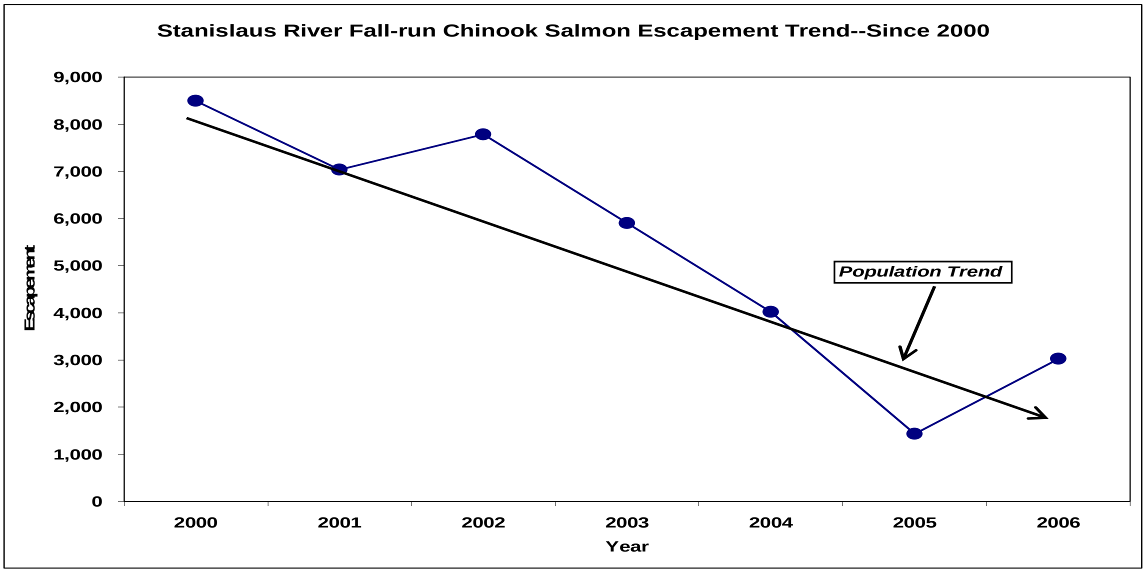
[12] The 3 year moving average is a continuous moving average of 3 year blocks over the period of record. The first average is the 1952 to 1954 annual escapement average. The second average is the 1953 to 1955 annual escapement average. The 3 year annual escapement average continues up to the 2004 to 2006 year time period.

Figure 3. Stanislaus River Annual Salmon Escapement Trend Since 2000



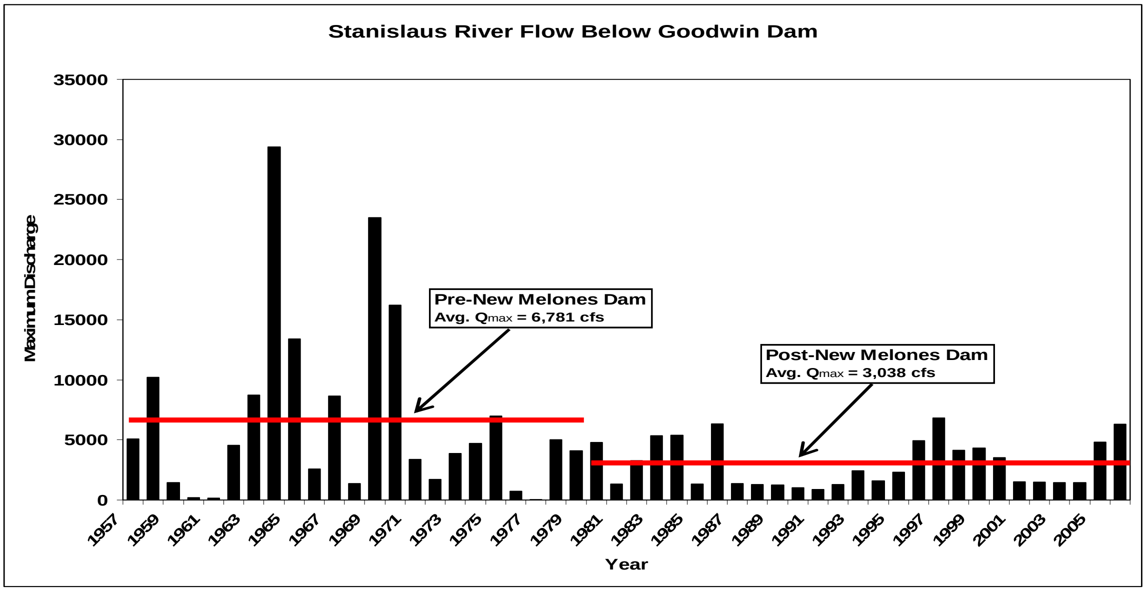
This graph shows the Stanislaus annual escapement trend for the years 2000 through 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since the peak escapement in the year 2000 (over 8,000 spawners), stemming from environmental conditions two to three years earlier (e.g. reference to water years 1997-98 and 1998-99) that would have contributed the year 2000 annual escapement (e.g. reference to two and three year old salmon which typically comprise the bulk of any one escapement year's abundance) has dropped sharply by the year 2006.

Annual flow releases into the lower Stanislaus River has lessened over time as water development has occurred (Figure 4). As water development has occurred, the magnitude, duration, and frequency of elevated spring flows has diminished. This reduction in annual maximum flow has resulted in substantial geomorphological impacts (reduced channel scouring) and fishery impacts (reduced salmonid production) in the Stanislaus River. There is a strong correlation between annual spring flow magnitude and the production of smolt outmigrants from the tributary, survival of smolts in the Delta, and the production of adults in the escapement and ocean harvest (Mesick and Marston 2007).

There is a strong relationship between flow volume, as represented by Goodwin Dam flows into the lower Stanislaus River, and the longitudinal river reach water temperature trend (Figure 5). In the spring when Goodwin Dam release flows are reduced (less than 700 cfs) much warmer water temperature results (21ºC/69ºF), in comparison to when Goodwin Dam release flows are increased (about 1500 cfs) water temperature during the spring is reduced substantially (17ºC /63ºF). This longitudinal temperature trend reduction, for both low and higher flows, occurred at similar meteorological conditions and approximate release temperature strongly suggesting that Goodwin Dam release flow level is important in conveying adequate water temperatures downstream. Consistent with reduction in spring flow, is an associated increase in water temperature during the later spring time period when a substantial fraction of smolts are leaving the Stanislaus River. Figure 6 shows the Stanislaus River smolt outmigration trend timing for the years 1996 through 2006 and indicates that 25% of smolts outmigrate by April 20th, 50% by

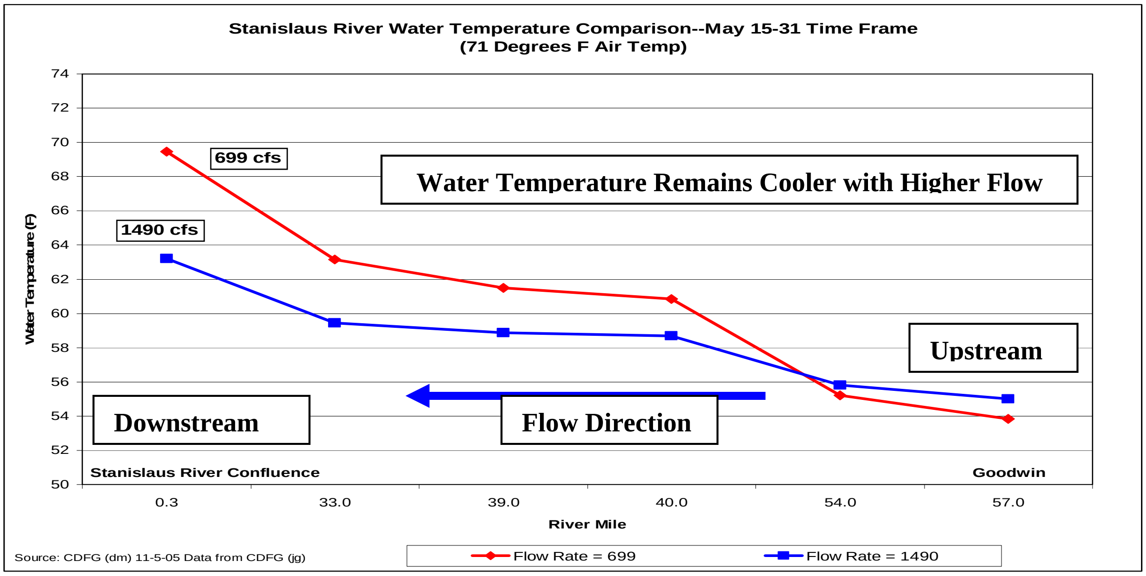
May 4th, and 70% by May 15th. Approximately 30% of smolts outmigrating from the Stanislaus River leave after May 15th.

Figure 4. Stanislaus Flow at Goodwin by Time Period



This figure compares the both annual maximum flow level in the Stanislaus River at Goodwin and the average annual maximum flow level for the pre and post-New Melones Dam time periods (data from U.S. Geological Survey Gage No. 11302000). Prior to New Melones the annual maximum flow level (3,038 cfs) was substantially higher than the post-New Melones Dam time period maximum flow level (6,781 cfs).

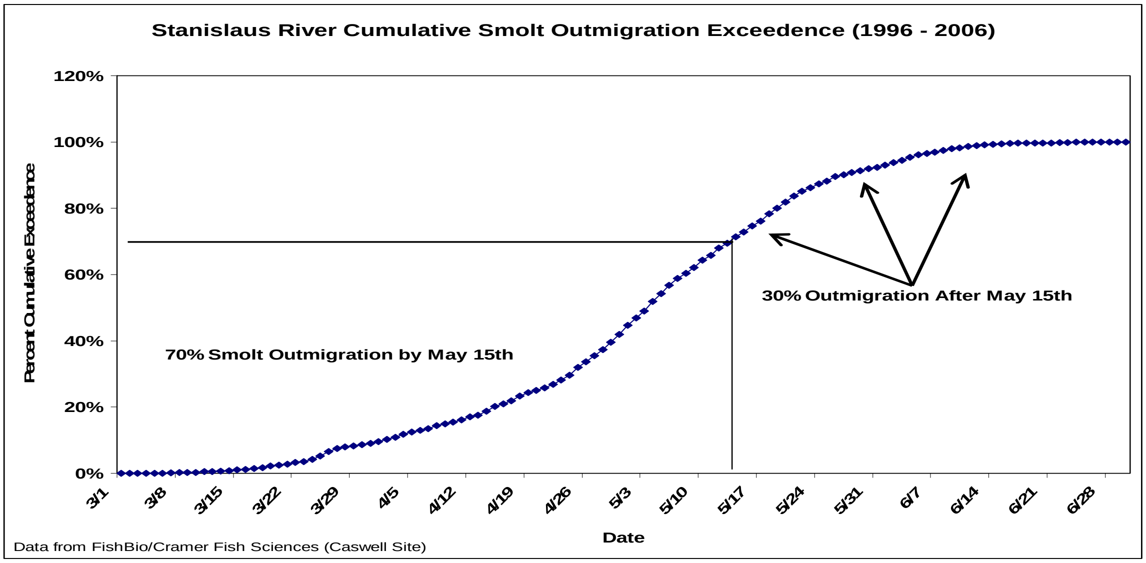
Figure 5. Goodwin Dam Flow Release Level and Downstream Water Temperature Response



Source: CDFG (dm) 11-5-05 Data from CDFG (jg)

This figure shows that Goodwin Dam release volume and release water temperature level determine the longitudinal (downstream) water temperature level (at the mouth) during the late spring time period when salmon smolts are migrating out of the Stanislaus River. Both the reduced, and elevated, flow levels depicted in this figure occurred during similar meteorological conditions (approximately 71ºF). Elevated flows have the ability to withstand meteorologically induced thermal warming of the water as it moves downstream in the Stanislaus River.

Figure 6. Stanislaus River Cumulative Smolt Outmigraton Exceedence (1996-2006)



Data from FishBio/Cramer Fish Sciences (Caswell Site)

This graph combines the smolt outmigration from the Stanislaus River (Caswell Rotary Screw Trap expanded catch data) for each year by date and shows the outmigration abundance time trend over a 10 year period from 1996 to 2006.

In addition to excessively warm spring time period water temperatures, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present the lower San Joaquin and lower Stanislaus Rivers during the fall adult upstream migration seasons for the years 1999 thru 2006 (Tables 7 and 10 in CDFG's Letter to the RWQCB dated February 2007). Also, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Stanislaus River spawning habitat reaches, during the first half of the spawning season for years 1999 thru 2005 (Table 11 in CDFG's Letter to the RWQCB dated February 2007). An example of the relationship between spawning activity, as measured by spawning redd density, and water temperature is provided in Figure 7[13].

Steelhead, the anadromous form of rainbow trout, is a highly sought game fish in the Stanislaus River. Little is known regarding overall population abundance and trends over time. Adult steelhead have been recently captured while migrating upstream at the fish counting weir located near Riverbank[14]. Juvenile rainbow trout (smolts) out-migrating the Stanislaus River are caught annually in rotary screw traps. Steelhead in the Stanislaus River are considered winter run. Anecdotal reports by anglers suggest that steelhead abundance is greatest following years where summer rearing conditions are good (e.g. number of river miles possessing cold water temperatures). State and Federal fish agency biologists believe that steelhead abundance trends over time have followed that of salmon, only more so precipitating the need to list Steelhead in the Central Valley as

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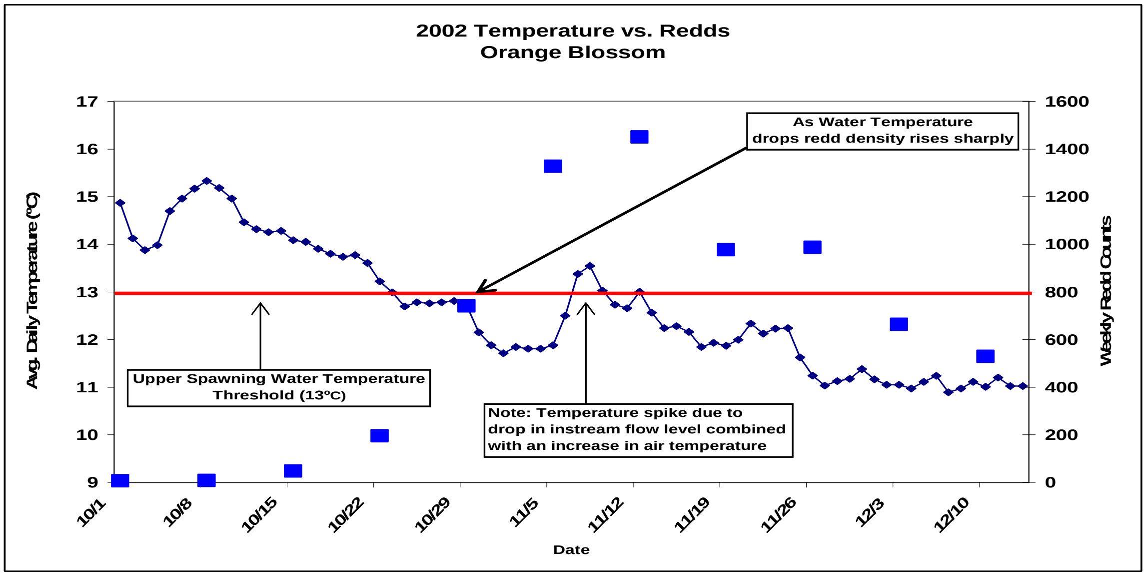
[13] Data provided by Jason Guignard (California Department of Fish Game Fishery Biologist)
[14] From weir data collected by Cramer Fish Sciences.

threatened. The Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Stanislaus River juvenile steelhead rearing reach, during the summer for years 1999 thru 2006 (Table 11 in CDFG's Letter to the RWQCB dated February 2007). It should be noted that of the three primary San Joaquin River east-side tributaries the Stanislaus has the most abundant steelhead population (e.g. not in good condition but most abundant). This may be attributable to the New Melones being required to meet winter and summer Vernalis flow objectives that require elevated flows to be released into the lower Stanislaus River during the winter and summer time periods.[15]

Figure 7. 2002 Stanislaus River Fall Spawning Season—Orange Blossom Bridge



This figure shows the relationship between salmon spawning activity in the Stanislaus River, at Orange Blossom Bridge, and water temperature level. As water temperature decreases to a level less than 13ºC (59ºF) spawning activity, as measured by weekly spawning redd counts, rises markedly. The water temperature spike occurring during the first week of November is associated with a rise in air temperature level and also with a reduction in Goodwin Dam release flow into the lower Stanislaus River. Typically a fall pulse flow is provided during the month of October to attract salmon into the Stanislaus River. In 2002, the Stanislaus River fall pulse flow occurred between October 21st and October 29th and ranged between 250 to 700 cubic feet per second. The purpose of the fall pulse (e.g. attraction flow) is threefold: i) lower water temperature in the lower Stanislaus River and lower San Joaquin River; ii) improve dissolved oxygen conditions (e.g. raise DO) in the San Joaquin River at the Stockton Deep Water Ship Channel; and iii) attract upstream migrating salmon into the Stanislaus River. The rise in spawning redd counts occurs concurrent with increased Goodwin Dam release flow levels (e.g. fall attraction or pulse flow) and associated decrease in water temperature level.

Tuolumne River

Both spring and fall-runs occurred in the Tuolumne River historically and were able to ascend a considerable distance. Both adult steelhead and salmon probably had access all the way to Preston Falls, which is about 50 miles upstream of New Don Pedro Dam. The occurrence of salmon in the Tuolumne River in the early years was noted by John Marsh

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[15] The State Water Resources Control Board Decision D-1641 requiring New Melones releases to achieve summer San Joaquin River at Vernalis water quality flow objectives went into effect in the year 2000.

who had arrived in California in 1830. John Marsh stated that the Tuolumne River "particularly abounds with Salmon." In 1849, in his memoirs of the Gold Rush, Samuel Ward recalled "a plenteous fish supper of salmon, caught by rifle shot in the lower Tuolumne River." A later historical account noted the local native people "Every spring, when the salmon were running up the river, enough salmon were caught and dried to last nearly all the year" and "The waters of the Tuolumne, Stanislaus, Merced, and San Joaquin generally furnish them with good fishing."

Significant blockage of salmon runs in the Tuolumne River began in the 1870's when various dams and irrigation projects were constructed, although dams and water diversions associated with mining had been present as early as 1852 and undoubtedly had some effect. Wheaton Dam, built in 1871 at the site of present day La Grange Dam, may have blocked the salmon run. By 1884, both the Tuolumne and Stanislaus Rivers were dammed in such a way as to prevent the fish from ascending. In 1894 La Grange Dam was built and permanently cut-off the spring-run spawning areas upstream of La Grange Dam. In 1896 the California Fish Commission declared that a proposed fish ladder on the Tuolumne River was not warranted because the fish ladder would not be of much benefit due to the small size of the Tuolumne River the salmon population which would likely continue to decline due to the waters being taken out of the river for irrigation purposes. It should be noted that John Muir recorded in his journal, 1877, that when he passes the mouth of the Tuolumne that the river was brown with mining mud and that the San Joaquin River water was clear. It is possible that mining, in combination with dam building and water diversion, affected the salmon runs in the late 1800s.[16]

In 1929 G. H. Clark stated: "The spawning run of the salmon in the Tuolumne is during the spring and fall. The fall run is the only one of any consequence. The spawning grounds extend from the town of Waterford to La Grange, a distance of twenty miles of good gravel river. The Tuolumne River, like the other rivers of the San Joaquin system, is used for irrigation. Two dams on the river affect the salmon. The lower is the La Grange Dam near the town by that name. It is an irrigation diversion dam which supplies water for the ranches in the lower country. The dam is 120 feet high and has no fish ladder. Thirteen miles above this is the Don Pedro Dam, which is about 300 feet high and was built in 1923. It forms a large storage reservoir for irrigation and also generates some power. Salmon in the Tuolumne River are scarce. The spring run amounts to almost nothing, but there are some fish that come up the stream in the fall. The river, like the rest in years past, used to abound with salmon. Three years ago (1925) a good run was reported in the stream that surpassed anything that had appeared in several years."[17]

When looking at San Joaquin River hydrology records between 1902 and 2005, a period of 105 years, it is not surprising that the 1925 year escapement was notable. In the years 1921 to 1923, the juvenile production time periods contributing the 1925 year

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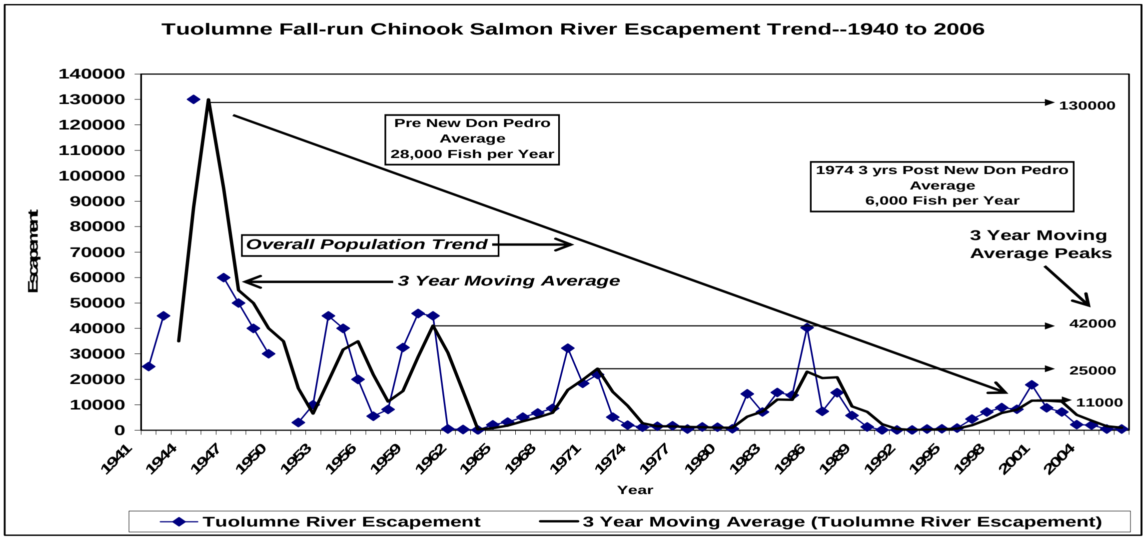
[16] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

[17] From G.H. Clark. 1929. Sacramento-San Joaquin Salmon (Onchorhynchus tschawytscha) Fishery of California. Fish Bulletin No. 17. Division of Fish and Game of California.

escapement, the spring run-off in Tuolumne River for these years was one of the higher three year spring run-off periods on record. This suggests that the San Joaquin River east-side tributary boom and near bust fall-run salmon population cycle has been in existence for at least the last 80+ years (Figure 5). The current reduction in peak abundance over time is very disturbing and suggests that overall population resiliency (e.g. production over time) is steadily decreasing and may reach a point where given enough successive dry years the population could become extinct. In 2007, the estimated abundance of out-migrating salmon smolts, the life-history phase which is strongly correlated with adult production, was extremely low[18] (less than 1,000 smolts). From 1998 to 2006, the estimated number of smolt outmigrants was much higher ranging from 9,960 smolts in 2003 to about 350,000 smolts in 2005.

Between 1940 and 2006 the Tuolumne River fall-run escapement population has oscillated over time and has dropped to levels less than 1,000 on several occasions. The average escapement of fall-run salmon in the Tuolumne River seriously declined post New Don Pedro time frame (Figure 8). By 2000, the Tuolumne River fall-run salmon escapement population had steadily declined and by 2006 (500 salmon) had dropped to about 97% percent below the year 2000 peak abundance of 17,875 salmon (Figure 9).

Figure 8. Historical Annual Tuolumne River Salmon Escapement Trend



The blue dotted line represents the historical Tuolumne River salmon escapement for the years 1941 to 2006 (note: escapement data not available for years 1943, 1945 and 1950). Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1941 there have been several peak escapement periods. The 3 year moving average[19] of escapement trend is intended to account for the various ages of salmon that comprise an annual escapement. Juvenile salmon produced in one year (e.g. brood year) typically return as adults to spawn as age 2, 3, or four year old salmon. The three year moving average is intended to cover the three year period that salmon return to spawn post brood production year. The three year moving average indicates that the overall Tuolumne annual escapement is

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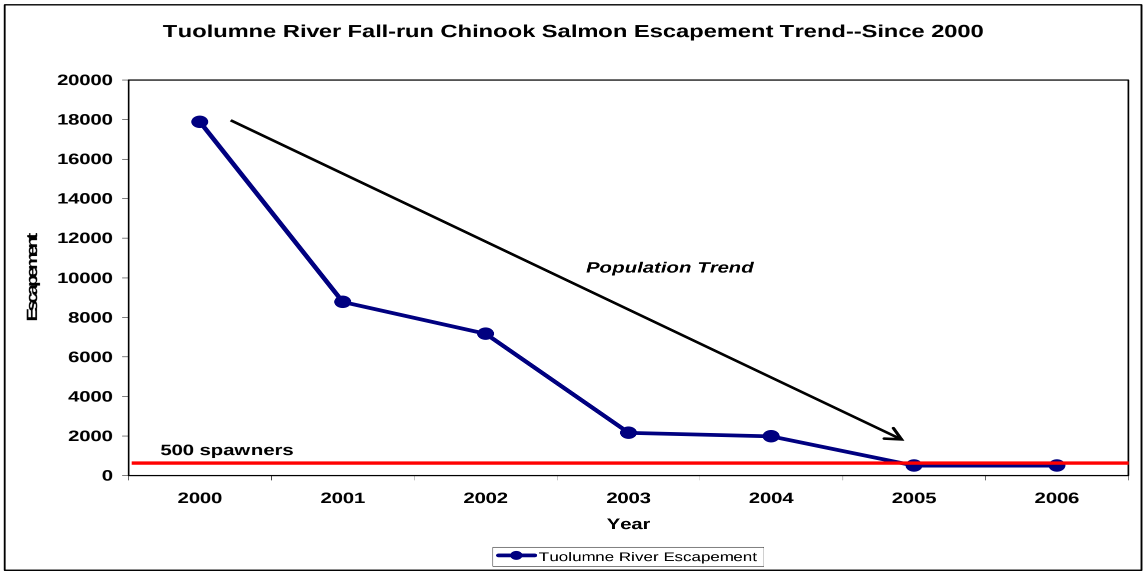
[18] Estimate provided by FishBio in August of 2007.

[19] The 3 year moving average is a continuous moving average for a 3 year period. The first average is the 1952 to 1954 annual escapement average. The second average is the 1953 to 1955 annual escapement average. The 3 year annual escapement averages continue up to the 2004 to 2006 time period.

declining over time. This declining trend is consistent with the overall declining trend observed in Figure 1 for the SJR salmon escapement trend.

Figure 9. Tuolumne River Annual Salmon Escapement Trend 2000 to 2006



This graph shows the Tuolumne annual escapement trend for the years 2000 through 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since the peak escapement in the year 2000 (over 17,000 spawners), escapement has dropped sharply to 500 spawners for both the 2005 and 2006 escapement years.

Figure 10 shows how annual flow releases into the lower Tuolumne River has lessened over time as water development has occurred. As water development increased, the magnitude, duration, and frequency of elevated spring flows has diminished. There is a strong correlation between annual spring flow magnitude and future year adult production (Mesick and Marston 2007). Also, as spring flow increases smolt survival increases (TID/MID Annual Report to FERC 2005)[20]. As a consequence of reduced spring flows, when smolts are out-migrating, water temperatures are increased. There is a strong relationship between flow volume, as represented by La Grange Dam flows into the lower Tuolumne River, and the longitudinal river reach water temperature trend (Figure 11). In the spring when La Grange Dam release flows are reduced (less than 569 cfs) much warmer water temperature results (22ºC/71ºF), in comparison to when La Grange Dam release flows are increased (about 4500 cfs) water temperature during the spring is reduced substantially (15ºC /59ºF). This longitudinal temperature trend reduction, for both low and higher flows, occurred at similar meteorological conditions and approximate release temperature strongly suggesting that La Grange Dam release flow level is important in conveying adequate water temperatures downstream. Excessively warm water temperatures in the lower reach during the spring have occurred at a time when juvenile salmon are still present in the upper reach of the Tuolumne River (Table 1).

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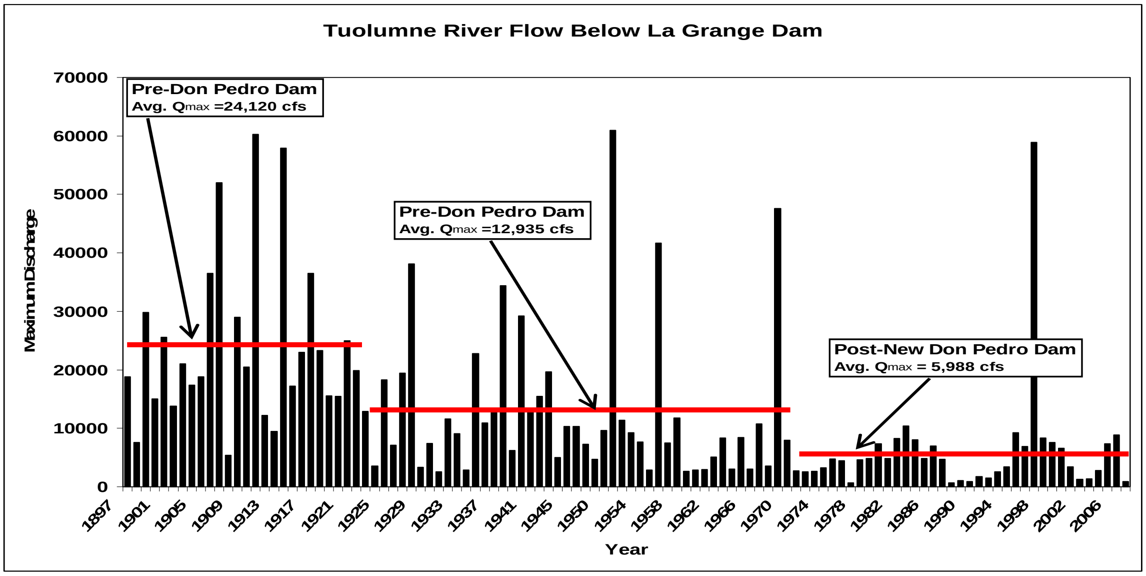
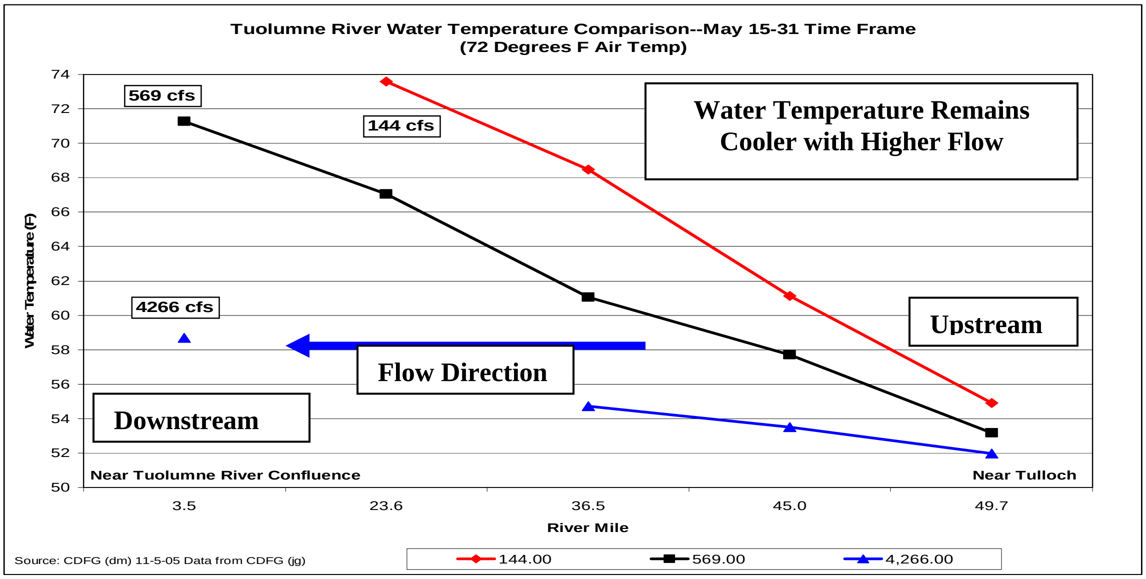
[20] 2005 Turlock and Modesto Irrigation District Annual Report to the Federal Energy Regulatory Commission.

Figure 10. Historical Tuolumne River Flow at La Grange (Annual Peak Flow)



This figure compares the both annual maximum flow level in the Tuolumne River at La Grange and the average annual maximum flow level for the pre and post-New Don Pedro Dam time periods (data from Turlock Irrigation District). With each dam construction a substantial reduction in average annual peak flow has occurred.

Figure 11. Tuolumne River Water Temperature and River Flow Volume



Source: CDFG (dm) 11-5-05 Data from CDFG (jg)

This figure shows that La Grange Dam release volume and water temperature level determines the longitudinal (downstream) water temperature level (at the mouth) during the late spring time period when salmon smolts are migrating out of the Tuolumne River. Both the reduced, and elevated, flow levels depicted in this figure occurred during similar meteorological conditions (approximately 72ºF). Elevated flows have the ability to withstand meteorologically induced thermal warming of the water as it moves downstream in the Tuolumne River.

Table 1. Tuolumne River Seine Catch at Rivermile 48 (Near La Grange)

Tuolumne Seine Catch at Rivermile 48					
Year	**Date**	**Salmon Catch**	**Year**	**Date**	**Salmon Catch**
1999	08APR	5	2002	09APR	58
1999	22APR	0	2002	23APR	33
1999	**05MAY**	**18**	2002	07MAY	50
1999	19MAY	1	**2002**	**21MAY**	**49**
2000	04APR	0	2003	01APR	132
2000	02MAY	1	2003	16APR	25
2000	**17MAY**	**17**	2003	30APR	0
2001	04APR	6	**2003**	**14MAY**	**27**
2001	17APR	47	2003	28MAY	0
2001	01MAY	17	2004	30MAR	109
2001	15MAY	118	2004	14APR	6
2001	**30MAY**	**211**	2004	27APR	0
			2004	11MAY	0
			2004	**25MAY**	**27**

This table shows that salmon are still present in the Tuolumne River late in the year (e.g. late May and early June) in the upper reaches of the Tuolumne River when temperatures are excessively warm for smolt development and during outmigration in the lower Tuolumne River. Data from Turlock Irrigation District's Federal Energy Regulatory Commission Annual Reports.

In addition to excessively warm spring time period water temperatures, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present the lower San Joaquin and lower Tuolumne Rivers during the fall adult upstream migration seasons for the years 1998 thru 2005 (Tables 8 and 10 in CDFG's Letter to the RWQCB dated February 2007). Also, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Tuolumne River spawning habitat reaches, during the first half of the spawning season for years 1998 thru 2005 (Table 12 in CDFG's Letter to the RWQCB dated February 2007).

Steelhead, the anadromous form of rainbow trout.(Onchorhynchus mykiss), is a sought game fish in the Tuolumne River. Little is known regarding overall population abundance and trends over time other than adult catch is considered infrequent. Juvenile rainbow trout (smolts) out-migrating the Tuolumne River are caught annually in seining surveys conducted by the Turlock Irrigation District. Steelhead in the Tuolumne River are considered winter run. Anecdotal reports by anglers suggest that steelhead abundance is greatest following years where summer rearing conditions are good (e.g. number of river miles possessing cold water temperatures). State and Federal fish agency biologists believe that steelhead abundance trends over time have followed that of salmon, only more so precipitating the need to list Steelhead in the Central Valley as threatened. The Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Tuolumne River juvenile steelhead rearing reach, during the summer for years 2001 thru 2006 (Table 19 in CDFG's Letter to the RWQCB dated February 2007).

Merced River

Both spring-run and fall-run salmon, and steelhead, historically occurred in the Merced River. Of the salmon runs, only the fall run has survived and the Merced River fall-run is the southernmost native Chinook salmon run in existence. Native Americans were observed harvesting salmon in the Merced River in 1852 at Merced Falls. In November 1877, John Muir noted that salmon were abundant in deep pools. It appears that adult salmon were definitely able to access the Merced River up to the confluence of the South Fork; however, some unconfirmed reports suggest that both salmon and steelhead migrated as far up the South Fork as Wawona and in the mainstem as far as into Yosemite Valley. As early as 1852, a temporary barrier was constructed, by fishermen, about 10 miles downstream of Merced Falls which blocked upstream migration of spring-run. In later years, a succession of dams was built at Merced Fall and locations upstream. These dams had impeded upstream passage of salmon by the 1920's. However, the construction of Exchequer Dam barred salmon from migrating into their former spawning grounds. As of 1928 there were three upstream migration blockages: i) Crocker-Huffman irrigation diversion dam near Snelling; ii) the Merced Falls, with non-working fishway, about three miles upriver from Crocker-Huffman dam; and iii) Exchequer Dam about 20 miles upstream of Merced Falls[21]

In 1929 G. H. Clark stated: "The salmon of the Merced River run in the spring and fall. The spawning beds extend from the mouth of the river to the Exchequer Dam on occasional gravel bars that occur along the river. Perhaps the length in linear miles of stream be available is about 12 miles. There are three obstructions that affect the salmon. The Crocker Huffman irrigation diversion dam near Snelling is the lowermost. This dam, which was built about 1918, is about 15 feet high and has a good working fishway in high water. There are a few screens but not over all the ditches. At Merced Falls there is a natural fall and a 20-foot dam has been constructed to form a millpond and to generate power for a sawmill. The dam was built prior to 1913. There is a fishway, but it has been closed and out of order for a number of years. There are screens over the intakes to the power house. The Exchequer Dam is about 20 miles above the Merced Falls and is impassable to fish. It is a 120-foot power dam.

The abundance of salmon in the Merced River now (1925) as compared to the past years tells the same story of depletion as do the other rivers. The reports of the early residents along the Merced River speak of great quantities of fish coming up the river to spawn in the summer and fall. In 1920, a letter received by the Fish and Game Commission from a resident of the country states that there were fifty salmon in the past for each one now (1920). In the above-mentioned letter the blame for this decrease was attributed to the construction of dams. Residents along the river in 1928 say that the salmon are so scarce that they rarely see any. They remember the fish being so numerous that it looked as if one could walk across the stream on their backs. One report from Merced stated there were no salmon which ran up the river any more, but later the statement was to the effect that a few went up in the fall. Another statement from a deputy of the Division of Fish

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[21] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

and Game, dated November 12, 1928, says that there are several hundred salmon in the Merced this fall. The deputy counted 391 in one small stream below a dam. The river was dry or a distance above the creek so the salmon could not continue up the river until the rain came and increased the water supply.

A great deal of the water in the Merced River is used for irrigation during the spring, summer and early fall. The river during this irrigation season is very low, and the salmon find it hard to get up the river until after the rains. This condition has just about killed off the spring and summer runs and now the only fish that come in active during the late fall." [22]

The statement that the salmon run was low in 1928 is not surprising as the brood production years comprising the 1928 escapement occurred during the water years 1924 through 1926, a time period that consisted of some of the lowest historical spring flow years. As stated above, the recurrent boom and near bust San Joaquin River east-side tributary salmon escapement population trend is of great concern to the Department given the associated declining population resiliency trend that continues to occur (e.g. production boom population abundance numbers are far fewer now than what historically occurred).

By 1961, the Merced River was considered to be only a marginal salmon stream due to the diversion of water by irrigation diversions. The Merced River fall-run salmon population was described as "poor." Run size estimates for fall-run in the 1960's average about 250 salmon per year. In 1970, a fall-run salmon hatchery was built was on the Merced to augment natural production. The operation of a hatchery on the Merced, in combination with increased stream flows by the Merced Irrigation District (e.g. Davis-Grunsky Program), resulted in the average annual escapement to increase from an average of 900 a year to about 5,500 per year. However the Merced, like the Stanislaus and Tuolumne River salmon escapement populations, drastically declined by the end of the six year drought (e.g. 1986-1992 average of 2,500). The cause of the decline is believed to be primarily due to low flow and elevated water temperature conditions during adult immigration into and juvenile (smolt) spring out-migration from the Merced River. When flow and water temperature improved post-drought, between 1993 and 1998, Merced River salmon escapement improved (Figure 12).

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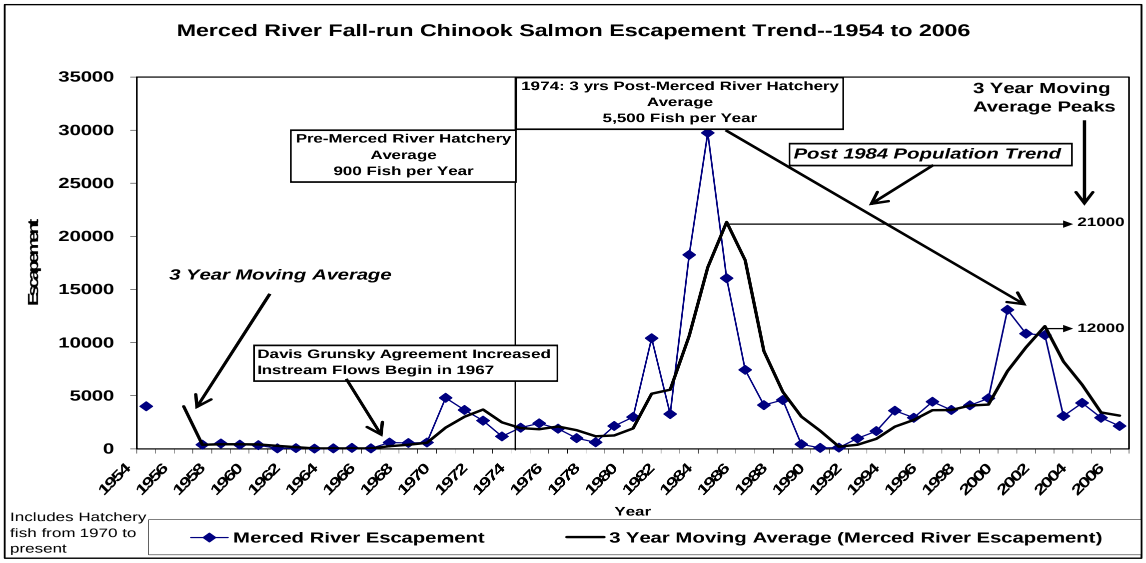
[22] From G.H. Clark. 1929. Sacramento-San Joaquin Salmon (Onchorhynchus tschawytscha) Fishery of California. Fish Bulletin No. 17. Division of Fish and Game of California.

Figure 12. Merced River Historical Salmon Escapement (1954 to 2006)



The blue dotted line represents the historical annual Merced River salmon escapement for the years 1954 to 2006 (note: escapement data not available for years 1955, 1956). The escapement trend includes salmon escapement into the Merced River Hatchery for years 1970 to 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1954 there have been several peak escapement periods. The 3 year moving average[23] of escapement trend is intended to account for the various ages of salmon that comprise an annual escapement. Juvenile salmon produced in one year (e.g. brood year) typically return as adults to spawn as age 2, 3, or four year old salmon. The three year moving average is intended to cover the three year period that salmon to spawn post brood production year. The three year moving average indicates that the overall Merced annual escapement is declining over time. This declining trend is consistent with the overall declining trend observed in Figure 1 for the SJR salmon escapement trend. It is also noted that the minimum instream flow levels changed (upward) during the fall spawning season (October 31 to March 31) in the approximate 20 mile spawning reach downstream of Crocker-Huffman Dam beginning 1967 per the State of California Davis-Grunsky Agreement with the Merced Irrigation District.[24]

Since the higher spring flows, and cooler spring water temperatures of 1998 and 1999, the population has declined steadily since 2000 and the fall-run salmon population has steadily declined and by 2006 (2,150 salmon) had dropped to about 84% percent below the year 2000 peak abundance of 13,076 salmon (Figure 13).

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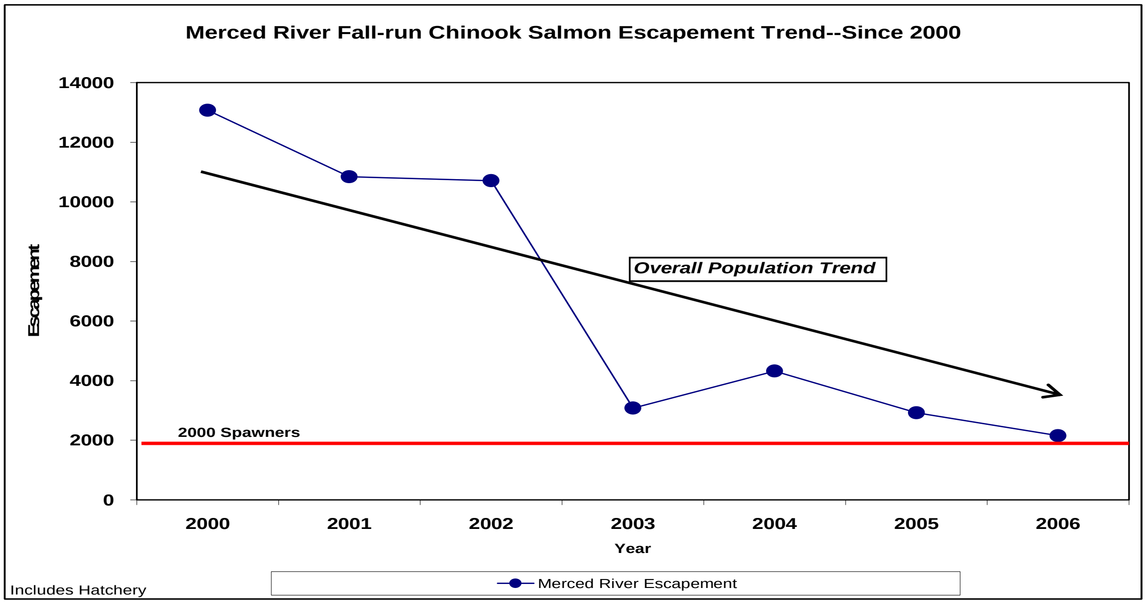
[23] The 3 year moving average is a continuous moving average for a 3 year period. The first average is the 1952 to 1954 annual escapement average. The second average is the 1953 to 1955 annual escapement average. The 3 year annual escapement averages continue up to the 2004 to 2006 time period.

[24] Vogel, D. 2003. Merced River Water Temperature Feasibility Investigation Reconnaissance Report.

Figure 13. Merced River Salmon Escapement 2000 to 2006.



This graph shows the Merced annual escapement trend for the years 2000 through 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since the peak escapement in the year 2000 (over 13,000 spawners), stemming from environmental conditions two to three years earlier (e.g. reference to water years 1997-98 and 1998-99) that would have contributed the year 2000 annual escapement (e.g. reference to two and three year old salmon which typically comprise the bulk of any one escapement year's abundance) escapement has dropped sharply to 2,000 spawners in the year 2006. The Merced escapement also includes escapement of salmon into the Merced River Hatchery.

Figure 14 shows how annual flow releases into the lower Merced River has lessened over time as water development has occurred. As water development occurred, the magnitude, duration, and frequency of elevated spring flows has diminished. There is a strong correlation between annual spring flow magnitude and future year adult production (Mesick and Marston 2007). As spring flow increases, smolt survival increases[25]. As a consequence of reduced spring flows, when smolts are out-migrating, water temperatures increased. There is a strong relationship between flow volume, as represented by Crocker-Huffman Dam flows into the lower Merced River, and the longitudinal river reach water temperature trend (Figure 15). In the spring when Crocker-Huffman Dam release flows are reduced (less than 569 cfs) much warmer water temperature results (22ºC/71ºF), in comparison to when Crocker-Huffman Dam release flows are increased (about 4500 cfs) water temperature during the spring is reduced substantially (15ºC /59ºF). This longitudinal temperature trend reduction, for both low and higher flows, occurred at similar meteorological conditions and approximate release temperature strongly suggesting that Crocker-Huffman Dam release flow level is important in conveying adequate water temperatures downstream. Excessively warm water temperatures in the lower reach during the spring have occurred at a time when juvenile salmon are still present in the upper reach of the Merced River (Table 2).

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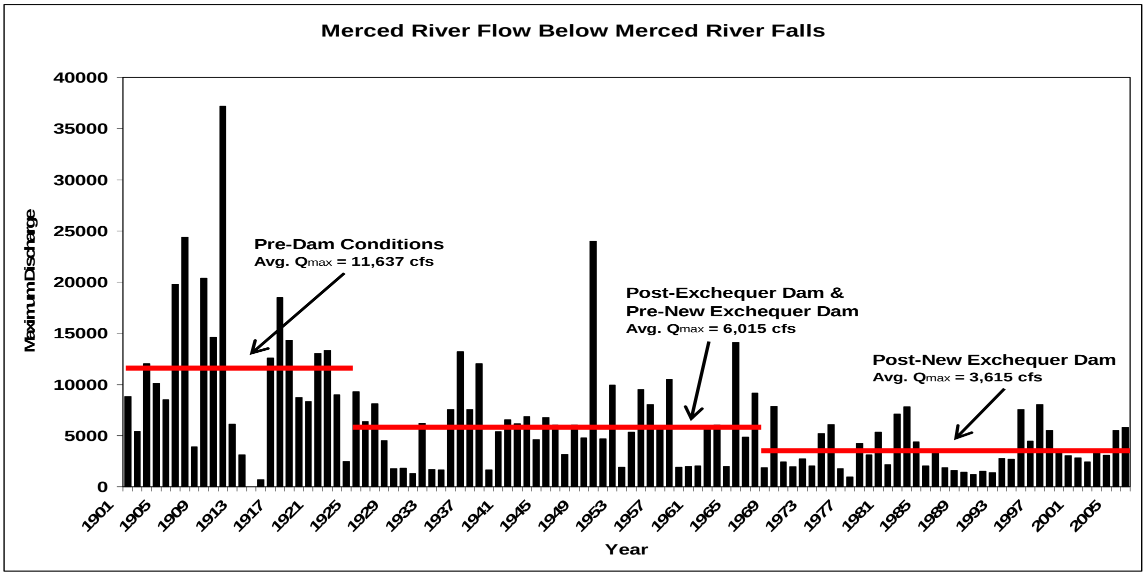
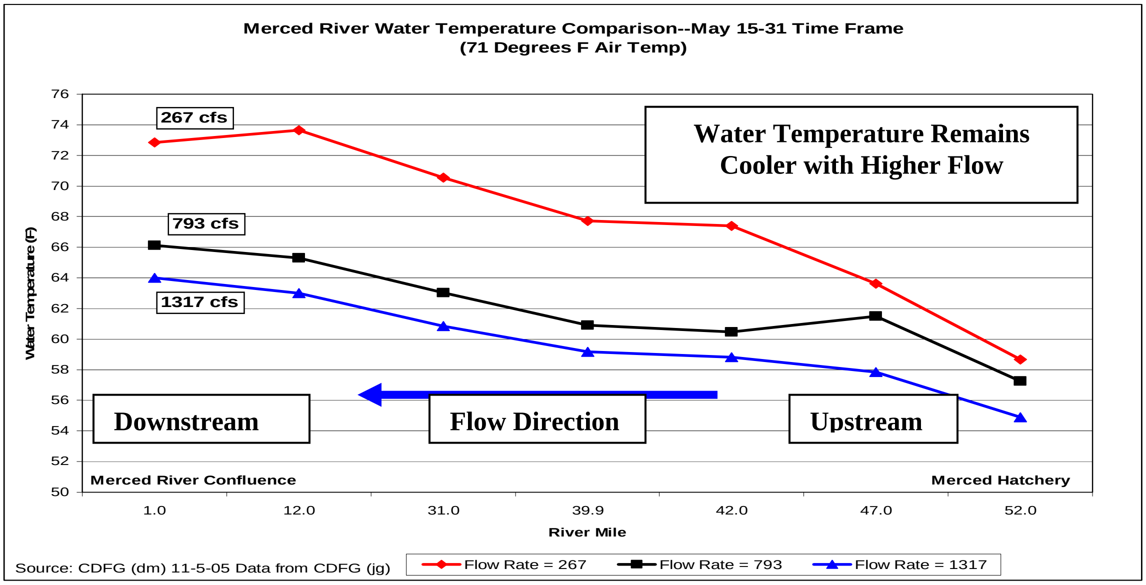
[25] California Department of Fish & Game Annual Reports.

Figure 14. Historical Merced River Flow at Merced River Falls (Annual Peak Flow)



This figure compares the both annual maximum flow level in the Merced River at Merced River Falls and the average annual maximum flow level for the pre and post-New Exchequer Dam time periods. With each dam construction a substantial reduction in average annual peak flow has occurred. Data from USGS Gage No. 11270000 Merced River Falls.

Figure 15. SJR East-side Tributary Flow and Water Temperature Comparison.



Source: CDFG (dm) 11-5-05 Data from CDFG (jg)

This figure shows that Crocker-Huffman Dam release, and water temperature, level determines the longitudinal (downstream) water temperature level (at the mouth) during the late spring time period when salmon smolts are migrating out of the Merced River. Both the reduced, and elevated, flow levels depicted in this figure occurred during similar meteorological conditions (approximately 71ºF). Elevated flows have the ability to withstand meteorologically induced thermal warming of the water as it moves downstream in the Merced River.

Table 2. Juvenile Salmon Catch in the Merced River Near Hopeton

Merced Upper Rotary Screw Trap Juvenile Salmon Catch					
1999	May 1-15	4593	2003	May 1-15	*
	May 16-31	**843**		May 16-31	*
	June 1-15	*		June 1-15	*
2000	May 1-15	2870	2004	May 1-15	*
	May 16-31	**15343**		May 16-31	*
	June 1-15	831		June 1-15	*
2001	May 1-15	20544	**2005**	May 1-15	5590
	May 16-31	**19595**		**May 16-31**	**6071**
	June 1-15	16		June 1-15	2204
2002	May 1-15	36374	* Trap Not Operated		
	May 16-31	**2060**			
	June 1-15	*			

This table shows juvenile salmon catch in the Merced River at Hopeton for the May 1 to June 15th time period during years 1999 to 2005. Late in the spring, when water temperatures in the lower Merced River are excessively warm for outmigrating salmon smolts, juvenile salmon are still trying to migrate from the upper reach of the Merced River to the lower reaches of the Merced River. Data from the Merced Irrigation District.

In addition to excessively warm spring time period water temperatures, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present the lower San Joaquin and lower Merced Rivers during the fall adult upstream migration seasons for the years 1999 thru 2005 (Tables 9 and 10 in CDFG's Letter to the RWQCB dated February 2007). Also, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Merced River spawning habitat reaches, during the first half of the spawning season for years 1998 thru 2005 (Table 13 in CDFG's Letter to the RWQCB dated February 2007).

Steelhead, the anadromous form of rainbow trout.(Onchorhynchus mykiss), is a sought game fish in the Merced River. Little is known regarding overall population abundance and trends over time other than adult catch is considered infrequent. Juvenile rainbow trout (smolts) out-migrating the Merced River have been caught in rotary screw traps operated by the Department. Steelhead in the Merced River are considered winter run. Anecdotal reports by anglers suggest that steelhead abundance is greatest following years where summer rearing conditions are good (e.g. number of river miles possessing cold water temperatures). State and Federal fish agency biologists believe that steelhead abundance trends over time have followed that of salmon, only more so precipitating the need to list Steelhead in the Central Valley as threatened. The Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Merced River juvenile steelhead rearing reach, during the summer for years 1999 thru 2005 (Table 20 in CDFG's Letter to the RWQCB dated February 2007).

San Joaquin River[26]

The earliest historical reports reveal that salmon were present in the San Joaquin River above the mouth of the Merced River in great numbers. Indigenous Yokuts and Mono peoples historically utilized these runs of fish very heavily as a source of protein. Dried salmon from the San Joaquin were stored and traded with more distant Yokuts tribes from the southern San Joaquin Valley, and the remains of these fish are a feature of middens from those areas (Gobalet, 1995). Historical abundance estimates are lacking, but historian, Frank Latta (1949) reported:

> "The southern Yokuts called the San Joaquin River Tihshachu, meaning salmon spearing place. Indians traveled great distances to spear salmon on the shallow sand bars there…. South of Table Mountain was the village of Muhnowlo. North of Table Mountain, on a large flat [today, this is called Temperance Flat] by the river where the Indians speared salmon, was the Kechayi village of Kiahno. During the time when the salmon were running, every bush and most of the ground in the vicinity was red with drying salmon." (Latta 1949. P.4.)

Historical sources (Hatton and Clark, 1942) indicate that the San Joaquin watershed had a very large spring-run of Chinook salmon, along with a much smaller fall-run. The differential magnitude of these salmon runs most likely reflected the natural hydrology: i.e., heavy snow run-off flows in spring and early summer, and lower discharges in fall, as flows seasonally receded.

While salmon dominated most of the historical reports concerning anadromous fish, steelhead rainbow trout were also mentioned. Steelhead were described by Latta (1929, 1949) and by other authors as being present in good numbers and at least casually being taken and utilized by the indigenous Yokuts peoples.

By about 1920, the Chinook salmon populations had seriously declined due to important changes within the upper San Joaquin River watershed. These included: (i) the development of the "sack dam" at Dos Palos and its seasonal unscreened diversion of irrigation water, (ii) development of the Kerckhoff Dam, in 1916 by San Joaquin Power and Light Company (later PG&E), (iii) screened and unscreened water diversions at Mendota, (iv) the initial development of the Big Creek series of dams and reservoirs by Southern California Edison Company, (v) development of a dam and water storage reservoir at Crane Valley, by the San Joaquin Power and Light Company, and (vi) extensive fishing, seining, and spearing of adult migrant salmon as they attempted to migrate across greatly flow-reduced river reaches on the San Joaquin Valley floor. Some of these features are discussed in more detail below.

Beginning in the late 1800's, a sack dam was annually installed at a point near Dos Palos, on the Lower San Joaquin River. The dam itself imposed a major barrier to upstream migrating adult salmon; particularly in the fall, after San Joaquin River flows became seasonally reduced. The routine springtime and summer diversion of irrigation water through the unscreened canal intake, also created a major source of mortality to downstream migrating salmon and steelhead juveniles. During dry years, when total

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[26] The majority of information provided in this section came from Dale Mitchell, Aquatic Program Manager for the California Department of Fish & Game. 2007.

discharges were below 1,000 cfs, this unscreened diversion consumed a very large fraction of downstream migrating salmon. A.D. Ferguson wrote in 1914:

> The fishing conditions in the valley section of Fresno Division are at once important and peculiar. Important, for the reason that many thousands of people in all walks of life, … find throughout the fishing season pleasure and recreation along the banks of the two great rivers of the valley. Peculiar in that , due to the diversion of the waters for irrigation purposes, both the San Joaquin and Kings Rivers are dry throughout a portion, at least, of their lower courses, almost every fall…." (Ferguson 1914, p. 23)

Upstream water development also contributed to the reduction of San Joaquin River salmon. The construction of Kerckhoff Dam and reservoir by San Joaquin Light and Power Company, in 1916, completely blocked the upstream access to over-summer habitats and spawning grounds by adult salmon and steelhead. The following early reports probably overstate the extent of this impact, but intuitively, the dam must have had truly dramatic impacts on both salmon and steelhead, given its presentation of a major migration barrier, located in the lower portion of the watershed.

> The last of the salmon breeding grounds in the San Joaquin will be destroyed this season by the completion of the Kerckhoff dam and powerhouse by the San Joaquin Light and Power Company. The water will be diverted through a tunnel 17,000 feet in length that will dry up about 12 miles of the river bed as well as prevent any salmon from ascending above the dam. A survey of the conditions on the San Joaquin River has been made, and an estimate of the number of breeding salmon that pass Mendota Weir, about 50 miles below the Kerckhoff Dam, is in preparation. A survey has been made for a fishway over the new Mendota Weir that is now under construction. This will allow the spring run of fish to pass on up the San Joaquin River to a point where the large irrigation canals take water out of the river. These salmon ascend the river during May, June and the first part of July. In the foothills near Friants [sic] they congregate in large pools and remain until such time in the fall as the temperature is right for them to spawn, then they ascend the river into the gorge of the San Joaquin River, where they spawn during the fall. This is the result of our observations gathered from the residents and deputies who have lived in that vicinity for years. If such proves to be the facts, the only way to save the remainder of this run of fish is to establish an egg collecting station near the Kerckhoff Powerhouse, collect the eggs, and transfer them by truck to Powerhouse No. 1., a distance of about seven miles, and there hatch and rear the fry in ponds. The fry should then be held until the following spring, after they are hatched and then release them in the river during flood periods before large canals are opened for the season's operations.
>
> If the water is turned into the large canals before the fry are ready to be released, or the water is not turned off from the large canals during the winter and early spring, the fry would have to be transported by truck down the river to where they could be distributed below the canal systems. All of this work should be forced on the power companies. They construct impassable obstructions in our rivers and streams in the shape of dams and diverting tunnels and canals without regard to the enormous destruction of the runs of commercial fishes…." (W.H. Shelby, 1920, p. 21)

> The propagation of Chinook salmon becomes a matter of greater importance each season, as the natural spawning grounds are being cut off in the rivers and streams of the state by the erection of high dams for the development of hydro-electric power and irrigation…. We desire to call particular attention to the salmon run in the Sacramento and San Joaquin rivers. Already greatly depleted, it is threatened with extermination if measures are not taken at once to increase the output of salmon fry from the hatcheries. The construction of impassable dams and the diversion of water for irrigation is fast cutting off the remaining spawning beds in the tributary streams of these rivers and this excellent fish is doomed to extermination if prompt action is not taken. This

> department has called attention to this condition for the last four years, but the Legislature and the commercial fishermen as well as the general public pay no heed to the recommendations offered and no action to save this fine fish is taken…." (W.H. Shelby 1922, p. 36)

Prior to Kerckhoff Dam's development, salmon reportedly were routinely harvested by indigenous Mono People as far upstream as Vermillion Valley (Present-day Edison Reservoir) and Graveyard Meadows, both far upstream of Present Day Mammoth Pool Dam and Reservoir (see Lee, 1998, below). To the extent these reports are correct, then about 90 percent of the overall spawning and over-summer habitat was lost with the dam's development.

> The old-timers fished year-round years ago, but their big fishing expeditions were for salmon, after they journeyed hundreds of miles from the Pacific Ocean up the San Joaquin River, surging against the swift flowing water and cresting rapids and waterfalls to finally reach their old spawning grounds upriver from Cha:tiniu. There Grandpa John reminisced, our ancestors speared salmon only a few hundred yards from the meadow where they lived…. Grandpa John also described a long-ago fishing trip. "Hotshot [Grandpa}. Willie P. [Grandpa Willie]. And John [their cousin, John Rogozinski] way down rock mountains, and then walked by river below Graveyard meadow. Lots big salmon lay on sand waiting for trout to eat…." (G. Lee, 1998, p.87) (Photo on page 15 depicts Cha:tiniu at roughly the area of Jackass Meadows, well above the location of present-day Mammoth Pool Dam.)

Water developments upstream of Kerckhoff Dam also began affecting salmon production and survival. Hydro-electric dams and reservoirs were being progressively developed, and through upstream impoundment of the otherwise free-flowing river, they altered the magnitude and timing of downstream discharges and water temperatures, which in turn affected the viability of salmon and steelhead within the now critically reduced remaining habitats downstream of Kerckhoff Dam. These upstream storage reservoirs also progressively subtracted from the amounts of water seasonally reaching and bypassing the irrigation diversion points at Dos Palos, and later at Mendota, which exacerbated those fish entrainment problems. As flows became reduced and the diverted volumes represented a larger and larger part of the total flow, an increasingly larger fraction of the downstream migrating salmon and steelhead juveniles were entrained and lost. These impacts continued to increase in magnitude over time, until, by the early 1920's, the salmon runs in the San Joaquin River (and also Sacramento River) were at alarmingly low numbers. Supplemental fish stocking of the San Joaquin River was undertaken using eggs collected at the Klamath River and reared at the Battle Creek and Mill Creek Hatcheries on the Sacramento River; both operated at the time by the State Department of Natural Resources, Division of Fish and Game, as below.

> In 1927 an investigation of the past and present status of the Sacramento-San Joaquin salmon was started by G.H. Clark, a member of the staff of this bureau, under the guidance of Dr. J.O. Snyder of Stanford University. The results of this investigation were published last year as "Fish Bulletin No. 17." The Bulletin is in three parts. … Part II of the Bulletin is a survey of the spawning grounds, in which is given in detail the conditions on the main streams and tributaries of the Sacramento-San Joaquin river systems, with their obstructions, fish ladders and screens, the time of salmon runs and the abundance of salmon in each. He estimates that there are now 510 linear miles of spawning beds suitable and available for spawning and that previous to any obstructions in the streams there were at least 6,000 linear miles of stream bed suitable for spawning. At least 80 percent of the spawning grounds have been cut off by obstructions…." (N.B. Scofield, 1930p. 119.)

> ".. The development of hydro-electric energy by the erection of high dams in the tributary streams of the Sacramento and San Joaquin Rivers has materially reduced the number of salmon in the Sacramento and San Joaquin Rivers and Monterey Bay regions. Practically all the salmon now found in the Sacramento and San Joaquin River basins and Monterey Bay region are the product of hatcheries at Battle Creek, Mill Creek, and Klamath River stations. The number of salmon fry produced in the Klamath River stations has assisted greatly in keeping up the supply in the Sacramento River. ... The larger portion of the salmon in the Klamath River are the Sacramento race of king salmon that were introduced into the Klamath River by the Fish and Game Commission in its salmon cultural operations during the past years. The native Klamath River salmon do not appear in any great numbers in the river in the last few years. Our fishcultural experts at the Klamathon station support the view that the large majority of the fish taken from the Klamath River at the Klamathon egg-collection station are of the Sacramento race." (Shelby, 1924, p.27.)

In 1929 G. H. Clark stated: “The salmon of this river run in the spring (the water is too low for the fall run). The spawning beds extend from the mouth of Fine Gold Creek to Kerchoff Dam and in the small streams of that area. Actual length of beds is about 36 miles. There are a few scattered beds below Friant. Four dams affect the salmon of this river. The lowermost is the Delta weir in a slough on the west side of the river, 14 miles southeast of Los Banos (e.g. present day Sack Dam, explanation added). The weir is about 10 feet high, 30 feet wide: a fishway on one side is in working order but there are no screens on the ditches. Stevenson’s weir is on the main river directly east of the Delta weir. The weir is 110 feet long and six feet high and has a good fishway. Both of these dams are irrigation projects. Mendota weir is on the main river a mile and a half from the town of Mendota. It is a large irrigation diversion dam owned my Miller and Lux; it is 30 feet high, 200 feet long and built of concrete. The fishway is in working order during high water. There are several large canals taking water out of this reservoir and on those that have lifts on them are screened. The Kerchoff Dam is in the foothills 35 miles above Friant. It is 180 feet high and impassable to salmon. It was built around 1920 to divert water for power generation. At the town of Friant there is a proposed project to be constructed in 1928-29. This structure is to be 125 feet high and will cut off most of the spawning grounds of the river.

Eighty to Ninety years ago, the salmon in the San Joaquin were very numerous and came in great hordes whenever prolonged spring flooding provided passage for the juveniles and adults below Sack Dam. As the various agencies of depletion such as dams, irrigation ditches and overfishing came into play, the runs fell off. In 1916-17 there was reported a very good run in the river at Mendota. In 1920 it was fairly good. The run has fallen off each year until in 1928 very few salmon were seen in the stream. In 1925 there was a fair run, better than it had been for several years.

Absent access to the upstream watershed for spawning and faced with the increases in upstream water storage and downstream diversions over time, the salmon gradually declined, until the complete seasonal discontinuation of flows occurred in 1945, when Friant Dam was completed and first operated. By the early 1940’s, despite efforts to screen the canal intakes at Mendota (Van Cleve, 1946), the fall run had disappeared completely, above the mouth of the Merced River, except in extremely wet (i.e., flood) years, when occasional individuals were encountered above the Mendota Pool area. The development of Friant Dam by the U.S. Department of the Interior, doubled the quantity of upstream storage, and significantly increased the quantities of water diverted for out-of-stream purposes. This proverbial “last straw” resulted in the elimination of even the hatchery supplemented runs of spring-run salmon from the reaches of San Joaquin River above the mouth of the Merced River.

> “Studies of Young Salmon: Fyke netting studies of downstream migrants have included studies of the time of migration in the Feather, American, Consumnes, Mokelumne and San Joaquin Rivers, and studies if the damage done by various large unscreened and inadequately screened irrigation diversions. The diversions are all taking salmon, but the ones in the Mendota area are the worst…” (Van Cleve 1946, p.32.)
>
> “… The migration of young salmon down the San Joaquin was heavy from January 27th [1944] through March, and reached its peak on February 24th. The canals diverting water at Mendota did no appreciable damage until February 11th, but from that time on the loss of young salmon was heavy. On February 18th one fyke [DFG sampling] net took 3,000 young salmon from one canal.” (Van Cleve. 1944, p39.).
>
> “San Joaquin River: Only the spring run was counted in the San Joaquin River. A small fall run manages to get through in years when there is water in the river in the area between Dos Palos and Gustine… The poor run in 1944 was due to a heavy kill of fish which took place in Merced County. At this time, the river was reduced to a string of nearly isolated pools for many miles below Dos Palos, resulting from a combination of factors: a light snow pack and impoundment of water to fill Friant Dam plus normal irrigation demand. Water was finally gotten down the stream, but the flow was low enough that in many places the fish had to swim through water less than two feet deep, making them easy prey for spears. Spearing was legal, and as many as 200 spearers were counted at a single sand bar….” (Van Cleve 1946, P. 29)
>
> “… During the biennium, the salmon runs were satisfactory in all the major spawning streams of the Central Valley, except the Mokelumne and San Joaquin Rivers…. The situation on the San Joaquin River could not be worse than it is. Inadequate water releases from Friant Dam have resulted in near extinction of the salmon run. The winter of 1946-47 was relatively dry, and the U.S. Bureau of Reclamation felt that it could allot no more than 15,000 acre-feet of water for the spring run. This water was released in such manner as to be of maximum benefit, but was still so inadequate as to be disastrous. Flows of 100 to 130 second-feet are inadequate during the hot weather. Only 6,000 salmon were counted past Mendota Dam in 1947, compared to 56,000 in 1945 and 30,000 in 1946.
>
> The winter of 1947-48 started as one of the driest on record. The U.S. Bureau of Reclamation announced that no water whatsoever could be spared for salmon; and in spite of all our efforts, as well as those of sportsmen’s groups, the fishing industry, and congressmen to obtain water, the river below Dos Palos remained dry during the time of the 1948 run. As the only recourse available, the Bureau of Marine fisheries operated a salvage plan which called for construction of a fish trap, hauling the salmon overland and releasing them in an canal whence they could make their way to the spawning areas. Tank trucks were furnished by the Bureau of Reclamation. The trap was located at the mouth of the Merced River. The only fish to reach the spawning beds in the San Joaquin were the 1,955 that were transported by truck. Heavy rains in April and May caused the Merced River to flood, and on May 28 the trap was lifted to allow all the fish to ascend the stream. Previously, 163 salmon had been trucked up the Merced, as these floods were not anticipated. No water was released in the San Joaquin, and those fish that did not ascend the Merced were lost in the warm backwaters of the San Joaquin. At the same time, most of the young downstream migrants also perished for want of water. “(Croker, 1948, p. 123)

Today, salmon in the San Joaquin River occur only in the wettest of years and are strays from other rivers, most likely the Merced River.

Conclusion

Salmon in the San Joaquin River basin have declined substantially over the past several decades. Concurrent with this population decline has been the reduction of stream flows in the mainstem San Joaquin, Stanislaus, Tuolumne, and Merced Rivers. Concurrent with reduction in streams flows, especially during the spring time period, has been the increase of water temperatures to levels that have been identified in the literature as being too warm for successful smolt outmigration. Both reservoir storage volume and reservoir release volume level into the river, have the ability to delay the meteorological induced warming that occurs as water flows downstream.

For steelhead, due to their diverse life history and the lack of a specific population monitoring program in the San Joaquin River basin, little is known (e.g. empirically speaking) regarding abundance trends over time. Migrating adult steelhead have been documented at the Stanislaus fish counting weir, and out going juveniles have been observed at the Caswell rotary screw traps. Out-migrating rainbow trout have been observed in each of the Stanislaus, Tuolumne, and Merced Rivers as well as the San Joaquin River at Mossdale. Anecdotal reports from anglers and guides that have fished the Stanislaus, Tuolumne, and Merced Rivers suggest that steelhead abundance trends are the same as that for salmon in that abundance levels, as defined by catch rates, improve after higher instream flow conditions occur.

As the water development pendulum swung in the direction of increased dams and water diversions in the San Joaquin River basin, a failure to provide adequate supplies of water for protection of the salmon and steelhead beneficial uses in the San Joaquin River basin occurred as noted by i) the elimination of salmon and steelhead from the mainstem San Joaquin River and ii) the substantial declines of these species in the Stanislaus, Tuolumne, and Merced Rivers concurrent with water development. By default (e.g. reference to declining population trends and linkage to instream flow conditions), the present level of instream flows are inadequate to protect the salmon and steelhead beneficial uses of the Stanislaus, Tuolumne, and Merced Rivers.

On-going studies suggest that there is sufficient non-flow habitat (e.g. spawning habitat) remaining the Stanislaus, Tuolumne, and Merced Rivers to provide for a substantially greater population of salmon and steelhead than exists today if sufficient instream flows are provided during key life history stage development time periods. When instream flow levels are increased during the spring there is an improvement in habitat quality, as measured by decreased water temperatures, that can extend to the confluence in each of the Stanislaus, Tuolumne, and Merced Rivers. The extent of flow related water temperature cooling is dependent upon reservoir storage volume and reservoir release level. This reduction in spring water temperature in the Stanislaus, Tuolumne, and Merced Rivers can influence reduced water temperatures in the San Joaquin River at Vernalis pending ratio of tributary to mainstem San Joaquin River flow.

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Appendix 7

The Moderate to High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases

(Dr. Carl Mesick)

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The Moderate to High Risk of Extinction for the Natural Fall-Run Chinook Salmon Population in the Lower Tuolumne River due to Insufficient Instream Flow Releases

Carl Mesick, Ph.D.
Stockton Fishery Resource Office
US Fish and Wildlife Service
14 August 2008

The following preliminary analysis indicates that the Tuolumne River fall-run Chinook salmon (*Oncorhynchus tshawytscha)* population of naturally produced fish is at a moderate to high risk of extinction because the instream flow releases are too low. Lindley and others (2007) have characterized the risk of extinction for Chinook salmon populations in the Sacramento-San Joaquin Basin relative to population size, rates of population decline, catastrophes, and hatchery influence. Populations with a high risk of extinction (greater than 20 percent chance of extinction within 20 years) have a total escapement that is less than 250 spawners in three consecutive years (mean of 83 fish per year), a precipitous decline in escapement, a catastrophe defined as an order of magnitude decline within one generation occurring within the last 10 years, and a high hatchery influence. Populations with a low risk of extinction (less than 5 percent chance of extinction in 100 years) have a minimum total escapement of 2,500 spawners in three consecutive years (mean of 833 fish per year), no apparent decline in escapement, no catastrophic declines occurring within the last 10 years, and a low hatchery influence. Populations with a moderate risk of extinction are those at intermediate levels to the low and high risk criteria (e.g., total escapement in three consecutive years between 250 and 2,500 spawners.

The Tuolumne River fall-run Chinook salmon population is at a moderate to high risk of extinction based on the criteria by Lindley and others (2007) because the total escapement of naturally produced fish was about 755 spawners from 2005 to 2007 (i.e., moderate risk), there was a precipitous decline in escapement (i.e., high risk), and there was a catastrophic decline in escapement over a generation between 2000-2002 and 2003-2005 (i.e., high risk).

Population Size

The effective population size criteria relates to the loss of genetic diversity (Lindley et al. 2007). The effective population consists of individuals that are reproductively successful. In Chinook salmon populations, not all individuals are reproductively successful and the mean ratio of the effective population size to total escapement over a three year period (N_e/N) has been estimated to be 0.20 based on spawner-recruit evaluations of over 100 salmon populations from California to British Columbia (Waples et al. 2004 as cited in Lindley et al. 2007). A few examples of why adult salmon may not reproduce successfully in the Tuolumne River include: (1) fish that return as two-year-old males; (2) redd superimposition that destroys eggs; (3) spawning in habitats with excessive levels of fines; and (4) low survival rates for juveniles that migrate late when high water temperatures in the lower Tuolumne River are unsuitable for survival.

Therefore based on population size, the Tuolumne River could be considered to be at high risk if annual escapement (N) drops below a mean of 83 fish for three consecutive years and at low risk if escapement remains above a mean of 833 fish for three consecutive years.

The analyses reported here are based on preliminary estimates of the number of naturally produced and hatchery produced adult fall-run Chinook salmon that have returned to the Tuolumne River between 1981 and 2005 (Table 1). The estimates of hatchery produced fish are based on expansions of the number of coded-wire-tagged (CWT) adults recovered during the Tuolumne River escapement surveys and estimates of the number of untagged hatchery fish from the Feather River, Nimbus, Mokelumne River, and Merced River hatcheries that returned to the Tuolumne River in the escapement (Appendix). The expansions of the CWT adult salmon were computed as the number of CWT salmon recovered during the escapement surveys, multiplied by the total escapement estimates, and divided by the number of salmon examined for tags during each escapement survey. The CWT fish were identified during the escapement surveys by the presence of an adipose fin clip. The numbers of fish examined for tags during each year, which usually included the fresh and decayed but not skeleton carcasses, were provided by Steve Khirihara, a Turlock Irrigation District biologist who participated in many of the surveys.

The estimates of the number of unmarked hatchery fish that returned to the Tuolumne River as adult salmon were based on the assumption that the unmarked hatchery fish would have returned to the Tuolumne River at the same rates that the marked hatchery fish returned to the Tuolumne River. The number of unmarked fish released from each hatchery was obtained from the CDFG annual reports for the Feather River, Nimbus, Mokelumne River, and Merced River hatcheries. Some of the Merced hatchery release data was obtained from planting release records. The CWT recoveries indicate that almost all of the adult hatchery fish in the Tuolumne River originated from Bay releases from the Nimbus and Feather River hatcheries, Delta and Bay releases from the Mokelumne Hatchery, and Tuolumne and Merced river releases from the Merced River Hatchery. Correlation analyses indicated that there were no statistically significant correlations between water year type or ocean conditions and the rate that juvenile hatchery fish returned to the Tuolumne River. Therefore, CWT return estimates for the Tuolumne River were used to estimate the number of unmarked returns for those same years; whereas the mean rates of CWT returns to the Tuolumne River were used to estimate the number of unmarked returns for all the other years in the study period (Appendix). The number of unmarked juveniles from each hatchery was multiplied by the corresponding CWT recovery rate and then the number of returns was segregated into cohorts based on the mean percentage of each age class in the Tuolumne River escapement based on scale analysis described in Mesick et al. 2007: 31.2% for Age 2, 50.7% for Age 3, and 17.2% for Age 4.

The estimates of natural and hatchery reared Chinook salmon in the Tuolumne River are presented in Table 1. They are preliminary for two reasons. First, the CWT recovery data for fall 2006 and 2007 have not yet been fully evaluated. Second, the estimates estimated CWT return rate for Merced River Hatchery releases to the Tuolumne River do not include all CWT releases for which there were no adult returns to Central Valley rivers. As a result, it is likely that the estimates of unmarked Merced River Hatchery fish that returned to the Tuolumne River are overestimated to a small degree. Future analyses will include all CWT releases from the Merced River.

The results of these analyses suggest that since the license was amended in 1996 to improve minimum instream flows, there was a total of about 755 naturally produced adult Chinook salmon from 2005 to 2007 (Table 1). The estimate of naturally produced for fall 2005 was 177 fish. In fall 2006 and fall 2007, the percentages of tagged hatchery fish were unusually low in the Tuolumne River. Only one of the 91 fresh and decayed adult carcasses collected had an adipose fin clip (evidence of a CWT) in fall 2006 and none of the 35 fresh and decayed adult carcasses collected had an adipose fin clip in fall 2007. A total escapement of 755 naturally produced Chinook salmon over three years suggests that the Tuolumne River population is at a moderate risk of extinction according to the recommended criteria by Lindley and others (2007).

Population Decline

Another serious threat to the viability of natural salmonid populations identified by Lindley and others (2007) is a precipitous decline in escapement, which has occurred on the Tuolumne River. Table 1 indicates that the escapement of natural spawners in the Tuolumne River has declined from about 16,000 adults in fall 2000 to 177 adults in fall 2005.

Another analysis indicates that the abundance of natural Tuolumne River recruits at a given flow declined by about 50% at a statistically significant level between the 1980 to 1995 pre-Settlement Agreement period and the 1996 to 2004 post-Settlement Agreement period (Figure 1). Adult recruits are adult salmon that all belong to the same cohort and were either harvested in the ocean or returned to spawn in the escapement. Approximately 40% of the adult recruits have been harvested in the ocean between 2000 and 2006. The number of recruits is estimated by first segregating the escapement estimates of naturally produced adult salmon (Table 1) into cohorts using an age analysis of fall-run Chinook salmon scales collected from the Tuolumne River between 1981 and 2002 that was conducted by CDFG (Mesick, Marston, and Heyne 2007). The abundance of recruits is then expanded by an index of the percentage of fish harvested in the ocean (Central Valley Index, Pacific Fisheries Management Council 2006). These methods are described in greater detail in Mesick and Marston (2007) and Mesick, Marston, and Heyne (2007). The statistical test of significance was a Permutation Test conducted by Dr. Allan Hubbard[1]. He used this test because it avoids the potential problem of autocorrelation in population trend analyses that would violate an assumption of correlation analyses. Dr. Hubbard's analysis indicates that the intercepts of the regressions between the two data sets shown in Figure 3 are significantly different (P = 0.01). These results provide evidence that the Tuolumne River natural salmon population has declined precipitously and would be considered to be at a high risk of extinction according to the recommended criteria by Lindley and others (2007).

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The studies conducted by the Turlock Irrigation District and the Modesto Irrigation District to date are inadequate to explain the cause of the population's decline (*see* Analyses & Recommended Studies for Fall-run Chinook Salmon and Rainbow Trout in the Tuolumne River, FERC e-Library no. 20070314-0089).

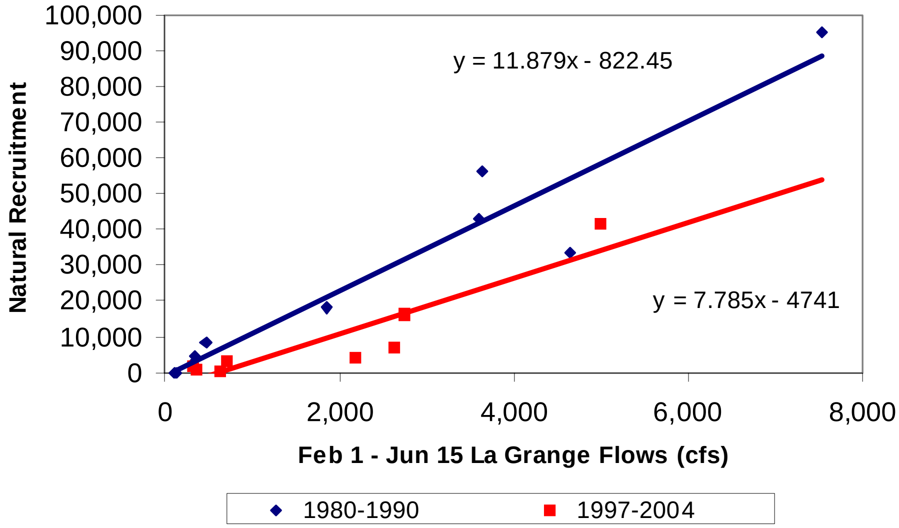

Figure 1. Tuolumne River natural fall-run Chinook salmon recruitment plotted with mean flow in the San Joaquin River at Vernalis during February 1 through June 15 during two periods: 1980 to 1990 (pre-FSA) and from 1997 to 2004 (post-FSA). Recruitment is the number of adults in the escapement and ocean harvest (including shaker mortality) that belong to individual cohorts of same-aged fish (Mesick et al. 2007). Estimates were excluded for which spawner abundance was less than 650 Age 3 equivalent fish to minimize the effect of spawner abundance on the relationship between flow and recruitment.

Catastrophe

Catastrophes are defined by Lindley and others (2007) as instantaneous declines in population size due to events that occur randomly in time that reflect a sudden shift from a low risk state to a higher one. They view catastrophes as singular events with an identifiable cause and only negative immediate consequences, as opposed to normal environmental variation which can produce very good as well as very bad conditions. Some examples of catastrophes include disease outbreaks, toxic spills, or volcanic eruptions. A high risk situation is created by a 90% decline in population size over one generation. Such a decline occurred in the Tuolumne River when the 2000-2002 generation declined from a total of 27,629 fish to a total 2,873 fish for the 2003-2005 generation.

Hatchery Influence

There are no data to directly assess the genetic impacts of adult hatchery fish on the naturally produced Chinook salmon population in the Tuolumne River. If there are impacts from the Feather River, Nimbus, and Mokelumne River hatchery releases, then the average annual escapement needed to maintain a low risk of extinction would be substantially greater than 833 fish.

Minimum Flow Releases

The number of naturally produced adult salmon that return to the Tuolumne River is primarily a response of the juvenile salmon to the flows released at La Grange Dam during the winter and spring (Figure 2; Analyses & Recommended Studies for Fall-run Chinook Salmon and Rainbow Trout in the Tuolumne River, FERC e-Library no. 20070314-0089). The assessment of the relationship between flows and adult salmon production utilizes estimates of adult recruitment. Assuming that ocean harvest rates continue to be about 40 percent (mean 2000 to 2006), a recruitment of 1,388 fish would result in an escapement of 833 fish. The quadratic relationship between the average flows from February 1 through June 15 and Tuolumne River adult recruitment (Figure 2) suggests that when the average winter and spring flows is less than 1,100 cfs, the average adult recruitment of naturally produced salmon is less than 1,388 fish.

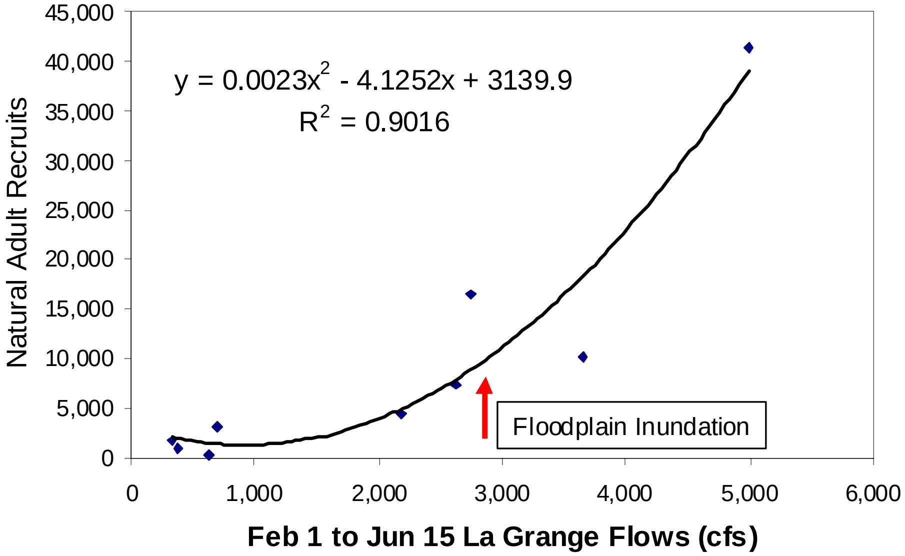

Figure 2. The number of natural adult recruits relative to the average flow release from La Grange Dam from February 1 through June 15 when the cohorts migrated as juveniles toward the ocean from 1996 to 2004. The quadratic equation and the R^2 value computed by Excel are presented for the relationship.

There is uncertainty regarding the precise duration and timing of the spring pulse flows needed to produce 1,388 adult Tuolumne River recruits. The correlations between flow releases and salmon recruitment are probably highest for the February 1 through June 15 period because extended floodplain inundation that occurs during wet years produces good conditions for both rearing and migrating juveniles. The exponential increase in recruitment as flows increase above 3,000 cfs (Figure 2) probably reflects the level where flows result in floodplain inundation throughout most of the river. However, under typical dry and normal water year conditions, it is likely that flows less than 3,000 cfs are primarily affect the survival of outmigrating subyearling smolts in April and May. Therefore, it is likely that the 1,100 cfs pulse flows would have to occur when most of the smolt-sized fish are migrating and conditions are suitable for their survival in the Delta. Studies will be needed to determine the precise timing and duration of these pulse flows (*see* Analyses & Recommended Studies for Fall-run Chinook Salmon and Rainbow Trout in the Tuolumne River, FERC e-Library no. 20070314-0089). In addition to spring pulse flows, it would be necessary to provide fall pulse flows to minimize the straying of adults to the Sacramento Basin and suitable year-round base flows for spawning, egg incubation, and rearing. A minimum flow schedule that should be able to sustain both naturally producing Chinook salmon and *O. mykiss* (steelhead and rainbow trout) populations includes the following three elements:

- Pulse flows of 1,100 cfs for 45 days during April and May to provide suitable conditions for migrating juvenile salmon and Central Valley steelhead.
- Fall pulse flows of 1,500 cfs for 10 days during mid-October to attract adult Chinook salmon to the Tuolumne River and minimize straying (Mesick 2001).
- Year round base flows of 235 cfs to provide suitable water temperatures throughout the summer in 12.4 miles of habitat for *O. mykiss* (unpublished results of real-time temperature management by Turlock Irrigation District and Modesto Irrigation District in 2002 and 2003) and suitable spawning and rearing conditions for fall-run Chinook salmon.

The total volume of water required for this flow schedule is 272,365 acre-feet (AF). In comparison, the volume of flow releases required in the Tuolumne River in the 1996 FERC order range from 94,000 AF in Critical and Below Normal Water Year Types to 165,002 AF in Median Below Normal water year types (Turlock Irrigation District and Modesto Irrigation District 2005). These relatively dry water year types cumulatively occur 50.7% of the time (Turlock Irrigation District and Modesto Irrigation District 2005). During the wetter water year types (49.3% of the time), the required flow release is 300,923 AF (Turlock Irrigation District and Modesto Irrigation District 2005).

Table 1. The Department of Fish and Game estimated escapement of fall-run Chinook Salmon in the Tuolumne River (GrandTab), the estimated total number of marked (coded-wire tag and adipose clipped) hatchery adults that returned to the Tuolumne River, the preliminary estimates of the number of unmarked hatchery adults from the Mokelumne, Nimbus, Feather, and Merced river hatcheries that returned to the Tuolumne River, the preliminary estimates of escapement of naturally produced adults, the preliminary estimates of escapement of hatchery produced adults, and the percent hatchery fish in the escapement from 1981 to 2005. The estimates of unmarked adults are based on bay releases from the Nimbus and Feather River hatchery, Delta and Bay releases from the Mokelumne Hatchery, and Merced River releases from the Merced River Hatchery. The estimates of natural escapement were truncated at zero. The estimate of natural escapement for fall 2006 is based on the ratio of marked hatchery recoveries with unmarked hatchery adults for fall 2005. The estimate of natural escapement for fall 2007 assumes that the percentage of hatchery fish observed in the escapement in fall 2006 (6%) would be the same for fall 2007.

			Unmarked Hatchery Adults						
	Total Escapement	Marked Hatchery Adults	Mokelumne Hatchery	Nimbus Hatchery	Feather River Hatchery	Merced River Hatchery	Estimated Natural Escapement	Estimated Hatchery Escapement	Percent Hatchery
1981	14,253	0	48	1	2	10	14,192	61	0.4%
1982	7,126	30	87	17	697	0	6,295	831	11.7%
1983	14,836	433	91	35	1,107	0	13,170	1,666	11.2%
1984	13,689	31	80	24	375	0	13,180	509	3.7%
1985	40,322	208	62	5	0	5	40,042	280	0.7%
1986	7,404	153	34	12	0	7	7,198	206	2.8%
1987	14,751	1,619	31	51	0	41	13,009	1,742	11.8%
1988	5,779	277	33	56	0	78	5,336	443	7.7%
1989	1,275	175	38	17	0	47	998	277	21.7%
1990	96	98	34	32	0	20	0	184	100.0%
1991	77	20	30	51	0	18	0	119	100.0%

			Unmarked Hatchery Adults						
	Total Escapement	Marked Hatchery Adults	Mokelumne Hatchery	Nimbus Hatchery	Feather River Hatchery	Merced River Hatchery	Estimated Natural Escapement	Estimated Hatchery Escapement	Percent Hatchery
1992	132	23	47	26	0	13	23	109	82.7%
1993	471	115	60	26	0	10	260	211	44.8%
1994	506	107	72	30	0	4	293	213	42.2%
1995	827	142	79	29	35	0	542	285	34.5%
1996	4,362	1,046	58	35	56	390	2,777	1,585	36.3%
1997	7,146	1,321	15	37	19	622	5,133	2,013	28.2%
1998	8,910	1,413	0	35	0	211	7,251	1,659	18.6%
1999	8,232	1,043	61	34	0	97	6,996	1,236	15.0%
2000	17,873	1,053	115	36	0	159	16,510	1,363	7.6%
2001	8,782	1,561	190	37	0	64	6,930	1,852	21.1%
2002	7,173	2,650	241	24	55	14	4,189	2,984	41.6%
2003	2,163	497	159	19	97	9	1,382	781	36.1%
2004	1,984	473	109	32	52	4	1,314	670	33.7%
2005	500	55	211	38	17	3	177	323	64.6%
2006	500	5	?	?	?	?	~470	~30	6%
2007	115	0	?	?	?	?	~108	~7	6%

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APPENDIX

Table A-1. The estimated mean number and standard deviation of coded-wire-tagged Feather River hatchery fish that were released into the San Francisco Bay and returned to the Tuolumne River as adults from 1978 to 2004 and the estimated number of unmarked Feather River hatchery fish released into the San Francisco Bay that returned to the Tuolumne River as adult fish from 1981 to 2005.

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement
1978	3	553,272	0.00098%	0.00170%	1	150,500	0.00098%	1	
1979	7	465,984	0.00000%	0.00000%	2	47,990	0.00000%	0	
1980	4	596,425	0.01376%	0.02751%	1	42,000	0.01376%	6	
1981	5	294,315	0.06263%	0.09208%	6	3,482,541	0.06263%	2,181	2
1982	3	134,094	0.00000%	0.00000%	8	3,154,575	0.00000%	0	697
1983	4	314,778	0.00000%	0.00000%	10	4,178,900	0.00000%	0	1,107
1984	3	249,720	0.00000%	0.00000%	8	2,642,625	0.00000%	0	375
1985	6	476,191	0.00000%	0.00000%	12	8,660,907	0.00000%	0	0
1986	3	216,714	0.00000%	0.00000%	10	6,063,425	0.00000%	0	0
1987	2	6,096	0.00000%	0.00000%	6	8,903,925	0.00000%	0	0
1988	1	11,980	0.00000%		9	8,181,520	0.00000%	0	0
1989	2	5,127	0.00000%	0.00000%	7	4,597,200	0.00000%	0	0
1990	0	0			5	7,509,700	0.00000%	0	0
1991	0	0			4	2,742,010	0.00000%	0	0
1992	0	0			14	10,444,395	0.00000%	0	0

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement
1993	4	256,071	0.00000%	0.00000%	10	12,162,348	0.00000%	0	0
1994	10	769,988	0.00097%	0.00206%	10	11,479,229	0.00097%	111	0
1995	9	354,255	0.00000%	0.00000%	15	9,163,717	0.00000%	0	35
1996	6	166,670	0.00000%	0.00000%	26	6,141,173	0.00000%	0	56
1997	5	234,296	0.00000%	0.00000%	37	7,139,270	0.00000%	0	19
1998	2	100,089	0.00000%	0.00000%		0		0	0
1999	10	966,808	0.00000%	0.00000%	4	5,725,535	0.00000%	0	0
2000	6	1,245,779	0.00000%	0.00000%	7	5,619,140	0.00000%	0	0
2001	13	841,561	0.00599%	0.00912%	7	2,870,360	0.00599%	172	0
2002	7	228,651	0.00061%	0.00111%	6	4,879,388	0.00061%	30	55
2003	6	737,027	0.00045%	0.00110%	8	5,084,160	0.00045%	23	97
2004	4	501,569	0.00000%	0.00000%	4	7,258,588	0.00000%	0	52
2005									17
OVERALL	125	9,727,460	0.00373%	0.02132%					

Table A-2. The estimated mean number and standard deviation of coded-wire-tagged Nimbus hatchery fish (American River) that were released into the San Francisco Bay that returned to the Tuolumne River as adults from 1978 to 2004 and the estimated number of unmarked Nimbus hatchery fish released into the San Francisco Bay that returned to the Tuolumne River as adult fish from 1981 to 2005. Estimates of CWT Return Rates for years with fewer than a total of 95,000 juveniles released were not used to estimate the number of unmarked fish that returned to the Tuolumne River.

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Fish Released	Expansion Rate	Total Estimated Adult Returns by Cohort	Total Estimated Returns in Escapement
1978									
1979									
1980					1	270,281	0.00085%	2	
1981					6	5,826,177	0.00085%	50	1
1982					3	3,515,570	0.00085%	30	17
1983	2	94,670	0.00000%	0.00000%	12	7,615,375	0.00000%	0	35
1984	3	148,304	0.00000%	0.00000%	3	1,093,250	0.00000%	0	24
1985	2	49,379	0.00000%	0.00000%	6	4,551,700	0.00085%	39	5
1986	2	101,992	0.00192%	0.00272%	4	5,065,810	0.00192%	97	12
1987	2	98,407	0.00000%	0.00000%	5	4,280,125	0.00000%	0	51
1988	3	126,498	0.00000%	0.00000%	5	4,339,300	0.00000%	0	56
1989	4	188,580	0.00226%	0.00453%	2	4,419,387	0.00226%	100	17
1990	4	185,466	0.00000%	0.00000%	4	4,430,800	0.00000%	0	32
1991					5	3,163,020	0.00085%	27	51
1992					3	4,399,150	0.00085%	38	26

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Fish Released	Expansion Rate	Total Estimated Adult Returns by Cohort	Total Estimated Returns in Escapement
1993					6	2,406,980	0.00085%	21	26
1994					5	4,396,400	0.00085%	38	30
1995					7	4,424,420	0.00085%	38	29
1996					7	4,030,450	0.00085%	34	35
1997					5	4,054,800	0.00085%	35	37
1998					9	4,010,784	0.00085%	34	35
1999	1	44,375	0.00000%		9	4,729,208	0.00085%	40	34
2000					5	3,851,700	0.00085%	33	36
2001	6	591,908	0.00194%	0.00212%	1	142,200	0.00194%	3	37
2002	3	713,619	0.00093%	0.00083%	6	4,162,066	0.00093%	39	24
2003					4	4,361,300	0.00085%	37	19
2004					1	4,693,466	0.00085%	40	32
2005					1	4,570,000	0.00085%	39	38
Overall	32	2,343,198	0.00085%	0.00199%	125	102,803,719			

Table A-3. The estimated mean number and standard deviation of coded-wire-tagged Mokelumne River hatchery fish that were released into the San Francisco Bay that returned to the Tuolumne River as adults from 1978 to 2004 and the estimated number of unmarked Mokelumne River hatchery fish released into the San Francisco Bay that returned to the Tuolumne River as adult fish from 1981 to 2005. Estimates of CWT Return Rates for years with fewer than a total of 95,000 juveniles released were not used to compute the mean return rate or to estimate the number of unmarked fish that returned to the Tuolumne River.

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement (Delta and Bay Combined)
1978	1	43,370	0.00000%		2	102,076	0.01179%	12	12
1979	1	39,137	0.00000%		4	268,367	0.01179%	32	32
1980	1	30,000	0.00000%		7	801,950	0.01179%	95	95
1981	1	47,247	0.00000%		5	907,848	0.01179%	107	107
1982					5	556,145	0.01179%	66	66
1983					4	757,640	0.01179%	89	89
1984					1	15,250	0.01179%	2	17
1985					1	27,300	0.01179%	3	31
1986						0			38
1987						0			26
1988					2	37,250	0.01179%	4	58
1989						0			0
1990						0			64

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement (Delta and Bay Combined)
1991						0			46
1992	1	100,508	0.00000%		3	513,990	0.00000%	0	81
1993					3	26,288	0.01179%	3	73
1994	4	206,302	0.01161%	0.01352%	1	514,350	0.01161%	60	89
1995	5	249,095	0.00166%	0.00371%		0			0
1996	6	309,877	0.00623%	0.00984%		0			0
1997	7	365,102	0.00000%			0			0
1998	2	103,354	0.00000%		1	105,450	0.00000%	0	193
1999	7	227,368	0.01278%	0.01353%	7	424,088	0.01278%	54	54
2000	2	101,612	0.03542%	0.00592%	2	156,671	0.03542%	55	407
2001	8	255,269	0.01225%	0.01973%	1	103,073	0.01225%	13	81
2002	9	255,337	0.03709%	0.02485%	2	205,828	0.03709%	76	153
2003					1	575	0.01179%	0	55
2004					5	3,716,357	0.01179%	438	492
2005									
Cumulative	58	2,418,464	0.01179%	0.01865%	57	9,240,496			

Table A-4. The estimated mean number and standard deviation of coded-wire-tagged Mokelumne River hatchery fish that were released into the San Joaquin Delta that returned to the Tuolumne River as adults from 1978 to 2004 and the estimated number of unmarked Mokelumne River hatchery fish released into the San Joaquin Delta that returned to the Tuolumne River as adult fish from 1981 to 2005.

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement (Delta and Bay Combined)
1978						0			12
1979						0			32
1980	1	29,503	0.00000%			0			95
1981	1	32,000	0.00000%			0			107
1982	1	47,199	0.00000%			0			66
1983	1	47,755	0.00000%			0			89
1984					13	639,065	0.00233%	15	17
1985	3	69,285	0.00000%	0.00000%	23	1,192,630	0.00233%	28	31
1986					8	1,624,600	0.00233%	38	38
1987	4	190,688	0.00110%	0.00219%	8	2,341,335	0.00110%	26	26
1988					5	2,302,900	0.00233%	54	58
1989	2	98,257	0.00000%	0.00000%	7	3,481,120	0.00000%	0	0
1990					5	2,766,425	0.00233%	64	64
1991	2	21,246	0.00000%	0.00000%	3	1,983,400	0.00233%	46	46

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement (Delta and Bay Combined)
1992	3	24,219	0.00000%	0.00000%	5	3,476,310	0.00233%	81	81
1993					3	3,011,600	0.00233%	70	73
1994					2	1,244,370	0.00233%	29	89
1995	3	148,724	0.00232%	0.00402%			0.00232%	0	0
1996	2	105,312	0.00000%	0.00000%	2	1,834,194	0.00000%	0	0
1997	2	102,552	0.00000%	0.00000%	5	1,947,000	0.00000%	0	0
1998	2	102,486	0.01613%	0.00008%	3	1,195,300	0.01613%	193	193
1999	1	95,203	0.00000%		3	1,476,207	0.00000%	0	54
2000	2	103,154	0.01550%	0.00008%	5	2,265,775	0.01550%	351	407
2001	2	51,259	0.00000%	0.00000%	3	2,914,172	0.00233%	68	81
2002					3	3,280,879	0.00233%	76	153
2003					3	2,368,425	0.00233%	55	55
2004					5	2,323,900	0.00233%	54	492
2005									
Cumulative	32	1,268,842	0.00233%	0.00537%	114	43,669,607			

Table A-5. The estimated mean number and standard deviation of coded-wire-tagged Merced River hatchery fish that were released into the Merced River that returned to the Tuolumne River as adults from 1978 to 2004 and the estimated number of unmarked Merced River hatchery fish released into the Merced River that returned to the Tuolumne River as adult fish from 1981 to 2005. Estimates of CWT Return Rates for years with fewer than a total of 95,000 juveniles released were not used to estimate the number of unmarked fish that returned to the Tuolumne River. These estimated CWT return rates do not include all CWT releases for which there were no adult returns to Central Valley rivers. As a result, it is likely that the estimates of unmarked Merced River Hatchery fish that returned to the Tuolumne River are overestimated to a small degree.

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement
1978	1	49,498	0.00000%		2	295,000	0.01970%	58	
1979	1	16,059	0.00000%		0	0			
1980					0	0			
1981	1	40,760	0.00000%		0	0			10
1982	3	96,825	0.00000%	0.00000%	0	0			0
1983	1	41,143	0.00000%		0	0			0
1984	1	49,649	0.00000%		1	73,600	0.01970%	14	0
1985	1	35,535	0.00000%		0	0			5
1986					9	616,728	0.01970%	121	7
1987					1	254,842	0.01970%	50	41
1988					2	4,200	0.01970%	1	78
1989	2	50,633	0.00000%	0.00000%	5	179,182	0.01970%	35	47
1990					0	0			20
1991	3	88,959	0.00000%	0.00000%	6	104,822	0.01970%	21	18

	CWTs in Tuolumne River Escapement				Unmarked Hatchery Releases in the Bay				
Release Year	Number of Tags	Number of Tagged Fish Released	Mean Return Rate	Standard Deviation of Return Rate	Number of Releases	Number of Unmarked Releases	Expansion Rate	Total Estimated Returns by Cohort	Total Estimated Returns in Escapement
1992	1	22,815	0.02738%		0	0			13
1993	6	98,931	0.04678%	0.09569%	0	0			10
1994	13	310,774	0.01508%	0.02228%	0	0			4
1995	7	194,301	0.15950%	0.08122%	7	769,130	0.15950%	1,227	0
1996	4	86,959	0.00000%	0.00000%	0	0			390
1997	11	282,239	0.00000%	0.00000%	0	0			622
1998	12	353,354	0.05823%	0.06091%	19	523,408	0.05823%	305	211
1999	12	293,681	0.01452%	0.02956%	25	91,229	0.01452%	13	97
2000	14	354,553	0.00793%	0.01338%	24	195,058	0.00793%	15	159
2001	14	341,159	0.00443%	0.01283%	50	274,332	0.00443%	12	64
2002	7	164,944	0.00000%	0.00000%	44	473,959	0.00000%	0	14
2003	19	445,783	0.00168%	0.00503%	33	301,246	0.00168%	5	9
2004	3	97,531	0.00000%	0.00000%	23	320,962	0.00000%	0	4
2005									3
OVERALL	137	3516085	0.01970%	0.04948%	251	4,477,698			

Appendix 8

Computational Detail for CDFG SJR Salmon Model Version 1.0

Existing SJR Salmon Model Inputs & Formulae

Model Inputs *(unless modified by user…default settings are used)*

1. **Regression Coefficients**
    a. Mossdale Smolt Abundance[1]
    Includes prior year escapement (x1) and present year average daily flow at Vernalis Flow (x2) slope, and y-intercept terms
    b. Delta Survival[2]
        1. HORB-In
        Includes Flow Level slope and y-intercept terms
        2. HORB-Out
        Includes Flow Level slope and y-intercept terms
    c. Adult Cohort Production (called "Escapement " in existing model)
    Returning adults and slope[3] (x1) and y-intercept terms
2. **Adult Salmon Age at Return** (escapement)[4]
    a. Age 1 (%)
    b. Age 2 (%)
    c. Age 3 (%)
    d. Age 4 (%)
    e. Age 5 (%)
3. **HORB Status**
Binary code (e.g. 1 = No; 0 = Yes) used as toggle switch to enable model to determine which Delta survival regression to use (e.g. HORB-In or HORB-Out)
4. **HORB Years**
Binary code (e.g. 1 = No; 0 = Yes) set for each year to determine which year(s) HORB-In is used

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[1] Regression coefficients established from multiple regression relationship between previous year escapement (Stanislaus, Tuolumne, and Merced annual escapements combined) and current year Vernalis daily average spring (March 15th thru June 15th) flow level and annual Mossdale smolt abundance for years 1987 thru 2003. Formula is: Annual Mossdale Smolts AbundanceY = Fall Spawners*Coefficient + Spring Flow*Coefficient + y-intercept. Regression coefficients used in the model are: Escapement_{X1} = 1.5E+01; Vernalis Flow_{X2} = 1.49E+02; y-intercept = 0 because y-intercept forced thru zero.

[2] Two regression equations are possible to describe survival of smolts passing thru the Delta: either Head of Old River Barrier-In, or out (e.g. HORB-In or HORB-Out). These relationships (e.g. HORB-In and HORB-Out) derived from South Delta juvenile smolt versus flow survival studies conducted from 1994 thru 2004. Formula is: Delta Survival = Flow*Coefficient + y-intercept. The HORB-In regression coefficients are: Flow_X = 2.87E-05 and y-intercept = 0 because y-intercept forced thru zero. The HORB-Out regression coefficients are: Flow_X = 1.80E-05 and y-intercept = 0 because y-intercept forced thru zero.

[3] Adult cohort regression coefficients were established by calculating the amount of smolts surviving daily from Mossdale to Chipps, summing the daily total to obtain a seasonal total. Then, the Chipps seasonal total was regressed against the adult brood year production total to estimate the ocean adult return rate. The formula is: Adult Cohort Return = Chipps Smolts*Coefficient + y-intercept. Regression coefficients used in the model are: Chipps SmoltsX = 5.00E-02 and y-intercept = 0 because y-intercept forced thru zero.

[4] Adult salmon age at return was derived from composite (e.g. multi-year) analysis of scales taken from adult salmon escaping into the Stanislaus, Tuolumne, and Merced Rivers. The specific age contribution rates used in the model are: Age 1 (1%), Age 2 (31%), Age 3 (45%), Age 4 (21%), and Age 5(2%). Thus, if 100 ocean returning adults were predicted to be produced by a single juvenile brood production year the adults were distributed as follows: Age 1 (1), Age 2 (31), Age 3 (45), Age 4 (21), and Age 5(2).

5. **HORB Dates**
   Binary code (e.g. 1 = No; 0 = Yes) set for each date to determine which date(s) HORB-In is used
6. **Flow Level** (cubic feet per second…set by water year type)
   a. Wet
   b. Above Normal
   c. Below Normal
   d. Dry
   e. Critically Dry
7. **Hatcheries**[5]
   a. Binary code (e.g. 1 = No; 0 = Yes) set for each water year type to determine which water year type(s) hatcheries are operated
8. **Flow by Year**
   a. Binary code (e.g. 1 = Yes; 0 = No) set for each year to determine which year(s) daily flow levels will be changed from historical
9. **Flow Window Duration**
   a. Binary code (e.g. 1 = Yes; 0 = No) set for each date to determine which date(s) daily flow levels will be changed from historical

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[5] Hatchery production was developed entirely from operational data collected from CDFG's Merced River Hatchery (MRH) (e.g., MRH escapement as a fraction of river escapement, female % of total MRH escapement, mean number of eggs per female, smolts produced per eggs taken, and percent of total release by week of release).

Model Formulae by Symbols

$$E_t= (BY_{t\text{-}1Age1}+BY_{t\text{-}2Age2}+BY_{t\text{-}3Age3}+BY_{t\text{-}4Age4}+BY_{t\text{-}5Age5})$$

$$BY=[[[[((E_t*E_x)+(Qt*Qx)+S_1)*WYSOEP_{di}]*((Fi*F_X)+F_b)]*CS_X+CS_b]+H]*(A_{1}\ldots A_5)$$

$$H = [[[[(((3.6973*(Escape_{py}\wedge 0.6561))*2500)*0.80)*Wk_{1\ \mathrm{thru}\ 8\%})]*[(0.0187*(VNS_q\wedge 0.4103))]] * ((Fi*F_X)+F_b)] *CS_X+CS_b]*(A_{1}\ldots A_5)$$

Model Formulae By Expression

Escapement Year "i" = Age 1 total from escapement year i-1 plus Age 2 total from escapement year i-2 plus Age 3 total from escapement year i-3 plus Age 4 total from escapement year i-4 plus Age 5 total from escapement year i-5

Brood Year = **[[[[**(Multiple Linear Regression between EscapementYr$_i$ & VernalisFlowYr$_{i+1}$)& Mossdale Smolt Production$_{i+1}$)*Percent Outmigration Exceedence$_{i+1}$**]***%Delta Migration Survival$_{i+1}$**]***%Chipps Island to Ocean Return$_{i+1}$**]**+Hatchery Contribution$_{i+1}$**]***%AgeCohort$_{1\ \mathrm{thru}\ 5}$

Hatchery = **[[[[**Prior Year Escapement * %Fraction of Merced Hatchery Escapement that escapes to the Merced River Hatchery)*%Females)*Eggs per female)*%Survival to Smolt Stage)*%Total Smolt Release by week**]***% Tributary Smolt Survival**]***%Delta Smolt Survival**]***%Ocean Return**]***%AgeCohort$_{1\ \mathrm{thru}\ 5}$

Formula Symbols Defined:

$A_{1\ldots}A_5$ = Adult Age Cohort return rates (e.g. A_1=Age 1, A_2=Age2, A_3=Age3. A_4= Age 4, and A_5 = Age 5)…refers to age adult salmon are expected to leave the ocean and return to spawn

BY = Brood Year

$BY_{t\text{-}1Age1}$ = Age 1 adult salmon produced in escapement year t-1 (e.g. the brood year prior to the current escapement year

$BY_{t\text{-}2Age2}$ = Age 2 adult salmon produced in escapement year t-2 (e.g two brood years prior to the current escapement year)

$BY_{t\text{-}3Age3}$ = Age 3 adult salmon produced in escapement year t-3 (e.g three brood years prior to the current escapement year)

$BY_{t\text{-}4Age4}$ = Age 4 adult salmon produced in escapement year t-4 (e.g four brood years prior to the current escapement year)

$BY_{t\text{-}5Age5}$ = Age 5 adult salmon produced in escapement year t-5 (e.g five brood years prior to the current escapement year)

CS_X = Chipps Smolt abundance coefficient for Chipps Smolt vs. Adult Return regression equation

CS_b = Chipps Smolt vs. Adult Return regression equation slope term

$Escape_{py}$ = prior year escapement

E_t = Escapement in year "t"
E_x = Escapement "x" regression variable from escapement (x1) and flow (x2) vs. Mossdale smolt abundance multiple regression equation
F_i = Daily flow at Vernalis (cubic feet per second)
FX = Flow coefficient for smolt survival vs. regression relationship[6]
Fb = Slope term for smolt survival vs. regression relationship
H = Hatchery produced adult age cohort return rates (e.g. H_1=Age 1, H_2=Age2, H_3=Age3, H_4= Age 4, and A_5 = Age 5)…refers to age hatchery produced juvenile salmon are expected to leave the ocean and return to spawn
Q_t = Spring flow (in cubic feet per second daily average for period March 15th thru June 15th) in year "t"
Q_x = Vernalis flow "x" regression variable from escapement (x1) and flow (x2) vs. Mossdale smolt abundance multiple regression equation
S1 = Slope for multiple regression relationship between fall escapement, spring flow, and Mossdale smolt abundance
t = year
VNS_q = Average daily flow in the San Joaquin River at Vernalis for the 93 day period from March 15th thru June 15th[7]
$Wk_{1 \text{ thru } 8\%}$ = The eight week time period over which smolts from an entire brood year production are released from the hatchery into the river
$WYSOEP_{di}$ = Water Year Type[8] Smolt Outmigration Exceedence Percentage
$_{di}$ = Calendar Date (e.g. from March 15th(Day 1) thru June 15th(Day 93) [9]

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[6] Smolt survival vs. flow relationship can either be with HORB-In or HORB-Out

[7] The March 15th thru June 15th time period was chosen as it represents the smolt outmigration time period from historical Mossdale Trawl data

[8] Water year type are Wet, Above Normal, Below Normal, Dry & Critically Dry

[9] This calculation is repetitive (e.g. for each day from March 15th thru June 15th)